

PROCEEDINGS OF CONSTRUCTIONISM / FABLEARN 2023

Edited by
Nathan Holbert &
Paulo Blikstein



Proceedings of Constructionism / FabLearn 2023

Proceedings of Constructionism / FabLearn 2023

NATHAN HOLBERT & PAULO BLIKSTEIN

CARNEGIE MELLON UNIVERSITY: ETC PRESS
PITTSBURGH, PA



Proceedings of Constructionism / FabLearn 2023 Copyright © 2024 by Carnegie Mellon University: ETC Press is licensed under a Creative Commons Attribution-NonCommercial-NoDerivatives 4.0 International License, except where otherwise noted.

Copyright © by ETC Press 2024 <http://press.etc.cmu.edu/>

ISBN: 978-1-300-99191-5 (Print)

ISBN: 978-1-300-96915-0 (Digital)

Online)

The text of this work is licensed under a Creative Commons Attribution, NonCommercial-NonDerivative 4.0 License (<http://creativecommons.org/licenses/by-nc-nd/2.5/>).

IMAGES: All images appearing in this work are property of the respective copyright owners and are not released into the Creative Commons. The respective owners reserve all rights.

COVER by Isabel Correa

This book was produced with Pressbooks (<https://pressbooks.com>) and rendered with Prince.

Contents

Introduction	xi
Program Committee	xiv
Full Papers	
Exploring Teacher Assumptions About Making Using MakerPCK	3
Can a Home be a Makerspace?	12
<i>Exploring Learners' Diverse Needs and Experiences in Remote Making</i>	
Learning through “playing with data”	21
<i>Teachers' perspectives on a constructionist approach to data literacy education</i>	
Design Futures	30
<i>Collaboration and creativity self-efficacy during design-based learning and maker education in elementary education</i>	
Unleashing the power of turtle graphics for graph algorithm visualization	40
Creative Movements in Maker-Material Collaborations Maker-Material Entanglements in Collaborative Making	55
Virtual reality and the art of empathetic teaching	65
<i>Enhancing teacher education through perspective-taking</i>	
Creative STEM activities offered by FabLabs	74
<i>How do they impact creativity and grit of high school students?</i>	
Fostering Maker Identity and Collaboration	85
<i>Affordances of the Connected Spaces Dashboard in Two Afterschool Makerspaces</i>	
Constructionist Measurement	94
<i>Using Making to Understand Multifaceted Identity Demonstrating the use of craft materials for quantifiable self-expression</i>	
Supporting lower attaining pupils in early computing education	103
Constructionist / Maker futures	
Generative AI as Mathland and Constructionist Frontier Logo traditions, computational fluency, and emerging technology converge to create new opportunities to amplify the potential of each learner	115
Programming as a Dialogue with GPT-4 Is this the future of programming?	125
Embracing the Challenge	134
<i>A Committed Constructionist's Reflections on Strategies for Fostering an Engaging Learning Community</i>	
Algorithms for Designing Learning	144
<i>A Constructionist Perspective on Teacher Professional Development</i>	

Brazilian Creative Learning Network	153
<i>A social movement approach to constructionist educational reform</i>	
Programming Microworlds for Elementary School Mathematics	161
<i>What we've been learning</i>	
Iterative Data-driven Optimizing Behavior (IDOB)	172
<i>A Structural Model for Enhancing Machine Learning Education and Understanding Software 2.0 Production</i>	
Mathematical Constructions in Makerspaces	180
Leveraging the powerful ideas of constructionism to enhance emergent design thinking pedagogy	185
New Technology Frontiers and Cultural Making	
Musical Manipulatives	197
The Emergence of the Samba School as a Learning Society	206
Empowering Youth for Climate Action Creative Learning in a University Museum Workshop Series	211
Culinary Making	216
<i>Democratized, Cultural Playgrounds of Possibility Democratized, Culturally-situated Learning in Culinary Making</i>	
Short Paper	
Agile Methods as a Methodology for Implementing Collaborative Constructionist Learning in Computer Science Education and Beyond	223
Pedagogy Scientists	228
<i>Enhancing the practices conducted by classroom educators</i>	
Visible learnings	233
<i>Shared digital tools for a Kindergarten investigation</i>	
Balancing hands-on scaffolding and play-based activities for young children's programming	238
<i>Affordances for learning from instruction and guided play</i>	
Symposia	
Constructionist Approaches to Learning Artificial Intelligence/Machine Learning	245
<i>Past, Present, and Future</i>	
Productive Designs for Successful Failure	255
<i>Constructionist Perspectives on Supporting Personally Meaningful and Culturally Empowered Learning and Teaching</i>	
Facilitating Computational Tinkering	264
<i>Exploratory and Expansive Collaborative Design Work with Informal Learning Educators</i>	

Posters

A novel generic app for mobile devices that utilizes Augmented Reality (AR) technology to create, share and deliver constructionist multimedia learning scenarios	275
<i>CARLA – introducing a novel constructionist AR learning app</i>	
Leveraging app making as a constructionist tool for developing Indigenous Hawaiian youth's rightful presence Integrating geology, geography, and rightful presence	278
Scaffolding School-Based Maker Education	281
<i>Investigating Expert Teachers' Designs and Student Learning using a Multiple Case Study Approach</i>	
Teachers' facilitation of maker-centered activities	284
<i>A framework for video analysis</i>	
Cobogó	286
<i>A tool to empower play and make imagination visible</i>	
Work-in-progress	
It's as Easy as 123	291
<i>Supporting Users via Multiple Programming Approaches on a Single Device</i>	
Wireless Embedded Visual Programming for Novices “Unplugging” CS education on embedded platforms	292
Writing as Making	293
<i>Towards a Critical Constructionist Praxis with Pre-Service Educators</i>	
AI-Enhanced Philosophy of Education Studies	294
Co-Constructing Language Learning through Tinkering with Wearable Soft Controllers in Galician Creative Libraries for Elementary Schoolers	295
Constructionist booster	296
<i>a quantitative bridge program for first year university students</i>	
Programmable Oven Toaster	297
<i>A Powerful Tool for Learning Chemistry & Home Economics in a Constructionist Way</i>	
Microworlds, Powerful Ideas, and What do we do Monday?	298
<i>An exploration of microworlds and powerful ideas with an eye to how they are used in practical activities and projects.</i>	
Constructionism in the Light of Computational Creativity	299
Empowering Learners with a Low-Barrier Mobile Data Science Toolkit Using MIT App Inventor to build data science mobile applications	300
Co-Constructing Expert Problem Solvers	301
<i>The Power of Constructionism in the Digital Age</i>	
Sock-It-To-Ya	302
<i>A Call for Collaboration on an Affordable Knitting Machine</i>	
K-12 Computer Science Ideals in Context Lessons Learned from Co-designing a Constructionist Computer Science Program in the Global South	303
Write Your First Song	304
<i>An Interactive Interface for Music Novices to Express Music Ideas</i>	

CYBATHLON @school scale up inclusion towards a new low cost, high scale STEM module approach	305
“Are you doing anything I can interrupt right now?”	306
Using Social Wearables to Support Communication in Remote Work Environments	
Conductive Chemistry Learning	307
Critical technological explorations for early childhood Work in progress toward the development of a conductive chemistry kit	
ChatLogo	308
A Large Language Model-Driven Hybrid Natural-Programming Language Interface for Agent-based Modeling and Programming	
Enchanting Woods	309
Engaging Children in Creative Expression through Interactive Storytelling and Embodied Interaction	
A Constructionist Learning Environment for Accessible Agricultural Robotics in Rural Communities via Making and Remixing	310
Constructing Sustainability	311
Integrating Constructionist Learning in Education for Sustainable Development	
Political Activism in a Youth Community Garden How the making of a community garden supports youth’s political activism in heterogeneous engineering	312
Turtle Geometry Today and Yesterday	313
Supporting Knowledge Construction in Making via Collective Process-Oriented Documentations Collective Process-Oriented Documentation for Making	314
Multivocal Play an Interactive Exhibit	315
Kaleidolight	316
An Interactive Device for Exploring Additive Color Theory Through Hands-on Creation Kaleidolight: An Interactive Educational Device for Young Students to Explore Additive Color Theory and Create Visual Art Through Hands-on Learning Experience with the Integration of Light, Color, and Shapes	
SPATIAL	317
An Embodied Learning Design To Support Geometry Learning Through Collaboration and Physical Movements	
Creative Expression through Color and Sound	318
A NetLogo Model for the Sonification of Color and the Visualization of Sound	
Stories and STEM	319
Designing for Relationship Building and Meaningful Forms of Expression in a Family Computing Workshop	
Civic Engagement in the Scratch Online Community as a Case for Civic Imagination in Creative Computing	320
Making at School	321
Experiences from the Design-Based Research Project	
Transforming Teaching Science Education	322
Case Studies on Implementing a Constructionist Curriculum for Middle School Students	
Cultural Making and Scientific Education	323
Elements for an ethical-critical approach from the south	
The Griot Dolls	324
Black Dolls to Think History	

ElectricCity	325
<i>Electrical Block Circuits for Elementary Learners</i>	
Making Floats for the Brazilian Carnaval Parade	326
<i>The Emergence of the “Situated Maker Space”</i>	
Fostering Literacy Development through Constructionist Pedagogy	327
<i>A Case Study in Elementary Education</i>	
Designing a Middle School Curriculum to Critically Explore Socioscientific Issues with Machine Learning	328
Act Happy! Act Crazy!	329
<i>Using Emotion-based Commands to Engage Young Learners in Robotics Programming</i>	
Constructing various learning activities on the Semantic MediaWiki playground	330
Introducing Digital Design Research (DDR)	331
<i>Constructionist Principles at the Methodological Level</i>	
Discover BBC micro:bit board as part of a dynamic and experimental AI learning process	332
Reconsidering a Picture Rewriting Rule-Based Programming Language for Preschool Children in Japan A Comprehensive Study Using Viscuit	333

Introduction

The Constructionism / FabLearn 2023 conference was held October 7-11th in New York City at Teachers College, Columbia University. The theme for the conference was “*Building the Future of Constructionism.*” While the Logo programming language was first developed in 1967, and the British Logo Group first gathered in 1983, in the years since the constructionist community has continued to evolve and expand. A critical effort of this year’s conference was not just the reflection and elevation of our shared history and values, but also an explicit effort to together envision a future for where constructionism might go. Our keynotes, panels, paper presentations, and workshops told stories of who we are, what we do, how we do it, and what comes next.

At the closing panel of the conference, the co-chairs invited the attending community to critically examine the conference and where we were as a community. In reading these reactions, we considered that the community’s comments would be the best way to frame these proceedings since they captured in real time what participants were excited and concerned about. Below, we have collated some of the conversations that occurred in that session, and used them as starting points to briefly reflect on the work presented at the conference (text in italics was shared by conference attendees.)

1. **There are tensions between strengthening our shared core values and explicitly making connections (connections that have been implicit) between the constructionist community and other progressive education movements.**

Constructionism was EuroLogo. Some people decided that it was too narrow, refocused the community, and lost focus, and actual participants in the conference/community. Now, there seems to be some effort to further marginalize the community by severing even more connections to its roots.

Are we as a community too insular – not taking into account the changing times around us? Outside, who knows or cares about constructionism?

There is a disconnect between the constructionism community and other progressive educational movements and traditions.

Perhaps there needs to be a “constructionism boot camp” at future events so there is a common language and folks just don’t appropriate the term for their own purposes.

Would not a more productive activity be creating a constructionism manifesto and action plan, perhaps like the UN Sustainable Development Goals?

We live in the era of administration, accountability, poverty, inequality, and fear of world crises. How can we communicate the value of constructionism?

An explicit tension exists in our community between those who desire to expand the tent and those who aim to strengthen the community’s existing bonds. Both aims are no doubt born out of a love of constructionism. On the one hand, it is appropriate and correct for us as a community to reflect on our history and shared values. Those values should be celebrated as revolutionary! Many of the most successful educational innovations today—from coding in schools to makerspaces—were borne out of constructionism. And though the rest of the world has taken up many constructionist ideas without naming our community, we should claim “victory.” On the other hand, we desire to continue impacting the world, which is in dire need of a vision of education that values humanity and treats young people as having perspective and passion that matters. Doing so may require expanding our tent to welcome like-minded educators, scholars, and technologists. How can we do this while holding true to our core values and not excising our history and traditions? In

true constructionist fashion, we believe there will never be a final answer to that dilemma but a constant conversation within our community. Out of that dialogue, we might construct not one but multiple models of how to go about acknowledging our history and principles while reinventing ourselves.

2. Making isn't new. What can we learn by paying attention to the many diverse forms of making that existed long before this educational movement was named? How might emerging fields of making offer opportunities to connect to every day and/or craft-making practices?

Making and learning through making have existed forever. How do we revisit ways learning through making might have looked prior to "us" giving it a name?

Is biomaking a way to reconnect to lost intergenerational funds of knowledge? Making yogurt, baking bread? Does the element of increased time needed for biomaking draw on gains from apprenticeship models of learning?

What might be missing from how we talk about and study making? Making in community. Making in cultural and social representations. How would we rename constructionism? Changing the "object-to-think-with" to something that is a "community-to-think-with." How do we centralize community? Changing the basis of problem-solving from an individualistic base to a community base. Making for what purpose? How are the things that we are making representative of various purposes

One would be hard-pressed to find writings about constructionism that didn't involve "making" of some kind—consider that Jeanne Bamberger's "Laboratory for Making Things" is from 1985! Papert himself credits his observation of a group of children carving soap sculptures as one of his inspirations for the foundational work of this community. Indeed, making is not new. What can we learn about making by studying making practices throughout history and across cultures? And how can we evolve constructionism by attending to these making practices and the sociocultural ecologies that brought them into being? Fundamentally, what exactly is the object of our study and interest within the very human act of making things?

3. A greater focus on schools

How much of constructionism's lack of presence in schools is related to research methods (quantitative vs. qualitative)? Unfortunately, grades are an effective way to collect data and used to justify a system.

Why is there so little interest or effort being dedicated to building and strengthening connections with K-12 schools, systems, and organizations?

"Schools are where the children are." The constructionist community has a long history of working in and directly with schools. For decades, we have built technologies, computer languages, and learning environments for classroom use. We have countless examples, the most visible today being the Scratch programming language. However, schools have also always presented challenges for the constructionist intent on revolutionizing the learning experience. While teachers and students are often willing to transform the classroom, schools, as large systems, are often resistant to change.

To what extent should we focus on evolution (slow, gradual change) vs. revolution (radical shifts)? There is wide agreement in the community that our efforts must include schools.

In some cases, that may mean adapting our revolutionary designs to accommodate the constraints of the classroom. Doing so doesn't have to compromise our core commitments. We have seen schools change! Computer science for all and makerspaces are two recent examples. However, we should not be content with incremental change and should never abandon our commitment to revolution.

We believe these proceedings of Constructionism / Fablearn 2023 represent our community well. In them, we see our community's deep commitment to children and humanity; scholarship that leverages the tools of scientific inquiry to understand vital questions of learning, teaching, and design; and a passion for making our world a more just and equitable place.

Like a family, we never quite agree on everything. We argue and get frustrated with one another, we refuse absolute truths or infallible leaders. And still, year after year, the conference transpires a deep sense of love and respect for each other. Constructionists have been predicting their demise for decades; nevertheless, here we are, refusing to go away and becoming more and more relevant as the years go by. We are honored to be part of this community and look forward to working with you all to continue building a bright future for constructionism and what it represents.

We are not going anywhere but forward (50).

Nathan Holbert & Paulo Blikstein

Editors, Proceedings of Constructionism / FabLearn 2023

Conference Co-Chairs

Nathan Holbert, Teachers College, Columbia University, USA
Paulo Blikstein, Teachers College, Columbia University, USA
Bernadette Spieler, Zurich University of Teacher Education, Switzerland
Carina Girvan, Trinity College Dublin, Ireland
Kayla DesPortes, New York University, USA
Tobias M. Schifferle, Zurich University of Teacher Education, Switzerland

Program Committee

Full Papers

David Weintrop, University of Maryland, USA
Márta Turcsányi-Szabó, Eötvös Loránd University, Hungary
Dorit Assaf, University of Applied Sciences and Arts Northwestern Switzerland, Switzerland
Engin Bumbacher HEP Vaud, Switzerland

Short Papers

Justice Walker, The University of Texas El Paso, USA
Tamar Fuhrmann, Teachers College, Columbia University, USA
Colby Tofel-Grehl, Utah State University, USA
Debbie Fields, Utah State University, USA

Posters

Francisco Castro-Norwood, NYU, USA
Mia Shaw, University of Pennsylvania, USA
Ana Isabel Sacristán, Centre for Research and Advanced Studies, Mexico

Special Paper Track

Maria Olivares, Boston College, USA
Chronis Kynigos, National and Kapodistrian University of Athens, Greece

Symposia

Yumiko Murai, Simon Fraser University, Canada
Jim Clayson, American University of Paris, France
Jake Rowan Byrne, Trinity College, Ireland

Educator Submission Track

Bernhard Standl, University of Teacher Education Karlsruhe, Germany
Heather Pang, Castilleja School, USA
Aaron Vanderwerff, Urban Adamah, USA
Christa Flores, Mountain Makers, USA

Young Makers

Nalin Tutiyaphuengprasert, Darunsikkhalai School for Innovative Learning, Thailand
Eli Tucker-Raymond, Boston University, USA,

Work-in-Progress & Other submissions

Sawaros Thanapornsangsuth, United Nations University, Japan
Michael Mumbo, Edutab Africa, Kenya
Paulina Haduong, Harvard University, USA

Workshops

Matthew Berland, University of Wisconsin, Madison, USA
Antigoni Parmaxi, Cyprus University of Technology, Cyprus
Charles Pimentel, American School of Rio de Janeiro, Brazil

BarCamp

Tobias M. Schifferle, Zurich University of Teacher Education, Switzerland

FULL PAPERS

Exploring Teacher Assumptions About Making Using MakerPCK

Sandra Becker, University of Calgary, sandra.becker@ucalgary.ca

Michele Jacobsen, University of Calgary, dmjacobs@ucalgary.ca

Douglas B. Clark, University of Calgary, douglas.clark@ucalgary.ca

Abstract

This comparative case study examines the assumptions three elementary teachers held around making and how those assumptions evolved after engaging in a supported maker activity. For analysis, the authors created a preliminary MakerTPK framework to assess teacher thinking about making in relation to pedagogy, content, and maker practices. Findings showed that one teachers' deeply held beliefs about teaching and learning meant that she readily adopted the pedagogy, content, and maker practices as part of her Maker TPK. Although the other two teachers' thinking about makerspaces evolved post-enactment, their efficacy in terms of changes in practice, their own design capabilities, and their adoption of maker practices was more limited, suggesting that long term support was required. The Maker TPK framework served to guide researcher thinking about the knowledge needed for becoming maker teachers.

Introduction

Makerspaces, environments that encourage the iteration of solutions to problems using digital and non-digital design and fabrication, have been promoted as powerful learning spaces in formal school settings. Indeed, over the past number of years, there has been a rallying cry for teachers and school districts to implement makerspaces and maker pedagogy, in particular to address the need for STEM learning [1]. Key features of makerspaces include choice of materials and technologies, free exploration of interdisciplinary topics of interest, and opportunities for social interaction where knowledge is distributed [2]. While makerspaces are frequently promoted as opportunistic environments for learning related to STEM, explorations in multimodal literacies, the humanities, arts practices, and the dispositions necessary for their advancement are also seen as possibilities [3].

Researchers, however, suggest there are challenges in implementing makerspaces in school settings given that the goals and features implicit in makerspaces differ greatly from formal school settings [4, 5]. To this point, enactment models in schools vary widely and the development of some type of standardized template for implementation is still an emerging proposition [1, 6]. This is in part due to the fact that “facilitating maker-centered learning in the classroom is a non-trivial task” [6] that involves pedagogical, technological, and subject matter concerns (p. 319). In addition, teachers often come with beliefs about makerspaces and making which may or may not be productive. A recent study that explored preservice and inservice teachers' preconceptions and misconceptions around maker pedagogy found that although participants saw value in making for learning, an over focus on technology meant that participants often saw more barriers to implementation than possibilities [7]. A second implementation challenge for teachers is designing for learning in school makerspaces while addressing curricular, assessment, and reporting concerns. An investigation of several schools “observed both excessively prescriptive and “anything goes” types of projects” [8] (p. 100). Our research [9] suggests however, that with scaffolding and over time, collaborative and iterative implementation of maker activities can foster a teacher's creative design and maker practices, although how it is realized in individual contexts may

involve rethinking practicalities, including the adoption of pre-planning, organization, and support structures with knowledgeable others [4, 9, 10] as well as considering the maker practices required by both teachers and students for successful implementation. Brahm and Crowley [11] determined “seven core learning practices associated with recognizable participation in the maker community” by analyzing one year of articles in *Make* magazine. The practices identified are (a) “explore and question” to inspire and find purpose (b) “tinker, test and iterate” in a playful and experimental manner to further distill ideas; (c) “seek out resources,” by acknowledging one’s own limited knowledge and the expertise of others (d) “hack and repurpose” to augment an already existing process or product; (e) “combine and complexify” leading to expertise and invention (f) “customize” to suit (g) “share,” making ideas and methods available for the community (p. 16). Although the authors acknowledge that the population represented in *Make* magazine is limited (i.e. a primarily white “male, well educated, and affluent population of makers”), we feel the practices identified not only have aspirational potential for educators in relation to their own and their students’ mindsets required for implementation of makerspaces, they also provide potential articulations of the technological knowledge and dispositions required when designing and implementing activities.

In a recent study conducted in a small rural district we explored a maker community of practice (CoP) that consisted of six elementary teachers from three different schools. We sought to consider how teachers’ maker, pedagogical, and content knowledge might evolve through a scaffolded experience in a school makerspace. Our research questions were: What assumptions about maker pedagogy and practice do elementary teachers bring to a maker CoP? How do these assumptions evolve as teachers explore pedagogy, content, and maker practices in a supported makerspace environment? In order to study these questions, we conceived a preliminary MakerPCK framework that considers pedagogical and content knowledge (PCK) as well as maker practices to assess maker teacher knowledge.

Framing MakerPCK

To avoid an overfocus on tools and technologies in school makerspaces, Cohen and associates [7] advise “fram[ing] maker education in terms of” TPACK (p. 39). To date, there has been limited exploration of makerspaces using the TPACK model with key focuses on learning [12] and assessment [13]. Scholars do state that “school-based making activities need to better emphasize the importance of teaching and acts of intentional teaching” [4] (p. 324).

The TPACK framework [14], extended from Shulman’s seminal work on PCK [15] suggests that successful teaching requires an integration of technological, pedagogical, and content knowledge. Within the literature, however, there are critiques of TPACK, one being the “lack of clarity” around what is meant by technological knowledge, and another being “whether the relationship between elements is integrative or transformative” [16] (p. 1956). According to Niess [17], when *integration* of knowledge of content, pedagogy, and technology takes place, a “distinct form of knowledge [emerges] where the inputs to the knowledge have been rearranged, merged, organized, assimilated, and integrated in such a way that none are individually discernible” (p. 176). Niess states that when teachers are challenged to “integrate their thinking” about pedagogy, content, and technology “their knowledge for teaching with technology is transformed.” (p. 177). We wondered if enactment in a school makerspace environment might support the transformative integration of TPACK. Rather than a focus strictly on technology as tool, that is, understanding how different technologies can be used “to transform content and pedagogy for learners” [17] (p. 156), we deemed it important to consider the key practices found in makerspaces that support learning, particularly in relation to knowledge and applications of technology. Indeed, “There is no single technological solution that applies for every teacher, every course, or every view of teaching” [14] (p. 1029). Integral to making, however, is the thoughtful ideation, testing, and continual reconsideration of possibilities for the use of technologies in community. Corum et al. [12], building on Niess’ [18] developmental levels for TPACK, describe “MakerPACK as TPACK for makerspaces” (p. 2194). We respectfully suggest this may be an oversimplification of learning in makerspaces in that maker practices developed through making have the potential to

not only “transform content and pedagogy for learners,” but also transform teachers’ technological knowledge and the way they consider its use.

Leijen and colleagues [19] recent literature review surrounding the definitions, dimensions, and assessment of General Pedagogical Knowledge (GPK), determined that over the past few decades the focus has been on two of three general categories “student related dimensions and teaching related dimensions,” with a third dimension, context, “easily integrated”. In proposing a new definition of GPK, they consider three elements: (a) that GPK is “subject transcendent”; (b) that GPK is focused on “both learning and teaching processes,” (e.g. how learners learn, and how teachers should teach them), “classroom management (e.g. how to build a collaborative improvement-oriented learning environment,” and “context (e.g. how to organize learning and teaching activities in line with wider educational purposes),” and; (c) that GPK is “supporting students’ development (e.g. how to support the development of students’ learning and collaboration skills) and motivation” (p. 218). We adapted the subsequent revised GPK framework, [19] combined with maker practices [11] to consider a preliminary MakerPCK framework that includes pedagogical, content, and maker knowledge to assess the teachers in this study (Figure 1).

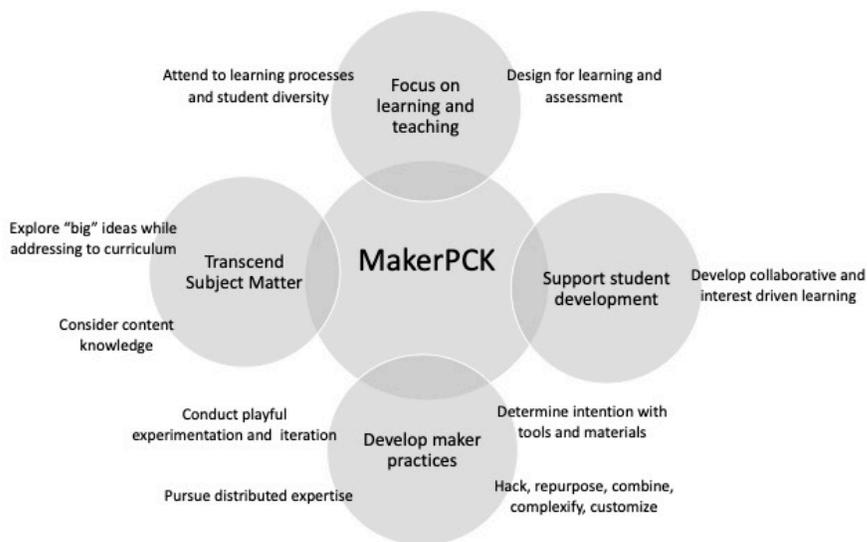


Figure 1. MakerPCK, adapted from Leijen et al., (2022) and Brahms & Crowley (2016)

Methods

This research arose out of a larger study of an elementary school maker community of practice (CoP) with six teachers in three schools in a small rural school district. Although our original goal was to co-design and co-teach with the participants, given restrictions in time and school access related to the Covid-19 pandemic, the co-design aspect of the study was limited. For the purposes of this paper, we focus on three teachers, who all presented varied school, makerspace, and teaching assignments. Based on pre-enactment interviews and discussions in the CoP, the activity designs responded to the expressed learning needs of the teachers (Table 1).

Name	School	Grade	Maker Activity Design and Technology Used	Curriculum Links
Toni	K-8, classroom makerspace	K	Exploring story elements with the Beebot, Squishy Circuits, Scratch Jr., LED lights, found materials	Language Arts, Science, Mathematics
Claire	K-3,school makerspace	3	Classifying 2D shapes and making complex Islamic shape pattern tiles with Sphero, Scratch, Cricut	Mathematics,Social Studies, Language Arts
Riva	4-8,school makerspace	7, CTS	Exploring current events to address the question “What gates are open? What gates are closed?” with loose parts and Google slides	SocialStudies, Language Arts

Table 1: Participant name, teaching assignment, and maker activity

Using TPACK teacher-related performance indicators [20], we assessed the designed activities at level 4 (exploring) of 5, where the activities were meant to “explore and experiment with technology for subject matter development” (p. 9), “develop thinking leading to a conceptual understanding” (p. 10), “align with curriculum topics, and provide an alternative way of topic exploration” (p. 11), and “use deductive and inductive instructional strategies that support students thinking” (p. 12).

We used comparative case studies of the three teachers to consider the assumptions about making they held, and to determine how these assumptions might change after having engaged in a maker activity with researchers. This study aligns with the elements of case study: it is a bounded study focusing on elementary maker teachers and their experiences; it has detail and variance (i.e. the teachers have different backgrounds, teaching assignments, and work in different schools); it evolves over time; and it holds the makerspace environment as context [21].

Data collection took place from January to May, 2022, with follow up discussions with two teachers (Claire and Riva) continuing into the 2022-2023 school year. Data included recorded transcriptions of individual interviews of two teachers (Toni and Claire), an email question and answer exchange (Riva), transcriptions of five recorded meetings with members of the district maker CoP, researcher notes from each CoP meeting (5) and school visit (13), as well as email communication between participants, and photographs taken in classrooms. To determine participant positioning as maker teachers, we analyzed individual teacher comments each as a separate case, from interviews and the CoP meetings using first cycle descriptive codes (i.e. pedagogy, content, technology, making). From this process emerged two insights: we realized there were many instances where the codes overlapped (e.g. most prevalent was technology overlapping with making), and we noted that conversations with teachers seemed to have a focus centered on teaching, learning or technology. To confirm this, we conducted a second round of analysis, this time, using teaching, learning, and technology as new descriptive codes. We sought to develop a framework with which to further analyze these perspectives post maker activity enactment to determine if and how patterns in teacher thinking about teaching, learning, and technology might have changed [22]. Our initial thought was to utilize the TPACK framework as recommended in the literature. However, determining a well-established definition of technological knowledge in relation to making was problematic. In addition, we felt that maker practices as a form of knowledge were not well represented in TPACK. Embedded in maker practices, however, is the use and knowledge of technology. Bridging making practices with Leijen and colleagues latest version of PCK [19] seemed to be a compromise that would help us illuminate both ourselves and the teachers’ thinking about the intersection of pedagogy, content, and maker knowledge. We used individual aspects of the MakerPCK as second cycle codes to analyze individual teacher responses in CoP meetings post activity which assisted us in considering their evolving perspectives about making. We were then able to look for instances where particular aspects of the MakerPCK framework emerged with all three participants. This led us to thinking about the framework as a tool to establish possible recommendations for each teacher moving forward.

Findings

Finding 1 -Teachers Held Varied Assumptions About School Makerspaces

Although all three participants had previous experience as maker teachers prior to the study, they each held a different perspective of making.

Toni: Focused on Learning

Toni, a kindergarten teacher, indicated she was greatly influenced by the Reggio Emilia approach to teaching and learning, which holds as some of its principles, respect for children as capable and active learners in community, generative teacher responsiveness based on student interest, inquiry as a way of being, and the importance of listening [23] (Edwards & Gandini, 2018). These principles were evident in observations of Toni's teaching and in her discussion in the CoP. In our pre-study interview, Toni told us that during open center time, children often chose to make objects (we observed for example, jet packs, cranes, buildings) using found materials at the "maker table". Toni expressed a desire to bring more digital technology into the maker work with the children, stating, "If I don't do anything digital they're missing a huge element of the possibilities, right?" Throughout the interview, we noted Toni's focus on student learning related to big curriculum ideas, such as "thinking with a line," and understanding story. She also emphasized the socio-emotional learning implicit in maker work. "Learning how to play, learning how to clean up after it, to share. That's been a big, big focus." Toni built the teaching curriculum from the students' interests. "You look back at the curriculum? And you think, Oh my goodness, I just touched upon eight of the outcomes."

Claire: Focused on Teaching

Prior to her full time assignment as grade three teacher, Claire had worked as a maker teacher leader in the school, co-enacting projects with other staff members in the "tinkering lab," a space adjacent to the library that mainly housed low tech materials. Although she possessed no formal maker training, Claire indicated "I don't mind jumping in and trying it." Claire's focus was on the activities she designed for teaching. For example, she described activity stations centered on the study of Peru (e.g. reconstruction of Machu Picchu using Lego, weaving, constructing pan flutes, and puzzling) and an art project using Sphero robots: "We're gonna get inspired by Jackson Pollock but I've done this project before and they do that graffiti, you roll the Spheros in paint and then do graffiti art, but then that's about it. And then I stopped there, right? Like, I kind of just dip into it but don't kind of go deeper into it sometimes." In Claire, we sensed a desire to move beyond activities that were, in her words, "hands-on" to a deeper exploration of content and ideas, using digital technologies. She stated, "most of my stuff tends to lie at the low tech level," and she advocated within the CoP for support in integrating digital technology into her teaching.

Riva: Focused on Technology

Riva primarily worked as a grade seven teaching generalist, but described an additional role in the school makerspace to her colleagues. "It's grade seven CTF and it's multimedia kind of makerspace stuff. And it's not connected specifically to a subject, it's more, let's just try it out and expose you to all sorts of different things." According to online documents, "Career and Technology Foundations (CTF) is an *optional* program that allows students to explore their interests and

passions as they learn about various career possibilities and occupational areas,” however, Riva stated in her school, “Every child does CTF. So we switch every 9-10 weeks. And so you’ve got kids in there that really couldn’t care less. So the behavior, so you get to manage it all. But when it works, it’s really fun.” Riva presented a list of technologies and activities she had conducted with her students with support from a community volunteer who ran the 3D printer. These included Thingiverse, Tinkercad keychains, and soldering Harry Potter wands. With the CoP Riva demonstrated Ozobot, and forwarded notices of technology workshops (e.g. Makey Makey “Integrated STEM ideas for Black History Month”) and activities (e.g. “Voila . . . the bristlebot!”). In Riva’s emails and CoP discussions, it became evident that she felt tools were “synonymous with making” [7] (p. 38). In her statements there was limited reference to teaching or learning.

Of the three participants, Claire and Riva were considered to be informal maker leaders in their schools, which was linked to their expertise with materials and tools. For both, participating in a supported maker activity allowed them to see possibilities beyond this view of making.

Finding 2: Participating in Supported Activities in the Makerspace Promoted Aspects of MakerPCK

Participating in supported maker experiences with researchers led the teachers to observe powerful aspects of MakerPCK, in particular, attending to student diversity, student interest, the exploration of big ideas, and intentionality and playfulness in the use of tools and materials.

Focus on teaching and learning: Attend to student diversity

All three teachers shared with their colleagues examples of how making addressed the diverse learning needs of students. Toni described how an autistic student in her class created a stop animation story (with support) using an egg carton lid to develop the scene. “So for him, he loved just putting this together and making it animated. Really, we didn’t need to encourage him. He wanted to do this.” Claire shared an example of a nonverbal student in her class using the Sphero robot to make a shape pathway. “If you pull up this grid feature when you run the program, you can see [the square pathway], so that’s how we could tell if they weren’t working. And he knew he was making a square.” Riva expressed her positive disbelief at the quality and depth of thinking demonstrated by her students’ loose parts compositions. “I was like, Who *are* you? . . . Like the kids that would usually struggle . . .”

Support student development: Develop interest driven learning

All three teachers acknowledged the power of tapping into student interests. Toni referenced her students creating scenes of their choice inside egg carton lids. “Yeah, so many possibilities. And I mean, it’s cute to us. But to them, it’s like a living little world in there. And with the light [LED], oh, my goodness . . .” Claire described the interest and engagement of students using block codes in Sphero to create shape pathways delineated by their choice of sounds and lights. “They were actually using the coding blocks to make a square. Well, I couldn’t have imagined it going so well. I would say everyone was fully engaged for an hour. Yeah, it was purposeful.” Riva articulated that student choice in the loose parts activity was central to its success. “They were really passionate about it. Whereas they got to choose something that was really on their mind that they were troubled by, or really happy about and really proud. And I think that it was just closer and nearer to them and dearer and so that’s why they were more involved.

Transcend subject matter: Explore big ideas

From the start, Toni's focus was on story, but her approach to teaching was such that she was always open to possibilities. In that sense, she was a maker alongside her students. Her respect for their ideas meant that the notion of "distributed expertise" and her "recognition of one's own not-knowing" [11] (p. 16) was a maker practice embedded in her classroom. Claire saw possibilities in going beyond "a fragment of knowledge" [19] (p. 219) that is, identifying shapes by the number of sides, when she stated, "I think it was the most in depth I've ever done 2D shapes. I find in the curriculum it's a fairly limited and narrow outcome that *can* be so cool." Riva also witnessed possibilities for subject matter transcendence: "We look at current event topics and kind of do, you know, some objectives that went with that topic, and we'd go through things, but we never really did a huge critical thinking type of project like this."

Develop maker practices: Determine intention with tools and materials through playful experimentation

As researchers, we witnessed multiple examples of the students' intentionality with materials in Toni's class, which we linked to daily opportunities over time to play and experiment with ideas. What we felt was important, however, was Toni's willingness to listen, respect, and attend to the students' ideas. When speaking about the story scene she stated, "So there's multiple ways that they wanted to use it. Because the image that I showed them was just one scene, one character." For Claire, she acknowledged that playful experimentation led to students discovering possibilities with technology. "I don't know if anyone figured it out on the first go. In the coding, they were making mistakes. So instead of making a square, they were just going straight. And then they started figuring it out. And some kids started making hexagons. They started playing around . . ." Riva also acknowledged her students' intentionality by affirming Researcher 1's comment about her students: "One thing that really surprised me was how thoughtful they were in their choice of loose parts."

Using MakerPCK to consider future learning for teaching

Toni's deep pedagogical knowledge and belief system about how children learn meant that she and her students had already adopted many maker practices (i.e., intentionality, playful experimentation, distributed expertise) which we felt led to her agency as a maker teacher. When Claire asked Toni if "you could have done this on your own, or you needed someone to collaborate" she responded, "I think I could have done what I finally ended up doing." For Toni and her students moving forward, developing further competency with digital technologies, particularly maker practices such as hacking, complexifying, and customizing should be an area of focus in her MakerPCK. Claire, on the other hand, did not see herself as able to continue without support. "I couldn't have done mine without [Researcher 1]. I wouldn't have done CNC printing and then shifted to [Cricut] . . . It's just interesting – not having someone in that collaborative role." Riva saw the loose parts project as powerful, but there was no evidence of changes in her practice. Although we presented the suggestion of a "capstone project" for CTF to build on student interest and diversity, Riva continued with her described implementation. After the CoP concluded, however, both Claire and Riva approached Researcher 1 for continued support in design and enactment. This suggests that they recognized, if not explicitly, the importance of all aspects of MakerPCK in implementation, but would need extended opportunities to develop, potentially using the MakerPCK framework as a tool for reflection. Although both were seen as maker leaders, clear evidence of the adoption of maker practices was not evident in their teaching, particularly in relation to intention, iteration, and promoting distributed expertise (especially with their students) that would enable customizing and complexifying of ideas and technologies. Supported and carefully designed enactments that promote maker practices are recommended, in particular, an emphasis on becoming comfortable with not knowing [10] and engaging students' expertise in ideating and problem solving.

Conclusion

This study considered the assumptions teachers bring in understanding making and how those assumptions might change over time. Our creation of the first iteration of a MakerPCK framework allowed us to examine specific aspects of teacher practice that could support them in school makerspace implementation. Building on the recommendation to frame maker education around TPACK [11], we went beyond by including maker practices [10] that we deemed as key components to enactment. We recognize the limitations in this study, particularly in the scope and number of participants. We see this first attempt at delineating MakerPCK, however, as a starting point for discussion for the potential use of PCK frameworks to better understand makerspace implementation in formal school settings.

References

1. Rouse, R. & Rouse, A. G. (2022). Taking the maker movement to school: A systematic review of preK-12 school-based makerspace research. *Educational Research Review*, 35, 1004133. <https://doi.org/10.1016/j.edurev.2021>
2. DiGiacomo, D. K., Van Horne, K., & Penuel, W. R. (2020). Choice and interest in designed learning environments: The case of FUSE Studios. *Information and Learning Sciences*, 121(3-4), 137-154. <https://doi.org/10.1108/ILS-09-2019-0098>
3. Halverson, E., & Peppler, K. The maker movement and learning. In F. Fischer, C. E. Hmelo-Silver, S. R. Goldman, & P. Reimann (Eds.), *International handbook of the learning sciences* (pp. 285-294). Routledge.
4. Godhe, A., Lilja, P., & Selwyn, N. (2019). Making sense of making: Critical issues in the integration of maker education into schools. *Technology, Pedagogy and Education*, 23(3), 317-328. <https://doi.org/10.1080/1475939X.2019.1610040>
5. Weiner, S., Jordan, S. S., & Lande, M. (2021). What to “make” of school: Revealing the conflicting institutional logics of grassroots making and formal education. *Journal of Research on Technology in Education*, 53(3), 264-278. <https://doi.org/10.1080/15391523.2020.1767526>
6. Jones, W. M., Caratachea, M., Schad, M., & Cohen, J. D. (2020). Examining K-12 teacher learning in a makerspace through the activity-identity-community framework. *Journal of Research on Technology in Education*, 53(3), 317-332. <https://doi.org/10.1080/15391523.2020.1774824>
7. Cohen, J. D., Jones, W. M., & Smith, S. (2018). Preservice and early career teachers' preconceptions and misconceptions about making in education. *Journal of Digital Learning in Teacher Education*, 34(1), 31-42. <https://doi.org/10.1080/21532974.2017.1387832>
8. Campos, F., Soster, T., & Blikstein, P. (2019). Sorry, I was in teacher mode today: Pivotal tensions and contradictory discourses in real-world implementations of school makerspaces. In *Proceedings of FabLearn 2019* (pp. 96-103). <https://doi.org/10.1145/3311890.3311903>
9. Becker, S. & Jacobsen, M. (2021). A year at the improv: The evolution of teacher and student identity in an elementary makerspace. *Teaching Education*, 34(1), 1-18. <https://doi.org/10.1080/10476210.20211978968>
10. Stevenson, M., Bower, M., Falloon, G., Forbes, A., & Hatzigianni, M. (2019). By design: Professional learning ecologies to develop primary school teachers' makerspaces pedagogical capabilities. *British Journal of Educational Technology*, 50(3), 1260-1274. <https://doi.org/10.1111/bjet12743>
11. Brahms, L., & Crowley, K. (2016). Making sense of making: Defining learning practices in MAKE magazine. In K. Peppler, E. R. Halverson, & Y. B. Kafai (Eds.), *Makeology: Makers as learners*, pp. 13-28. Routledge.
12. Corum, K., Spitzer, S., Nichols, L., & Frank, K. (2020, January). Developing TPACK for makerspaces to support mathematics teaching and learning. In Sacristán, A.I., Cortés-Zavala, J.C. & Ruiz-Arias, P.M. (Eds.), *Mathematics education across cultures: Proceedings of the 42nd Meeting of the North American Chapter of the International Group for the Psychology of Mathematics Education*, Mexico. Cinvestav / AMIUTEM / PME-NA. <https://doi.org/10.51272/>

pmena.42.2020

13. Max, A. L., Lukas, S., & Weitzel, H. (2022). The relationship between self-assessment and performance in learning TPACK: Are self-assessments a good way to support preservice teachers' learning?. *Journal of Computer Assisted Learning*, 38(4), 1160-1172. <https://doi.org/10.1111/jcal.12674>
14. Mishra, P., & Koehler, M. J. (2006). Technological pedagogical content knowledge: A framework for teacher knowledge. *Teachers College Record*, 108(6), 1017-1054.
15. Shulman, L. S. (1986). Those who understand: Knowledge growth in teaching. *Educational Researcher*, 15(2), 4-14.
16. Graham, C. R. (2011). Theoretical considerations for understanding technological pedagogical content knowledge (TPACK). *Computers & Education*, 57(3), 1953-1960. <https://doi.org/10.1016/j.compedu.2011.04.010>
17. Niess, M. L. (2013). Central component descriptors for levels of technological pedagogical content knowledge. *Journal of Educational Computing Research*, 48(2), 173-198.
18. Niess, M. L., Ronau, R. N., Shafer, K. G., Driskell, S. O., Harper, S. R., Johnston, C., ... & Kersaint, G. (2009). Mathematics teacher TPACK standards and development model. *Contemporary Issues in Technology and Teacher Education*, 9(1), 4-24.
19. Leijen, Ä., Malva, L., Pedaste, M., & Mikser, R. (2022). What constitutes teachers' general pedagogical knowledge and how it can be assessed: A literature review. *Teachers and Teaching*, 28(2), 206-225. <https://doi.org/10.1080/13540602.2022.2062710>
20. Lyublinskaya, I., & Kaplon-Schilis, A. (2022). Analysis of differences in the levels of TPACK: Unpacking performance indicators in the TPACK Levels Rubric. *Education Sciences*, 12(2), 79.
21. Flyvbjerg, B. (2011). Case study. In N. K. Denzin, & Y. S. Lincoln (Eds.), *The SAGE handbook of qualitative research*, pp. 301-316. SAGE.
22. Saldaña, J. (2016). *The coding manual for qualitative researchers*. SAGE.
23. Edwards, C. P., & Gandini, L. (2018). The Reggio Emilia approach to early childhood education. In J. L. Roopnarine, J. E. Johnson, S. F. Quinn, & M. M. Patte (Eds.), *Handbook of international perspectives on early childhood education* (pp. 365-378). Routledge. <https://doi.org/10.4324/9781315562193>

Can a Home be a Makerspace?

Exploring Learners' Diverse Needs and Experiences in Remote Making

Yipu Zheng, Teachers College, Columbia University, yipu.zheng@tc.columbia.edu

Paulo Blikstein, Teachers College, Columbia University, paulob@tc.columbia.edu

Abstract

By investigating how students in a graduate-level project-based design class reacted to the transition from face-to-face to remote making and learning, this paper spotlights the inequalities exacerbated by remote learning and illustrates the distinctive needs of learners in remote making based on their familiarity with the tools and their help-seeking habits. Semi-structured interviews, observation field notes, and student-generated artifacts were analyzed using the case study approach. Our findings suggest that remote making could pose a disproportionate disadvantage to students who were less active in help-seeking and highlight how some students' success could hide missed learning opportunities and obstacles.

Introduction

As novel forms of technology and materially rich learning environments, makerspaces and spaces for building and creation have shown potential for reaching progressive educational goals that are not easily realized in more traditional spaces (Halverson et al., 2017; Pepler et al., 2016). Given that remote learning environments became increasingly prevalent post-pandemic, the concept of *remote making* or *making at home* has gained more attention over the past three years in the maker education community. On the one hand, remote making presents a unique opportunity to address issues of justice, equity, and culture that have recently caught the attention of maker education by democratizing access to resources, tools, and collaborative learning experiences. By embracing this new paradigm, we could potentially empower individuals from diverse backgrounds and locations and ensure that students have equitable access to creative, hands-on experiences. On the other hand, previous studies have revealed how the introduction of digital tools, project-based pedagogies, and “nonlinear” organization of collaboration – all common in making – could be challenging for students and teachers (Stahl and Hakkarainen, 2020; Kajamaa et al., 2020). When there is no access to physical makerspaces, the removal of face-to-face interactions and just-in-time support could leave students and their teachers with even more challenges navigating the complex learning activities involved heterogeneous learner groups, tools, and artifacts (Jayathirtha et al., 2020; Pepler et al., 2020).

Given such a context, this study investigates how a hands-on, project-based design class in a higher education setting transitioned from an in-person environment to a remote, at-home mode—focusing on how different students reacted to the transition. Our work adds to the ongoing conversation by demonstrating how learners might have different needs in remote making based on their *familiarity with the tools* and *help-seeking habits* and by spotlighting the exacerbated inequalities. We aim to provide rich descriptions of how different students reacted distinctively within the same class, emphasizing diverse types of learners' experiences and needs in remote making. Uncertainty about the advantages and disadvantages of remote or hybrid learning could harm certain groups of students, especially those with limited resources. By providing rich descriptions of different types of learners' experiences and needs in remote making, this

comparative case study also aims to provide insights into future research directions and interventions for reducing the exacerbated inequalities in other modalities of remote learning.

Background and Related Work

Help-seeking, defined as the ability to solicit help when needed, from a teacher, peer, book, or the online resources, is a complex process that involves several steps in self-regulation and communication (Karabenick, 1998). Research shows that effective help seeking is positively correlated with learning outcomes, and that those who need help the most are the least likely to ask for it (Gonida et. al, 2019; Won et. al, 2021). Furthermore, there is evidence that different types of help (Wu, 2021) or feedback (Li et al., 2022) affect learning differently in collaborative environments. With regard to prior knowledge, Dong et. al (2020) shows cognitive load and help-seeking as mediating factors on how prior knowledge influences learning engagement. In the context of makerspaces, studies on socio-cultural perspectives of makerspaces shed light on help-seeking, suggesting social support and scaffolding participation made it easier for novices to reach out for help (Roldan, Hui & Gerber, 2017). Fields et al. (2019) discuss how various environmental features, such as physical, curricular, social, and teacher attributes, can support emergent collaboration and help-seeking in more open-ended situations.

On the topic of remote making, Kinnula et al. (2021) have pointed out two major challenges of teaching digital fabrication online: the engagement of students and the motivation of teachers. They found that students had challenges following the class due to their unfamiliarity with software tools and the online setting and that the online mode made it impossible for teachers to provide direct feedback to students, while students could not, for the most part, identify their problems and needs independently. Benabdallah et al. (2021) emphasized that although remote collaboration is challenging, it is a necessary part of virtual making, since it allows students to demonstrate and share their expertise and interests. Similarly, Jayathirtha et al. (2020) suggested that visibility is crucial in students' making and that isolation stops students' help-seeking and learning from peers. Asynchronous feedback from teachers also limited students from exploring different possibilities with their coding projects, which resulted in superficial understanding. From these findings, the authors stressed the importance of visibility in these types of activities and learning environments.

Outside of the subfield of maker education, studies have also shown that online learning in general changes the nature of interactions between students, their peers, and their teachers (Joyce et al. 2015; Alpert, Couch, and Harmon 2016). The flexibility of online courses could allow students to better allocate time and effort but could also be a challenge for students who have not learned to manage their own time. Students likely feel less oversight from their teachers and less pressure to respond to teachers' and peers' questions due to the lack of face-to-face interactions (Chevalier et al., 2016). Furthermore, Bettinger et al. (2017) suggested differentially larger negative effects of online course-taking for students with lower prior GPAs. Research conducted during the COVID-19 pandemic has also shown that exacerbated inequalities and diminishing student motivation are two prominent themes in online learning (Reich et. al, 2020a). Besides the fact that many families don't have access to online options, students also have different levels of capability, motivation, and family supervision to support remote learning (Reich et al., 2020b).

However, one aspect that has been understudied in the existing literature is the fact that learners might have different needs and reactions in remote making. Focusing on students' familiarity with maker tools and help-seeking habits, our work provides rich descriptions of distinct types of learners' experiences and needs in remote making, and aims to provide insights into interventions for reducing the exacerbated inequalities in remote making and learning.

Methods

This study employs a case study approach (Creswell, 2009) focusing on a design class offered at an R1 university in the United States during the early months of COVID-19 pandemic. The natural experiment conditions (same group of students, same teachers, same content, but different modes of learning) unfortunately created by the pandemic lockdown provided us a valuable opportunity to examine how students learned differently in in-person and remote making settings. In addition, the unique roles physical spaces, tangible tools, and face-to-face interactions play in a design class which (pre-pandemic) utilized a makerspace were reflected.

Research Site

This project-based design course consisted of two parts: weekly theory-oriented lectures and hands-on labs. During the practice-focused labs, students were immersed in a university makerspace, where they learned to use digital fabrication tools to realize their design projects. There were 12 graduate students (two males and 10 females) in the class. Ten of the students had no prior experience with digital fabrication. The class was in-person for the first seven weeks and then moved online for the remaining eight weeks of the semester. Considering the lack of access to the makerspace, the teaching team introduced tools that were accessible to most students at home or that could be physically mailed, such as Arduino boards, LilyPads, 3D design software or crafting tools during the remote making weeks. By the end of the class, students were required to build a final project by identifying a problem of interest, brainstorming solutions, prototyping, testing, iterating the design, and presenting their functional prototypes.

Data Collection and Analysis

Three types of data were collected: (1) student-generated artifacts, (2) field notes, and (3) semi-structured interviews. Student-generated artifacts include students' weekly lab journals, written assignments, and projects (453 pages of written artifacts and 54 projects were collected in total). Field notes consisted of written notes about critical incidents that happened in the course and photos of students' making processes and final products (37 pages of field notes and over 200 photos were collected in total). Additionally, semi-structured interviews were conducted with each student at the end of the semester to gain an in-depth understanding of their experiences and feelings during the transition. The interview questions prompted participants to reflect on their learning and making experience in the lab and at home, challenges encountered in the transition process, their attempts at seeking information and/or help, use and help with different resources, and barriers in accessing help. A total of 14 hours of interviews were recorded with consent and transcribed.

The interview transcripts, along with other data collected (i.e., field notes, written assignments, photos, and physical artifacts) were extensive and allowed us to draw on multiple sources of information (Creswell, 2009), triangulate data, and develop case studies of how each student adapted to the transition from in-person to remote learning. All forms of data were analyzed case by case using thematic analysis, followed by a cross-case analysis (Stake, 1995). The themes that were salient across all cases, as well as themes that were distinctively different across cases, were noted. The first author conducted the initial coding of the emerging themes, and then the themes were discussed and refined with the second author over the course of three months with four iterations.

In the first and second iterations of the data analysis, we looked for patterns in how different students responded or were affected by the transition. The goal was to categorize students in terms of those patterns and then conduct in-

depth case studies on prototypical students in each category. After the initial analysis, we found that the best criteria for the categorization were: (a) students' level of prior knowledge with digital fabrication (DF) tools and (b) their level of initiative in help-seeking. We further categorized all students into three categories according to these two dimensions and identified one prototypical student in each category for developing in-depth cases based on our multiple data sources in the third and fourth iterations.

Findings

To offer rich and thick descriptions for each category and to illuminate their nuances, we present one representative student case from each of the three learner groups (there were no students that had both high prior knowledge and high help-seeking actions in the class). We structure our findings with regard to two emerging themes in the data: (1) idea generation and exploration, and (2) construction and making. In each theme, we discuss each of the three students' learning experiences.

Idea Generation and Exploration

In this project-based class, idea generation and exploration was a crucial step in all class projects. Before the actual building of artifacts, students usually spent a substantial amount of time identifying a problem or need, brainstorming possible solutions, and experimenting with various tools and materials. In this section, we reveal how different types of learners adapted their idea generation and exploration processes when moving from in-person making to remote making and what kinds of challenges and opportunities they encountered.

Betty (low prior knowledge with DF / high level of help-seeking actions)

During in-person making, most of Betty's idea generation and exploration took place in the makerspace. For her, the physical lab created a "creative space" where she could draw inspiration from peers, experts (the teaching team), and the environment itself. She mentioned in the post-interview that "random interactions" with peers and TAs were an important source of ideas for her [individual interview]. After moving online, Betty missed the *organic interactions* with peers and the inspiration from *the visibility of materials* in the lab. She tried hard to "rebuild her creative space" online through different approaches, such as finding a partner for the final project, signing up for online office hours frequently, and forming a WhatsApp group with other students in the class [observation field notes]. These approaches helped her to accommodate the new remote learning situation, but she reflected in the post-interview that they were still different from the interactions in the offline lab space. For example, the WhatsApp group did foster some organic conversations, yet "it was super casual and not always necessarily related to [the class projects]". For Betty, the group ended up being more about emotional support and less about idea generation and exploration [individual interview].

In addition, Betty highlighted that the *inflexibility of online interactions* sometimes prevented her from asking for help. She wanted to ask for help during some online labs but hesitated because she didn't want to repeatedly stop the class and waste other students' time: "if it is in person, that wouldn't have been a problem because a TA could just help you individually if you're running behind. But, on the online platform I don't want to be like [...] can you re-do that and have the whole class wait for me" [individual interview].

Francisco (high prior knowledge of DF / low level of help-seeking actions)

Francisco's transition to virtual making was smoother. Since he had more experience with digital fabrication tools, he decided to change his idea generation and exploration to an individual decision process rather than a collective and interactive one [lab journal]. He was able to deliver great products, but he missed the opportunities of exploring more diverse tools and building physical prototypes [observation field notes]. To him, *visibility into others' making processes* is an important source of inspiration and motivation. He stressed that the difference between peer interactions online and offline was the main reason he decided to change his approach:

"It's not only about your own ideas or projects, it's about others' as well [...] We have breakout rooms [during online class], but I couldn't see what others were doing with their stuff [as an ongoing process] and get inspired by them in the making process. The makerspace is not just about the tools, but about seeing others using the tools."

Francisco also found *asynchronicity* to be an important factor that affected his exploration in remote making. He felt more comfortable asking his questions on the spot than scheduling a meeting to talk about it, saying, "you missed the synchronicity between when you have a problem and when the problem is going to be talked about." Francisco's learning loss is hidden and more subtle due to his high level of prior knowledge and strong independent problem-solving skills. However, he found himself more likely to jump into a quick fix and less willing to put extra time and effort into the class due to the lack of peer interaction and inspiration in remote learning [individual interview]. It is worth noting that, more than a missed learning opportunity for himself, it was also a missed learning opportunity for the group; Francisco often helped other students in the lab, and he contributed to the class' collective knowledge much more in person than in remote learning.

Sanaya (low prior knowledge of DF / low level of help-seeking actions)

Sanaya struggled in her idea generation and exploration process due to the transition to remote making and was unprepared at the beginning of the transition [individual interview]. She said in the post-interview, "I remember when we started out, the whole [pandemic lockdown] had just started and we were limited at home. It was very daunting to think about, okay, how will I be able to build or what can I do." Similar to Betty, Sanaya thought that *organic peer interaction and collaboration* was a significant component of her idea generation journey. She also highlighted the fact that, "a lot of times [offline] you're not signing up for that collaboration, but it naturally occurs." In contrast, "you have to be more deliberate online."

Sanaya's engagement in class dropped significantly with the transition to remote learning. She was sometimes absent from class without notice, and she stopped coming to office hours [observation field notes]. In her post-interview, she stated that "when we moved online, I kind of ran away." She pointed out that the physical lab created a "magic circle" in which "you can be more creative, and you are free to make mistakes, and other people will help you." Furthermore, the "peer pressure in a good way" also pushed her to keep improving her work. After moving online, Sanaya had a hard time separating her work for the class from the rest of her life, and she found it hard to concentrate on the class work. Also, the lack of peer interaction and the physical boundary gave her a feeling that "there was a sense of reduced accountability," and she found herself "procrastinating and escaping from work" more often [Individual interview].

Construction and Making

The physical construction of objects, often with accompanying programming activities, is another indispensable

component of a maker class. In this section, we demonstrate how different students' experiences and attitudes of building, testing, and iterating changed as we moved online.

Betty (low prior knowledge with DF / high level of help-seeking actions)

Betty liked the concept of “making at home.” She believed “a really big component of making education successful is being able to incorporate your community and your home and your family into the process” [lab journal]. Despite her excitement, the reality of “making at home” soon set in. It was hard to access the materials and tools she needed for her final project, and it significantly limited her design [individual Interview]. For example, when it came to electronics and physical computing, she realized her designs were limited by the tools she had at home, and she had to deviate from her original ideas. She also felt she “sort of missed on learning [some new skills and tools].” Betty highlighted that she had “an unfinished feeling” about her final project during the post-interview. She didn't think she was able to reach her full potential in her final project, and she wished to continue building the project in-person when the lab re-opens again [individual Interview].

Francisco (high prior knowledge of DF / low level of help-seeking actions)

Francisco found himself less motivated to “make stuff” or to challenge himself due to the *lack of interactions with physical materials, machines, and other colleagues*:

A huge part of it is being able to do stuff, so being able to interact with the materials and the machines, and also being able to interact with other colleagues [...] I know we tried to create things at home, but we definitely lost something. We didn't have interactions with machines, and that was the motivation to create things [...] When you get with all the machines there, I think everyone gets impressed both with your own work and with each other's because [the end results] were usually something you didn't think that you could do before. They really look professional. Like the stuff you see in the shop.

Figure 1(a) illustrates a “professional-looking” (as suggested by Francisco) board game Francisco made using 3D printers, laser cutters, and different materials in the makerspace during the in-person making phase. As he mentioned, the different machines and materials in the makerspace not only open up more opportunities for different design ideas but also the “motivation” for students to “make stuff.” Being able to make something that is *professional-looking* and that is outside students' expectations is an empowering experience for many students.



Figure 1:(a) Francisco's “professional looking” board game project built in the makerspace; (b)(c)(d) Sanaya's final project building with accessible materials at home

Sanaya (low prior knowledge of DF / low level of help-seeking actions)

Similar to Betty, Sanaya also reported challenges caused by the *lack of access to tools and materials*. However, she also pointed out the positive impact of making at home in respect of *sustainability and accessibility* [individual interview]:

The fact that you have to think about what you can make at home does open up a lot of positive opportunities. In makerspace, you are less conscious about the material that you're wasting. You will do multiple testing to see if it works well, but you have that consideration automatically [at home] because you do have a limited supply [...]
Also, if you want to make sure your solution is equitable and accessible, I think building something at home can help you think more about that.

After going through many different ideas for her final project, Sanaya decided to build a culturally relevant math learning kit for students in low-income neighborhoods in her country, Pakistan. She found the students were unable to make connections between the real world and what they are taught in the math classroom, so she designed a block-printing set (inspired by indigenous practices in Pakistan) to help students experiment with geometry concepts, such as area, perimeter, and symmetry. Figure 1(b)(c)(d) demonstrates iterations of prototypes Sanaya built using affordable and accessible materials she found at home. As she suggested, one positive side of “making at home” is that she was more conscious about what kinds of materials she incorporated into her kit and how she put them together.

Discussion

By investigating how 12 graduate students in a design class reacted to the transition from in-person making to remote making during the pandemic and highlighting three representative case studies, this paper sheds light on the distinctive needs of different types of learners in remote making and explores the roles the physical makerspace and face-to-face interactions play in students' learning.

With regard to idea generation and exploration, we found peer interactions, process visibility of others' projects and environments are crucial to students' making experiences. Betty, who had a high level of help-seeking actions, tried several ways to recreate the “creative space” for herself. Her approach highlighted the social need of students in their idea generation process and how this need can be unfulfilled during online learning. Francisco, who had more prior knowledge of digital fabrication and a relatively low level of help-seeking actions, changed his idea generation into an individual process rather than a collective one. Francisco was able to finish all assignments on time and in good quality, so it might seem like the transition to online learning had no impact on his learning. Yet this was not the case. Through the post-interview, we realized how the transition to online made him largely restrict his idea generation and exploration process and his opportunities to learn more, narrowing his choices to exclusively digital projects. Francisco's case reveals some negative impacts of remote learning and making that might be overlooked. Sanaya, who has relatively low prior knowledge in digital fabrication and low level of help-seeking actions, felt intimidated and lost at first and “ran away” from the class. Her experience shed light on the particular pitfalls students might fall into during idea generation in remote making.

In the theme of construction and making, all three cases suggested that, although “making at home” was required during the pandemic, its implications had multiple layered and unintended consequences. We found that students' ideas and designs were largely restricted by what kinds of tools and materials they could access. Despite the initial excitement with making at home, it became apparent that such limitations could result in an “unfinished” or unsatisfied feeling, as Betty suggested, and might exacerbate inequality based on the different resources students can access. However, a positive change brought by “making at home,” highlighted by Sanaya, was students' increased awareness of sustainability and accessibility in making. When making at home, limited supplies pushed students to be more

conscious about what kinds of materials they incorporated into their work and how they should put them together. In addition, Francisco's case revealed possible motivating factors behind students' making: physical interactions with different machines, professionally-looking or "out of expectation" results, and the visibility of others' making processes.

Conclusion

Given that remote learning environments might become increasingly prevalent in education, findings from this study could shed light on potential directions for understanding the limitations and possibilities of such environments and how they could be best combined with face-to-face contexts. Compared to lecture-based classes, hands-on, project-based design classes arguably impose more challenges on learners and teachers in remote settings, which could exacerbate inequalities. In this work, we suggest that learners' prior knowledge in the domain area and their levels of help-seeking actions are two worthwhile dimensions for future research to investigate the differences among learners in remote learning and making. Furthermore, our findings suggest that even though some students completed the course successfully after the move to remote making, their success could hide missed learning opportunities. Our findings also highlight that some groups of students might struggle considerably, even though they were successful in the in-person class. To design equitable online, face-to-face, or hybrid maker-based learning environments, these considerations should be front and center for teachers and researchers.

References

- Alpert, William T., Kenneth A. Couch, and Oskar R. Harmon. 2016. "A Randomized Assessment of Online Learning." *American Economic Review* 106 (5): 378–82.
- Benabdallah, G., Bourgault, S., Peek, N., & Jacobs, J. (2021, May). Remote Learners, Home Makers: How Digital Fabrication Was Taught Online During a Pandemic. In *Proceedings of the 2021 CHI Conference on Human Factors in Computing Systems* (pp. 1-14).
- Benabdallah, G., Bourgault, S., Peek, N., & Jacobs, J. (2021, May). Remote learners, home makers: How digital fabrication was taught online during a pandemic. In *Proceedings of the 2021 CHI Conference on Human Factors in Computing Systems* (pp. 1-14).
- Bettinger, E. P., Fox, L., Loeb, S., & Taylor, E. S. (2017). Virtual classrooms: How online college courses affect student success. *American Economic Review*, 107(9), 2855-75.
- Chevalier, Arnaud, Peter Dolton, and Melanie Lührmann. 2016. "Making It Count': Evidence from a Field Study on Assessment Rules, Study Incentives and Student Performance." Institute for the Study of Labor Working Paper 8582.
- Creswell, J.W. (2009). *Qualitative Inquiry and Research Design Choosing Among Five Traditions*. Thousand Oaks, CA: Sage Publications.
- Dong, A., Jong, M. S. Y., & King, R. B. (2020). How does prior knowledge influence learning engagement? The mediating roles of cognitive load and help-seeking. *Frontiers in psychology*, 11, 591203.
- Fields, D., Jayathirtha, G., & Kafai, Y. (2019). Bugs as a nexus for emergent peer collaborations: Contextual and classroom supports for solving problems in electronic textiles.
- Halverson, E., Lakind, A., & Willett, R. (2017). The Bubbler as Systemwide Makerspace: A Design Case of How Making Became a Core Service of the Public Libraries. *International Journal of Designs for Learning*, 8(1).

- Jayathirtha, G., Fields, D., Kafai, Y. B., & Chipps, J. (2020). Supporting making online: the role of artifact, teacher and peer interactions in crafting electronic textiles. *Information and Learning Sciences*.
- Joyce, Theodore J., Sean Crockett, David A. Jaeger, Onur Altindag, and Stephen D. O'Connell. 2015. "Does Classroom Time Matter?" *Economics of Education Review* 46: 64–77.
- Peppler, K., Halverson, E., & Kafai, Y. B. (Eds.). (2016). *Makeology: Makerspaces as learning environments (Volumes 1 and 2)*. Routledge.
- Peppler, K., Sedas, R. M., & Dahn, M. (2020). Making at home: Interest-driven practices and supportive relationships in minoritized homes. *Education Sciences*, 10(5), 143.
- Kajamaa, A., Kumpulainen, K., & Olkinuora, H. R. (2020). Teacher interventions in students' collaborative work in a technology-rich educational makerspace. *British Journal of Educational Technology*, 51(2), 371-386.
- Karabenick, S. A. (Ed.). (1998). *Strategic help seeking: Implications for learning and teaching*. Routledge.
- Kinnula, M., Milara, I. S., Norouzi, B., Sharma, S., & Iivari, N. (2021). The show must go on! Strategies for making and makerspaces during pandemic. *International Journal of Child-Computer Interaction*, 29, 100303.
- Li, C., Xing, W., & Leite, W. L. (2022). Toward building a fair peer recommender to support help-seeking in online learning. *Distance Education*, 43(1), 30-55.
- Stahl, G., & Hakkarainen, K. (2020). Theories of CSCL. To appear. *International Handbook of Computer Supported Collaborative Learning*. London: Springer.
- Stake, R.E. (1995). *The Art of Case Study Research*. Thousand Oaks, CA: Sage Publications.
- Reich, J., Buttner, C. J., Coleman, D., Colwell, R. D., Faruqi, F., & Larke, L. R. (2020a). What's lost, what's left, what's next: Lessons learned from the lived experiences of teachers during the 2020 novel coronavirus pandemic. Retrieved from <https://edarxiv.org/8exp9>.
- Reich, J., Buttner, C.J., Fang, A., Hillaire, G., Hirsch, K., Larke, L.R., Littenberg-Tobias, J., Moussapour, R.M., Napier, A., Thompson, M. and Slama, R. (2020b). Remote learning guidance from state education agencies during the COVID-19 pandemic: A first look. <https://doi.org/10.35542/osf.io/437e2>
- Roldan, W., Hui, J., & Gerber, E. M. (2018). University makerspaces: Opportunities to support equitable participation for women in engineering. *Int. J. Eng. Educ*, 34(2), 751-768.
- Won, S., Hensley, L. C., & Wolters, C. A. (2021). Brief research report: Sense of belonging and academic help-seeking as self-regulated learning. *The Journal of Experimental Education*, 89(1), 112-124.
- Wu, J. Y. (2021). Learning analytics on structured and unstructured heterogeneous data sources: Perspectives from procrastination, help-seeking, and machine-learning defined cognitive engagement. *Computers & Education*, 163, 104066.

Learning through “playing with data”

Teachers’ perspectives on a constructionist approach to data literacy education

Yumiko Murai, Simon Fraser University, ymurai@sfu.ca

Cassia Fernandez, University of São Paulo, cassia.fernandez@usp

Abstract

Despite the growing importance of data literacy education, school curricula have commonly been reported to focus largely on the interpretation of data and lack opportunities to engage in the construction of visualization. Applying constructionist learning principles, this study investigated the perspectives of school educators on the opportunities and challenges of applying the constructionist approach to data literacy education. To explore research questions, the authors designed and conducted an online workshop featuring a data visualization tool built on the visual programming tool Scratch to provide first-hand experiences of constructionist data visualization to draw their authentic perspectives. The case study analysis of the project output history and workshop transcript revealed that the workshop did provide constructionist learning experiences to educators. The main findings include constructionist learning can lower the barrier to data literacy by allowing learners to deepen their understanding of data by playing with data, even when they do not have a good understanding initially. Challenges include the lack of exposure to visualized data may impact the learners’ capacity to engage in constructionist learning.

Introduction

Background

As the volume and accessibility of data in society increase, data literacy is becoming an increasingly important skill for making informed decisions, participating in civic activities, and understanding the world. As a result, working with data has become a critical aspect of almost every discipline in school education today. For instance, in science education, data serves as evidence to support claims, construct arguments, and make sense of the world [14]. Recent science and math standards require students to engage in data analysis by interpreting and representing data (e.g. [1,5,18]). However, recent studies have shown that many adults struggle to fully interpret standard data visualizations, such as the ones presented in newspapers [4,13]. One of the potential factors of this reported lack of data literacy is how data literacy is commonly taught in school environments. For instance, a study has reported that most curriculum materials merely require students to interpret visualizations created by others instead of constructing them themselves [3]. This is limited because interpreting and constructing visualizations involve different cognitive processes both of which are important for data literacy [10]. It has also been reported that constructing a visualization leads to a better understanding of the visualization than deconstructing it [30]. Another research shows that students benefit from working with data through meaningful inquiry, and by constructing, representing, analyzing, and using data as evidence in integrated ways [11]. These studies highlight that more construction-oriented approaches to data visualization should be incorporated into K-12 classrooms to cultivate more data-literate citizens [7,29].

Researchers have claimed that constructionism may be a valuable guiding principle to support data literacy education for school children [2,6,26,31]. Constructionism posits that learners gain knowledge most effectively when they are involved in the construction of sharable and personally meaningful artifacts through iterative experimentations [8]. In constructionist pedagogy, learners are considered active builders of knowledge, rather than passive receivers, cultivating their understanding of the world through direct engagement with physical or digital materials that are considered as “object-to-think-with” [13, p. 11] that represent learners’ ideas and understanding and help learners refine them. Studies have shown that constructionist learning approach to learning can enable learners to bring in their own cultural experiences and values to learning environments, allowing more learners to be part of the educational experiences [19].

In this study, we investigated educator perspectives on the opportunities and challenges of constructionist pedagogy for data visualization education through an online workshop with public elementary and middle school teachers using a data visualization tool called PlayData. In order to understand the authentic perspectives of teachers, we first explored the question of: Does this workshop provide educators with constructionist learning experiences? Through the analysis of workshop documentation and project output history, we investigated whether the teachers were able to reflect on their first-hand experience with constructionist learning experiences. As a second step of this study, we conducted focus group interviews as part of the workshop and thematically analyzed the workshop transcript to explore the main question: What are the tensions and opportunities school educators perceive in the constructionist approach to data visualization education? The contributions of this study includes a tool and activity for engaging with and reflecting on constructionist learning experiences and the potentials (and tensions) of the constructionist approach in addressing the needs for data literacy education in school settings, grounded in in-service teachers’ voices.

PlayData

PlayData was developed as a modified version of a visual programming platform Scratch 3.0 [12], and seeks to support learners in making sense of data through the creation of personal representations by taking advantage of the flexibility offered by block-based programming environments. PlayData was created to support constructionist learning experiences by allowing children to engage in programming as a way to “explore, experiment, and express themselves” [23]. Its design was also guided by a desire to scaffold a “messing about” attitude towards data [9], based on the premises that: (1) the tool should be intuitive enough so it doesn’t require extensive instruction to get familiar with (low floors), and (2) it should allow learners to “tinker with their data”, trying out different ways of representing the same dataset by creating, testing and refining their visualizations iteratively [2].

PlayData comprises (1) new programming blocks to import, analyze, and visualize data, (2) a table embedded into the environment that allows users to see the dataset imported, which is opened through the table icon (3), and (4) new custom sprites and backgrounds that can be used in data visualization projects (For the details of the design of the tool, see [2]).

In PlayData, users can easily plot data values to visual components such as colors and shapes, as well as sounds, and manipulate them to create static or animated representations of the data. Its interface is based on Scratch editor which is designed specifically to provide a friendly interface and highly interactive feedback. Thus, PlayData allows users to easily see the outcome of their actions and make changes to the visualization while monitoring them on the same screen.

Methods

This study employed a case study method to investigate each teacher's perspectives through analysis of observation notes and focus group interviews. The case study method was chosen because it focuses on specific phenomena in a bounded system [15] of this particular workshop, enabling us to understand teachers' perspectives in the naturalistic context.

Participants

The participants of this study were four elementary and middle school educators in rural Japan (Table 1). They were recruited from an email listserv of the current and past participants of a professional development program focused on constructionist programming education [17]. Through the program, all of them had a basic understanding of constructionist pedagogy and Scratch. The workshop was conducted online using the videoconferencing tool Zoom and each participant participated from their home or workplace.

Teacher (Pseudonyms)	School Type	Subject Areas	Teaching Experience
Ms. Matsuda	Elementary	Music, Home economics, Language arts	13 years
Mr. Takada	Elementary	All subjects	12 years
Mr. Terao	Middle	Technology	2 years
Mr. Goto	Middle	Technology, Social science	17 years

^a In the Japanese school system, an elementary school equates to Grades 1–6 and a middle school to Grades 7–9. In this prefecture, some elementary school teachers have a disciplinary specialization, but most of them teach all major disciplinary areas.

Table 1: List of participants in the workshop

Workshop

The two-hour online workshop was conducted entirely in the Japanese language. The workshop consisted of (1) an ice-breaker asking about teachers' experiences and understanding of data visualization, (2) a brief introduction to data visualization, (3) a follow-along tutorial to PlayData, (4) an open-ended project creation in teams, and (5) final share out and reflections, which served as a focus group interview for data collection purpose. During the open-ended project, the teachers were asked to create visualization of a data set of the historical Nobel Prize winners (e.g., number, type of awards, country, and gender of the winners each year). We used a shared data set because of lack of time, but each teacher was encouraged to design any type of visualization and to focus on any part of the data of their interest. The first author facilitated the workshop while the second author helped to prepare the workshop materials asynchronously. The participants formed two groups of two and worked on a project independently while discussing with one another in breakout rooms.

Data Collection and Analysis

We collected and thematically analyzed a transcript of the workshop in the main Zoom room. The transcript was translated into English by the first author. The second author first analyzed the project output history data (i.e., how the project was transformed over time) to see if any patterns aligned with constructionist learning principles (e.g.,

constructive, iterative, peer-oriented, interest-driven) can be found in the way participants engaged in the workshop to address the first research question. Both authors then met and discussed each pattern while also referencing the transcript of the workshop to deepen understanding of how participants interacted with the project, and did so until there are no analytic disagreements. Two authors then closely read the transcript and individually conducted evaluation coding [22] in order to address the second research question regarding teachers' perspectives on opportunities and tensions of constructionist learning activities for data visualization education. The transcript was organized in a spreadsheet by each verbal sentence and examined for relevancy to the research questions. They then met and discussed each code until they reached an agreement for all the coded segments. Next, they conducted pattern coding [16] to identify major themes in the codes identified during the first cycle of coding. Each educator's PlayData project data and a remote whiteboard used during the ice-breaking were also collected and reviewed to triangulate what participants verbally described during the workshop.

Findings

RQ1: Does This Workshop Provide Educators With Constructionist Learning Experiences? If So, How?

During the workshop, each participant shared a variety of visualization of the data of the historical Nobel Prize winners (Figure 1). Since teachers paired up to work together as they create their own projects, the final outcomes of those who were in the same group resembles each other, indicating they worked together as they created the visualization.

Teacher (Pseudonyms)	School Type	Subject Areas	Teaching Experience
Ms. Matsuda	Elementary	Music, Home economics, Language arts	13 years
Mr. Takada	Elementary	All subjects	12 years
Mr. Terao	Middle	Technology	2 years
Mr. Goto	Middle	Technology, Social science	17 years

^a In the Japanese school system, an elementary school equates to Grades 1–6 and a middle school to Grades 7–9. In this prefecture, some elementary school teachers have a disciplinary specialization, but most of them teach all major disciplinary areas.

Figure 1: Screenshots of the animated final visualizations created by participants.

The analysis of the project output history and the workshop transcripts showed several evidence that participants did engage in constructionist learning processes [8], indicating that the participants were able to reflect on their first-hand constructionist experience in the context of data visualization. Below, we describe three examples of identified participant experiences aligned with the principles of constructionism.

Tinkering With Representations

One example observed during the workshop was iterative exploration, or tinkering, which is one of the most common characteristics of constructionist learning. For example, Mr. Goto, a middle school technology and social science teacher, initially described data visualization as graphs made out of the questionnaires, when he was asked at the beginning of the workshop. During the workshop interacting with PlayData, his project output history showed that he went through various experiments trying multiple representational forms, changing the sprite's size, colors, and shape

to produce different, and also adding musical elements to express the data with sounds (Figure 2). While he was not able to finish what he wanted in the given time and was not able to showcase his work at the end of the workshop. he said “two hours flew by,” implying that he was deeply immersed in the process. He noted, “it’s been a long time since I’ve had this feeling,” suggesting that he perceived this as a positive experience. Mr. Goto’s case showed how he engaged in playful experimentation with the tool, and acknowledged that he had “hard fun” [20], a feeling that Papert claims to be associated with constructionist learning where an activity feels fun despite its difficulty because of a deep level of engagement.



Figure 2: History of visualizations created by Mr. Goto during the workshop (older work on the left and newer work on the right)

Connection to Personal Interests

Another example brought up by one participant was that the workshop allowed her to connect her personal interests to the engagement with PlayData, which is another important principle of constructionist learning. Ms. Matsuda was an elementary teacher who taught music, home economics, and language arts, but was particularly interested in the connections of data to music. At the beginning of the workshop, she mentioned having prior experience with using data visualization with her students in her music classes. During her experimentation with PlayData, she created bar charts and added sounds of different instruments to represent the Nobel prizes won by men and women. Her example shows that she connected data representation to personal interests, extending her prior experience. This showed that involvement of learner interest, which is considered to be an important element of constructionist learning was present, allowing participants to make the experience more relevant to them.

Collaborating and Learning From Others

Another constructionist experience we identified teachers had during the workshop was the opportunity to learn from their peers. During the creation part of this workshop, teachers worked together in pairs, but the way they work was left for them to decide. In the final discussion, Mr. Takada and Mr. Terao, who mapped the data of Nobel Prize winners onto a world map, mentioned that they started their creation processes by imitating each other’s projects. Despite the fact that they started their work together, their final projects looked different. Noting that “imitating was a good first introduction to the tool,” Mr. Takada mentioned that it was interesting to engage with ideas from other teachers, which they had not imagined before. Their example shows that the tool and workshop provided the opportunity to explore and refine their own ideas and understanding through peer interaction, which is consistent with the constructionist process of learning.

RQ2: What Are the Tensions and Opportunities Japanese School Educators Perceive in the Constructionist Approach to Data Visualization Education?

Opportunities

One of the opportunities mentioned across participants was that data visualization experiences enabled them to see the data in various, sometimes totally unexpected ways, helping their understanding of the data. For example, Mr. Terao said, “PlayData attracted my interest when I noticed that data can be so much easier to understand when you can see some changes visually like in a graph that changes over time.” And he continued, “I had never thought of expressing data with sound, so I found it quite interesting,” indicating that PlayData gave him a new insight into the data by allowing him to see it in various different formats. Considering that all teachers had limited conception about data visualization at the beginning (i.e., all described that data visualization usually meant creating a bar or pie chart using Microsoft Excel), constructionist engagement with visualization has the potential to open up a new opportunity for students to incorporate various types of mediums such as sound and animation.

The educators frequently shared how PlayData inspired various ideas to visualize data and encouraged them to try them out. For example, Mr. Goto mentioned that observing his partner’s project idea using sound, he was inspired to imagine ways to animate visual components to go with the sound. Similarly, Mr. Takada was inspired to include multiple variables to enrich the information when he saw a sample project about the home countries of Nobel Prize winners. PlayData’s capacity to provide immediate feedback showing the results of their codes enabled each educator to imagine how the images could be otherwise, and try them out immediately. This immediate feedback and accommodation for iterations are often considered important in constructionist learning environments [25] and the educators’ comments underscored their importance in inspiring creative ideas and personal contributions to a visualization process.

Another opportunity articulated by the participants was that it enabled them to explore the data without much understanding of the data itself. Ms. Matsuda noted that she used to believe at least some understanding of data is required to conduct data visualization and thought that could be a challenge for some of her students. However, she continued, “when I tried PlayData today, playing on the table was quite interesting, and I got absorbed in it, and I started to think that children could play with data without knowing anything about the data.” Her comments aligned with the commonly known constructionist learning process, which often begins with active engagement and then leads to reflection and comprehension [27]. Ms. Matsuda highlighted how this approach to data visualization may help teachers to create a “low floor” [24], a learning environment that is accessible to novice learners.

Another participant also brought up how the constructionist approach to data visualization helped him communicate the otherwise complex data sets in an accessible, comprehensible way. Through the workshop, Mr. Goto realized that “programming is deeply involved in communication and conveying messages to others,” pointing out how PlayData helps users be more intentional about communication by allowing users to adjust and define different variables to best convey the message, in this case, the story of a data.

Tensions

One tension expressed by all participants was the open-endedness of the tool; by allowing users to visualize data in various different ways, it added too much complexity to the process of learning the tool. Mr. Terao, for example, mentioned that he could not figure out how to change color but ended up running out of time. Mr. Takada also described how he struggled to figure out where to start and started by completely copying sample codes provided during the workshop. Mr. Goto also could not make his project work at the end as it crashed and he could not figure out how to fix

it. More consideration on how to introduce the tool and provide technical support to the users is especially important for constructionist learning activities where learners often self-directedly navigate their experiences.

Another interesting tension brought up was the potential difficulty of generating visualization ideas to try out when users have not seen many visualization examples. Mr. Takada noted, “I felt that it would be a bit of a challenge to work on it if you are an elementary school student and have not been exposed to many data or graphs before. So it might be important to help them expose to examples and cultivate their imagination before working on it,” stressing the importance of expanding their knowledge level about visualization to some extent in order to make use of the tool. This discussion about the necessary scaffolding for constructionist engagement is a common one [25] and requires further exploration.

Finally, we also identified a tension between the constructionist data visualization’s capacity to visualize data in various different ways and its tendency to make users focus too much on visual elements. Mr. Terao described how he became obsessed with changing the color to specific ones and wasted a lot of time even though his original intention was to change more than colors. While this is a common issue identified in constructionist projects, some also say that enthusiasm to work on visual elements of projects is not always destructive and sometimes even beneficial for learning [21], for example, by forcing them to define exactly what they want to see visually. Further exploration is needed to investigate the benefits and shortcomings of constructionist projects’ capacity to support visual and aesthetic explorations.

Discussion and Conclusion

This paper reported on findings from the analysis of the transcript and artifacts from an online data visualization workshop with four elementary and middle school educators in Japan, specifically focusing on how they perceive opportunities and challenges of the constructionist approach in data visualization education. The study contributed clear evidence that the participants engaged in constructionist learning experiences during data visualization with PlayData, a data visualization tool designed to support constructionist learning. The references teachers made to their own constructionist experiences (some described in 3.2) show that they were directly reflecting on constructionist learning and therefore supporting the authenticity of the insights for the RQ2. This highlights that constructionist learning can be supported and fostered by the use of intentionally-designed tool and activity. The constructionist experiences observed during the workshop can be useful references when designing tools and workshops for such reflective activities.

Based on their constructionist data visualization experiences during the workshop, the educators indicated that while there were tensions to introducing data visualization through the constructionist approach, the constructionist approach can open up a number of educational opportunities for data visualization education; for example, by inspiring creativity and enabling students to learn through play with data, even when they were unfamiliar with the data at the beginning. The data also showed that the constructionist approach may elevate data visualization activities beyond data literacy education, by creating opportunities for users to cultivate their communication skills through coding. This contributes promising evidence to the growing discussion of the role of coding in public education. It was worth noting that the participants of this study who were in the Japanese context indicated their experience with data visualization was somewhat homogeneously focused on graph making with Microsoft Excel software. One young teacher even commented that he had never heard of the term data visualization. This indicates that data visualization is a field that is still largely unexplored particularly in Japanese elementary and middle school contexts, and therefore more work is warranted. Finally, as a limitation, this study reported on a discussion with four school educators from a one-off, two-hour workshop due to the scheduling difficulty with teachers at the time. Future studies should explore the topic through deeper engagement with constructionist data visualization activities with a more diverse group of educators.

Acknowledgements

We thank Shinshu Maker Fellow teachers who participated in the workshop and shared their time to explore the tool and their perspectives with us.

References

1. Australian Curriculum Assessment and Reporting Authority (ACARA). 2015. Foundation–Year 10 Australian Curriculum: Science. Foundation–Year 10 Australian Curriculum: Science. Retrieved from <https://www.australiancurriculum.edu.au/f-10-curriculum/science/>
2. Cassia Fernandez, João Adriano Freitas, Paulo Blikstein, and Roseli de Deus Lopes (2023). PlayData: Expressive data visualization through block-based programming. In ISLS 2023 –Proceedings of the 3rd International Society of the Learning Sciences (ISLS) Annual Meeting.
3. Katy Börner, Andreas Bueckle, and Michael Ginda. 2019. Data visualization literacy: Definitions, conceptual frameworks, exercises, and assessments. *Proceedings of the National Academy of Sciences* 116, 6 (February 2019), 1857–1864. DOI:<https://doi.org/10.1073/pnas.1807180116>
4. Katy Börner, Adam V. Maltese, Russell N. Balliet, and Joe Heimlich. 2016. Investigating aspects of data visualization literacy using 20 information visualizations and 273 science museum visitors. *Information Visualization* 15, 3 (2016), 198–213. DOI:<https://doi.org/10.1177/1473871615594652>
5. British Columbia Ministry of Education. 2017. British Columbia’s Science curriculum. Retrieved May 6, 2023 from <https://curriculum.gov.bc.ca/curriculum/science>
6. Catherine D’Ignazio and Rahul Bhargava. 2018. Creative data literacy: A constructionist approach to teaching information visualization. (2018).
7. William Finzer. 2013. The Data Science Education Dilemma. *Technology Innovations in Statistics Education* 7, 2 (2013). DOI:<https://doi.org/10.5070/T572013891>
8. Idit Harel and Seymour Papert. 1991. *Constructionism*. Ablex Publishing.
9. David Hawkins. 1965. Messing about in science. *Science and children* (1965).
10. Sukwon Lee, Sung-Hee Kim, Ya-Hsin Hung, Heidi Lam, Youn-Ah Kang, and Ji Soo Yi. 2016. How do People Make Sense of Unfamiliar Visualizations?: A Grounded Model of Novice’s Information Visualization Sensemaking. *IEEE Transactions on Visualization and Computer Graphics* 22, 1 (January 2016), 499–508. DOI:<https://doi.org/10.1109/TVCG.2015.2467195>
11. Victor R Lee and Michelle H Wilkerson. *Data Use by Middle and Secondary Students in the Digital Age: A Status Report and Future Prospects*.
12. Lifelong Kindergarten MIT Media Lab. 2003. Scratch. Scratch. Retrieved from <https://scratch.mit.edu/>
13. Adam V. Maltese, Joseph A. Harsh, and Dubravka Svetina. 2015. Data Visualization Literacy: Investigating Data Interpretation Along the Novice–Expert Continuum. *Journal of College Science Teaching* 45, 1 (2015), 84–90.
14. Katherine L. McNeill and Leema Berland. 2017. What is (or should be) scientific evidence use in k-12 classrooms? *Journal of Research in Science Teaching* 54, 5 (2017), 672–689.
15. Sharan B. Merriam. 1985. The case study in educational research: A review of selected literature. *The Journal of Educational Thought (JET)/Revue de la Pensée Educative* (1985), 204–217.
16. Matthew B. Miles, A. Michael Huberman, and Johnny Saldaña. 1994. *Qualitative data analysis: An methods sourcebook* (3rd ed.). SAGE Publications.
17. Yumiko Murai and Hiroyuki Muramatsu. 2020. Application of creative learning principles within blended teacher professional development on integration of computer programming education into elementary and middle school classrooms. *Information and Learning Sciences* 121, 7/8 (January 2020), 665–675. DOI:<https://doi.org/10.1108/>

18. National Research Council. 2012. *A Framework for K-12 Science Education: Practices, Crosscutting Concepts, and Core Ideas*. National Academies Press.
19. Seymour Papert. 1980. *Mindstorms: Computers, children, and powerful ideas*. NY: Basic Books (1980), 255.
20. Seymour Papert. 2002. *Hard Fun*. Bangor Daily News. Retrieved from <http://www.papert.org/articles/HardFun.html>
21. Kylie A. Peppler and Yasmin B. Kafai. 2007. From SuperGoo to Scratch: exploring creative digital media production in informal learning. *Learning, Media and Technology* 32, 2 (June 2007), 149–166. DOI:<https://doi.org/10.1080/17439880701343337>
22. Sharon F. Rallis and Gretchen B. Rossman. 2003. Mixed methods in evaluation contexts: A pragmatic framework. *Handbook of mixed methods in social and behavioral research* (2003), 491–512.
23. Mitchel Resnick. 2017. Fulfilling Papert’s Dream. In *Proceedings of the 2017 ACM SIGCSE Technical Symposium on Computer Science Education (SIGCSE ’17)*, New York, NY. DOI:<https://doi.org/10.1145/3017680.3025046>
24. Mitchel Resnick. 2017. *Lifelong kindergarten: Cultivating creativity through projects, passion, peers, and play*. MIT press, Cambridge, MA.
25. Mitchel Resnick and Eric Rosenbaum. 2013. Designing for tinkerability. In *Design, make, play: Growing the next generation of STEM innovators*, Margaret Honey and David E. Kanter (eds.). 163–181.
26. Mike Tissenbaum, David Weintrop, Nathan Holbert, and Tamara Clegg. 2021. The case for alternative endpoints in computing education. *British Journal of Educational Technology* 52, 3 (2021), 1164–1177. DOI:<https://doi.org/10.1111/bjet.13072>
27. José Armando Valente and Paulo Blikstein. 2019. Maker education: Where is the knowledge construction? *Constructivist Foundations* 14, 3 (July 2019), 252–262.
28. Shirin Vossoughi, Paula K. Hooper, and Meg Escudé. 2016. Making through the lens of culture and power: Toward transformative visions for educational equity. *Harvard Educational Review* 86, 2 (June 2016), 206–232. DOI:<https://doi.org/10.17763/0017-8055.86.2.206>
29. Alyssa Friend Wise. 2020. Educating Data Scientists and Data Literate Citizens for a New Generation of Data. *Journal of the Learning Sciences* 29, 1 (January 2020), 165–181. DOI:<https://doi.org/10.1080/10508406.2019.1705678>
30. Mary Ann Wojton, Sasha Palmquist, Victor Yocco, and Joe Heimlich. 2014. *Meaning making through data representation: Construction and deconstruction*. Technical report. Columbus, OH: Lifelong Learning Group. Accessed November
31. Rabia Yalcinkaya, Hamid Sanei, Changzhao Wang, Li Zhu, Jennifer Kahn, and Shiyang Jiang. 2022. Remixing as a Key Practice for Coding and Data Storytelling. In *Proceedings of the 15th International Conference on Computer-Supported Collaborative Learning-CSCL 2022*, pp. 407–410, International Society of the Learning Sciences.

Design Futures

Collaboration and creativity self-efficacy during design-based learning and maker education in elementary education

Annemiek Veldhuis, Simon Fraser University
Aakash Johry, Indian Institute Of Technology Delhi
Tilde Bekker, Eindhoven University Of Technology
Maaïke Jetten, Eindhoven University Of Technology
Emer Beamer Cronin, Designathon Works
Madalina Bouros, Allgrow
Ioanna Garefi, Stimuli For Social Change
Georgia Safouri, Aristotelio College

Abstract

Design-based Learning (DBL) and Maker Education (ME) are educational approaches that aim to equip students with 21st-century skills. In this work, we designed a lesson plan that facilitates students' collaborative exploration of a societally relevant, complex problem for which each team defines its own focus, called Design Futures. We investigated how this open-ended design process influences students' self-efficacy regarding creativity and collaboration by implementing it in 23 classrooms in three countries (the Netherlands, Greece, and Romania). We found that after implementation, students perceived themselves as significantly more creative, but their teamwork self-efficacy was measured to be lower. Additionally, we report on insights into the general experiences and difficulties of students and teachers.

Introduction

A growing consensus exists that formal education should cultivate students' creativity and collaboration skills in order to help them succeed in modern, globalized economies [24]. Design-based learning (DBL) and Maker Education (ME) are educational approaches that might equip students with these necessary skills to thrive in these non-linear and constantly evolving contexts. These learning approaches nurture 21st-century skills through creative, making processes [4, 12] and can be combined as they both involve ideating, creating, and reflecting on experience [13]. DBL can be defined as a team-based learning method that aims to help students deal with complex problems through supporting critical problem understanding and the creation of various solutions [3]. ME is a type of project-based learning where the learner produces a physical object or artifact resulting from newly learned concepts and skills [4]. However, there are still few implementations of DBL and ME in formal, elementary education [22].

Prior work has primarily looked into how DBL can impact students' skills [9, 10, 14]. Many of these works implement a more structured approach in which students don't conduct the inquiry process that supports gaining a deep and holistic understanding of the problematic situation that are designing for [7]. In our work, we aim to go beyond this design-as-making paradigm [8] by placing the project-briefs presented to the students in a broader context and allowing students to frame their own design opportunities within. In such a process, students need to become more self-regulated [3]. Students' regulation of learning and motivation is influenced by their perceived self-efficacy [1], defined as their beliefs

about their capabilities to produce designated levels of performance that exercise influence over events affecting their lives. As such, we aim to investigate students' self-efficacy regarding the more challenging skills in DBL and ME [6, 10].

We present *Design Futures (DF)*, a lesson plan aimed at students ages 8 to 12, that consists of a sequence of nine lessons. This lesson plan bridges the educational context with the outside world by teaching students about societal problems. The students learn about electronic circuits and use basic electronic components in the creation of a mock-up of their design. The teaching activities incorporate DBL- and ME-related learning objectives and student self-assessment. We report the results of triangulated mixed-methods case studies in which the DF curriculum gets tested in 25 classrooms distributed over three countries (Romania, Greece, and the Netherlands). We investigate the questions: “How does a DBL and ME program, that goes beyond design-as-making, impact elementary school students’ (ages 8 to 12) self-efficacy regarding collaboration and creativity?” and “What are the teachers’ and students’ experiences regarding the implementation of such a program?” We combine data from pre- and posttest measures, post-intervention interviews and focus groups. We hope to contribute to the further re-envisioning of formal elementary education towards the inclusion of DBL and ME activities by 1) investigating how students’ self-efficacy regarding two 21st century skills fundamental to DBL – creativity and collaboration – is affected by a DBL program in which they are able to define their own design opportunity, 2) showcasing the experiences and challenges of teachers and students in multiple countries while implementing DBL and ME in formal primary education, and 3) making recommendations for the future development of DBL and ME material for early education.

Related Work

Design-Based Learning and Maker Education

As DBL and ME are fairly novel pedagogical approaches [20], much research has been conducted on their efficacy in regard to skills learning, impact on students’ attitudes [17], retention of knowledge [18], and impact on different student demographics [10, 18]. For example, investigations have indicated a positive impact of DBL on students’ computational thinking [14] and problem-solving abilities [9].

While the potential benefits of utilizing design and making in the classroom are clear based on the research above, the strategy is not without its limitations. Doppelt et al. [10] points out that although DBL can be highly motivating for students, its open-ended nature can also lead students to experience cognitive overload. Carroll et al. [6] noted that students identified collaboration as a challenging aspect of the project.

Most of the implementations of DBL and ME used in these research studies use an approach to DBL that forgoes the inquiry stages of the design thinking process [7]. Yet they focus on the ideation of multiple ideas and the ability to translate these into tangible creations, i.e., design-as-making [8]. Furthermore, they focus mostly on implementing DBL and ME at secondary schools, higher education institutions, or in extracurricular activities. By supporting all phases of the design thinking process, we encourage students to collaboratively explore a societally relevant, complex problem. Each team can choose their own focus within this broader context. As it is challenging for teachers to facilitate such a process, students need to become more self-regulated [3].

Self-Efficacy in Learning

Self-efficacy influences learning, motivation, and self-regulation [21]. Self-regulated learning is more likely to occur

when students feel more efficacious about their learning [21]. Bandura [1]'s model of triadic reciprocity shows that self-efficacy can be affected by environmental factors. We believe that the learning approach and other classroom variables can have an impact on self-efficacy. Through our work, we aim to understand the effect of using DBL and ME as learning approaches on students' creative self-efficacy [2] and teamwork self-efficacy [16]. This relationship could further help in understanding students' regulation of learning and motivation in such educational contexts

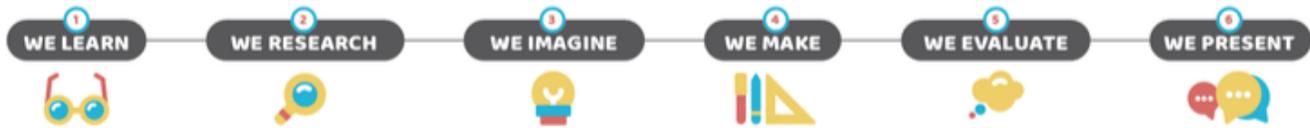


Fig. 1. The six phases of the DF method: 'We learn', 'We research', 'We imagine', 'We make', 'We evaluate' and 'We present'.

Design

The DF method¹ consists of nine lessons spread over six phases (see Fig. 1) related to the phases of the double diamond [19]. Through the method, students worked in teams to solve a societal issue based on one of the UN's Sustainable Development Goals (SDG). Each activity in the curriculum was described in a lesson plan, along with informational resources on the subject matter, PowerPoint presentations, worksheets, assessment materials, and a self-reflection booklet for students. In this booklet, the students could self-evaluate their competencies, set a personal goal for the project, keep track of their process, and reflect on their experiences. Additionally, teachers received a 'Makerkit' that included basic electronics for prototyping.

DF was designed using requirements gathered from teachers and students. In four countries, 91 participants participated in four requirement gathering activities: semi-structured interviews with teachers and school administrators, teacher focus groups, and student workshops. Additionally, we aligned the learning goals, learning activities, and assessment tools through the use of a curriculum blueprint developed in our earlier work [22].

The DF Process

Students are introduced to a societal problem during the *We Learn* phase, either clean energy (SDG13) or poverty (SDG1). The topics are intended to be broad enough for students to identify sub-problems within them. As ME element, the students learn about the Makerkit's technological components (see Fig. 2a). Finally, they fill out the first competency self-evaluation page in the self-reflection booklet and choose a goal (see Fig. 2b). A worksheet guides students through interviewing a community member to investigate the topic in the *We Research* phase.

1. visit www.designfutures.eu for an in-depth overview of the method and related materials.

Country	Classrooms	Teachers Total	Teachers Focus-group	Students Total	Students Self-report	Students Interviews
Netherlands	10	14	8	348	157	42
Greece	5	7	7	89	89	80
Romania	10	11	4	227	161	54

Table 1. Number of teachers and students participating in the DF program and various data gathering activities.

Additional research can be conducted if needed. During the *We Imagine* phase, students develop a problem statement guided by a worksheet using the information gathered previously. The subsequent brainstorming process is guided by another worksheet (see Fig. 2c). Once enough ideas have been generated, students are asked to discuss their ideas with their team. The design worksheet will help them develop their final idea and make a detailed sketch of what it should look like. *We Make* starts with students constructing the general structure of their prototypes using crafting materials (see Fig. 2d). They can then incorporate electronic components (such as DC motors, LEDs, switches) from the Makerkit. Next, students *evaluate* their prototypes via a worksheet and give and receive feedback from other teams. In the reflection booklet, they also reflect on their project. Finally, students *present* their projects to the class.

Participants & Procedure

In November of 2020, 32 teachers received a day-long training workshop on how to implement the DF program. Most workshops were held online in a seminar-like format due to the COVID-19 pandemic. Following a pilot study to test the materials, the DF program was implemented in 25 classrooms from February to May 2021. Due to pandemic-related constraints, no on-site observations could be conducted. The number of students and teachers participating in the implementation and data collection activities is shown in Table 1. The students were between the ages of 8 and 12, and all teachers had at least two years of experience.

Teachers implemented the DF process based on their context. Implementation of DF lessons occurred twice a week, once a week, or as a project week. In some cases, teaching assistants or other teachers helped to facilitate the process.

Data Collection & Analysis

Caregiver's consent was obtained before implementation. Students were asked to answer a 10-item questionnaire combining the creative self-efficacy [2] and teamwork self-efficacy [16] scales. This was done at the beginning and end of the DF program to evaluate the impact on creativity and collaboration self-efficacy. Questions were translated into the students' native languages. Students answered on a 5-point Likert scale. In addition, a structured protocol was used to interview some students at the end of the program (see Table 1). Researchers interviewed three to four students at a time. Lastly, focus groups were held with participating teachers (see Table 1).

The student interviews and teacher focus groups were recorded, transcribed, and translated into English. Two coders collaboratively analyzed these transcripts through thematic analysis [5]. The quantitative results of the two pre- and post-creativity and teamwork self-efficacy surveys were analyzed through analysis of means. We removed entries in

which students did not complete the full scale. We triangulated data on creativity and collaboration self-efficacy from interviews, surveys, and reflection booklet entries to answer RQ1. The experiences of students' and teachers' related to the implementation of the program (RQ2) emerged primarily from the focus group and interviews.

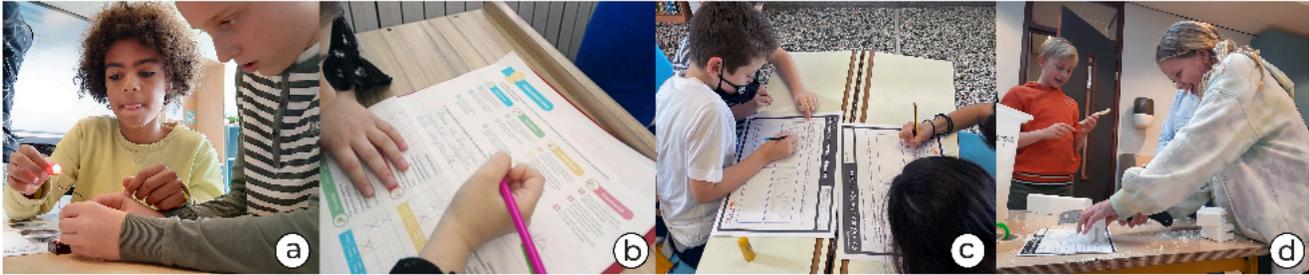


Fig. 2. Impression pictures of DF implementation: a) students getting acquainted with electronics; b) a student filling out their reflection booklet; c) students brainstorming; d) a student cutting styrofoam when prototyping.

Results

Self-Efficacy

As part of our research, we were interested in how DBL and ME affect students' perceptions of their skills. Participating students filled out the creative [2] and teamwork self-efficacy [16] scales.

Creativity

A paired samples t-test was conducted to measure all students' ($N = 294$) self-reported creativity self-efficacy before ($M=4.06;SD=.78$) and after ($M=4.27;SD=.76$) implementation to determine the possible effect of the DF curriculum. The results indicate a significant difference [$t(293)=-4.567,p=.000$] with a small effect size ($d=0.27$). This indicates that students felt more capable of creativity after participating in the project.

During the post-interviews, we asked the students whether they felt they had become more creative. Students linked creativity with activities such as generating ideas, sketching, working with new materials, prototyping, and solving problems. In line with the results from the questionnaires, some students expressed that they have gained a greater level of confidence in their creative abilities: *"I became more creative. I made multiple sketches, and I can use them for other ideas as well. I am confident that in the future I can put my ideas into practice."* In their reflection booklets, students also mentioned that perseverance, trying multiple options, taking more time for idea generation, asking questions, looking at what already exists, and using technology helped them develop their creativity. Among the students, creativity was described as the number of ideas that they could generate, the novelty of these ideas, and their openness to the ideas of their group members. *"I also was never really creative, but during this project I thought of a lot of ideas, and I liked that."* However, many students also reported that ideation was difficult for them. In their reflections on their process, students stated that their ideas were too ambitious: *"We didn't make what we had designed at the imagine phase because that idea couldn't be made."* One interesting finding was that some students evaluated their creativity according to the outcome of their project, for instance, the quality or completion of their prototype, as an indication of their creativity growth: *"No, I don't feel I've become more creative because our prototype isn't solid."*

Collaboration

Another paired samples t-test was conducted to determine the effect of the DF curriculum on the all students' (N =290) self-reported collaboration self-efficacy before (M=4.35;SD=.64) and after (M=4.24;SD=.68) implementation. The results indicate no significant difference [$t(289)=-268, p=.789$]. However, we observed a decrease in the means after the implementation of the project.

This is consistent with the reports that students made regarding their collaboration. The students noted that they experienced friction due to difficulties with compromising, authoritative, or disinterested team members, as well as poor communication due to frustration. In particular, students found it difficult to choose an idea to develop into a prototype and to work together during the prototyping process. Several teams developed strategies to mitigate friction, such as task division, team roles, combining ideas, or asking for assistance. Incorporating these strategies, however, requires students to be mindful. As this student points out, they need to ensure that they regulate their project collaboratively rather than directing their teammates: *"You wanted to say to the others, do this, do that. But you shouldn't do that because you just have to work together and divide tasks. You can't just tell the other person what to do; they have to choose what to do."*

Despite these frictions, students were able to describe important aspects of collaboration that they benefited from within this project. For instance, several students mentioned that listening to each other gave them new insights or improved their project's outcome. *"I used to be more like, working alone is faster and goes better, but if you work together, you end up somewhere very different than if you do it alone."* Within this project, they found that the collaboration went beyond the simple task divisions they had experienced previously in collaborative learning activities. During the interviews, some students reflected on the friction within their project. They concluded that the friction in their collaboration resulted in better project outcomes or made them more focused on collaboration due to the difficulty of the project. Unlike creativity, students felt that they improved in collaboration even if the project did not succeed.

Teacher & Student Experiences

Authentic Problems & Motivation

Students learned about an SDG in the first phase of the program. The social relevance of these SDGs was cited as a motivating factor by many students: *"...because you see the videos and you think 'Oh that's pretty big!' And then you want to do something about it."* Students had the opportunity to define their own goals and focus within the problem space. Students noted that this resulted in stronger bonds between their teammates and made them feel more engaged in the process. *"We made a goal together that we could really go for and that way you really built a stronger bond with your classmates."* *"My favorite was 'We Research' because I liked to interview my parents and come up with a solution for them."* These authentic problems also influenced some students beyond the classroom. Several of them described a change of attitude toward clean energy solutions, their behaviors at home, or wishing their parents were more aware of it: *"After this project, I was more attentive to the environment. I paid more attention if the lights were on in my house. I use more natural light. We should have a project for parents."* However, some teachers felt the problem statements were too open-ended for students. *"I think these topics are too far removed from primary education."* Other factors that students mentioned as motivating included the novelty, trial-and-error method of working, collaborative work, and physical aspect of the project.

Self-Efficacy, Goal-Setting & Reflection

Teachers perceived that the project increased social inclusion and addressed different talents. They found that it created a community-like feel in their classroom and helped students shine, especially those who struggle with more traditional (and less practical) didactic activities. *“They learned that each one of them has something to give and they need to pay attention to what others say even if they don’t have the best grades.”* In addition, students reported that they gained more confidence and were able to persevere through a setback.

According to the teachers, students’ ownership of learning increased as a result of the self-directed nature of the project. For example, one student described how the goal setting in the reflection booklet influenced their approach to working: *“I preferred to work alone, but that has changed now. I set it as a goal during this project and tried to work on it.”* Most students, however, responded that they were unsure or were not able to provide examples of how they achieved their goal. Teachers mentioned that they needed to support the students with goal setting. For example, teachers had to make sure that the students were setting goals at appropriate challenge levels. *“I had a one-on-one conversation with all the children about their goals. I wanted to learn how the children saw things and if they were challenging themselves.”*

Reflection was done either through the booklet or verbal formative assessment, such as class discussions or individual feedback, led by the teacher. However, the self-reflection booklet was difficult to use for many students. The repetition of similar questions at different stages of the process was confusing to some of them, while many disliked the written format as they preferred to do more activities. Some students, however, had a positive perspective on it. They noted that by using the booklet, they could recollect their process, see improvements, or voice their opinions. *“It was useful to use something like that, so you understand the project a little better. Then you can look back at the last lesson and see what you have done and what you can improve. I have sometimes done that, because then you see: ‘Oh, we can continue with that.’”*

Difficulties & Changes Made to The Process

Next to the difficulties with reflection, both teachers and students experienced time limitations. Because teachers in the Netherlands have considerable freedom in the way they implement their educational activities, they were able to add more time and extend the making phase, allowing students’ prototypes to go through more iterations. *“We spent 5 lessons instead of two on the prototypes making. This was good as they could critically evaluate their work, present it and then continue improving it.”* The electronic components were perceived to be difficult to work with for some students due to fine motor skills or a fear of electricity. Furthermore, they felt it was difficult to go from an idea to a physical prototype and would have liked more guidance during the making process. Other changes to the process included the addition of activities with specific learning goals and the integration of other topics. These activities, for instance, aimed to increase students’ vocabulary: *“We added some exercises for the children to work on their language skills as part of the project. The children also wrote out their pitch for their presentation, for example.”*

Discussion

Self-Efficacy & Regulation of Learning in DBL and ME

Bandura [1]’s self-efficacy theory is a subset of his social cognitive theory. Consequently, how a student perceives their ability to produce creative results is affected by how they understand the concept of creativity. Students’ creative self-

efficacy may be negatively affected by DBL and ME when they link the outcome of the process (e.g., completion or quality of a prototype) to the steps made within the process. Thus, we argue that it is crucial to create a shared understanding of design and making competences within classrooms. For example, the learning activity Superpower Hour [15] helps students pinpoint behaviors that constitute different maker competencies in real-life innovators. Further investigations could look into whether such activities may help student to set appropriate creativity mastery goals, that may increase their self-efficacy when achieved [2], or whether they help students to more adequately reflect on their experiences regarding creativity during DBL and ME.

Interestingly, we observed a decline in collaboration self-efficacy following the implementation of the DF program. Despite the novelty of the experience, research also indicates that students have difficulty collaborating during DBL [6]. In order to increase students' agency and autonomy, they should learn how to regulate their learning in groups. We may be able to support students' collaboration through appropriate scaffolds. Computer-supported collaborative learning scholars have studied the process of regulation in collaborative learning [11]. However, many of the regulation of learning tools developed in this field are computer-based and may not be easily implemented in the chaotic learning contexts of DBL and ME. Moreover, these tools tend to focus on cognitive aspects of regulation and do not take into account emotion regulation, which is particularly important for young students.

Evaluation is an important part of regulating the learning process [11]. Through processes such as self-reflection, students can learn from their experiences and guide their behavior in the future. While we have not examined the effects of the self-reflection in the students' booklet, students expressed dissatisfaction with the amount of writing required. For future work, it would be important to investigate how to support self-reflection and evaluation in a playful and engaging manner for young students.

Implementing DBL and ME in Early Education

The DF program intended to create materials that allowed teachers to implement DBL and ME in their elementary school classroom. We believe that in order to make a real impact, we must teach teachers how to design their own DBL and ME projects. Previously, we explored how this might be accomplished by translating our approach to project development into a workshop [23]. However, this did not seem to translate well to the way in which teachers approach the development of projects. It would be more appropriate to co-design these project authoring tools and teacher training materials with teachers with DBL and ME experience.

Further, we would like to see DBL and ME play a larger role in the formal school curriculum rather than being implemented as extracurricular activities or special projects. We have observed that teachers incorporated learning goals for core subjects, such as language, into the project. By integrating these core curriculum learning objectives into DBL and ME, we believe that these learning approaches may be more widely adopted.

Limitations

This article shows a mix of experiences with the DF approach. More insights could be gained from a cross-country analysis of this dataset. Additionally, we present generic self-perceptions of learning, which are often problematic, particularly for young children. We acknowledge that we adopted a particular approach to combining design and making. There are many alternative approaches, each with pros and cons. In this case, we chose electronics as a low-cost maker element that required little additional training for teachers. As digital fabrication has become more prevalent in secondary education, it may be worthwhile to explore the possibility of collaborating between fablabs and elementary

schools. Due to COVID-19 restrictions and the additional pressures it was putting on teachers at this time, we have developed the DF lesson plan using a user-centered design approach. However, we encourage the creation of DBL and ME modules for elementary schools that are more co-creative or participatory in nature.

Conclusion

We examined the impact of a lesson program that combined DBL and ME on students' self-efficacy in collaboration and creativity. This paper reports the results of the implementation of the program in 35 elementary school classrooms across three countries. The results of the study include quantitative measures of self-efficacy before and after the intervention and qualitative insights derived from interviews, focus groups, and artifacts. There was a significant improvement in creativity self-efficacy after implementation, but a decline in collaboration self-efficacy. Results from the qualitative analysis reveal difficulties students encountered regarding collaboration during the design process (such as difficulty compromising) as well as the making process (such as poor communication). We discuss ways we might design activities for students to promote their self-efficacy and social regulation of learning. Our hope is that this paper will contribute to the future implementation of DBL and ME in formal elementary education.

Acknowledgments

This work is part of the DESIGN FUTURES project and has been partially funded by the Erasmus programme of the European Union under the Project ID: 2019-1-NL01-KA201-060353.

References

1. Albert Bandura. 1986. *Social foundations of thought and action: a social cognitive theory* / Albert Bandura. Prentice-Hall.
2. Ronald A Beghetto. 2006. Creative self-efficacy: Correlates in middle and secondary students. *Creativity research journal* 18, 4 (2006), 447–457.
3. Tilde Bekker, Saskia Bakker, Iris Douma, Janneke Van Der Poel, and Koen Scheltenaar. 2015. Teaching children digital literacy through design-based learning with digital toolkits in schools. *International Journal of Child-Computer Interaction* 5 (2015), 29–38.
4. Paulo Blikstein. 2013. Digital fabrication and 'making' in education: The democratization of invention. *FabLabs: Of machines, makers and inventors*. 4, 1 (2013), 1–21.
5. Virginia Braun and Victoria Clarke. 2006. Using thematic analysis in psychology. *Qualitative research in psychology* 3, 2 (2006), 77–101.
6. Maureen Carroll, Shelley Goldman, Leticia Britos, Jaime Koh, Adam Royalty, and Michael Hornstein. 2010. Destination, imagination and the fires within: Design thinking in a middle school classroom. *International Journal of Art & Design Education* 29, 1 (2010), 37–53.
7. Kasper Skov Christensen, Mikkel Hjorth, Ole Sejer Iversen, and Paulo Blikstein. 2016. Towards a formal assessment of design literacy: Analyzing K-12 students' stance towards inquiry. *Design Studies* 46 (2016), 125–151.
8. Nigel Cross. 2023. Design thinking: What just happened? *Design Studies* 86 (2023).
9. Yaron Doppelt. 2009. Assessing creative thinking in design-based learning. *International Journal of Technology and Design Education* 19 (2009), 55–65.

10. Yaron Doppelt, Matthew M Mehalik, Christian D Schunn, Eli Silk, and Denis Krysiniski. 2008. Engagement and achievements: A case study of design-based learning in a science context. *Journal of technology education* 19, 2 (2008), 22–39.
11. Allyson Hadwin, Sanna Järvelä, and Mariel Miller. 2018. Self-regulation, co-regulation, and shared regulation in collaborative learning environments. (2018).
12. Idit Harel and Seymour Papert. 1991. Ablex Publishing.
13. Ole Sejer Iversen, Rachel Charlotte Smith, Paulo Blikstein, Eva-Sophie Katterfeldt, and Janet C Read. 2016. Digital fabrication in education: Expanding the research towards design and reflective practices. *International Journal of Child-Computer Interaction* 5, 1–2 (2016), 1–2.
14. SooJin Jun, SeonKwan Han, and SooHwan Kim. 2017. Effect of design-based learning on improving computational thinking. *Behaviour & Information Technology* 36, 1 (2017), 43–53.
15. YJ Kim, Yumiko Murai, and Stephanie Chang. 2020. Embedded assessment tools for maker classrooms: A design-based research approach. (2020).
16. Leeann M Lower, Tarkington J Newman, and Dawn Anderson-Butcher. 2017. Validity and reliability of the teamwork scale for youth. *Research on Social Work Practice* 27, 6 (2017), 716–725.
17. Judit Martínez Moreno, Patricia Santos, and Davinia Hernandez-Leo. 2021. Maker Education in Primary Education: Changes in Students' Maker- Mindset and Gender Differences. In *Ninth International Conference on Technological Ecosystems for Enhancing Multiculturality (TEEM'21)*. 120–125.
18. Matthew M Mehalik, Yaron Doppelt, and Christian D Schunn. 2008. Middle-school science through design-based learning versus scripted inquiry: Better overall science concept learning and equity gap reduction. *Journal of engineering education* 97, 1 (2008), 71–85.
19. Dan Nessler. 2018. How to apply a design thinking, HCD, UX or any creative process from scratch. <https://medium.com/digital-experience-design/how-to-apply-a-design-thinking-hcd-ux-or-any-creative-process-from-scratch-b8786efbf812>
20. Andrea Scheer, Christine Noweski, and Christoph Meinel. 2012. Transforming constructivist learning into action: Design thinking in education. *Design and Technology Education: An International Journal* 17, 3 (2012).
21. Dale Schunk and Maria DiBenedetto. 2016. Self-Efficacy Theory in Education. In *Handbook of Motivation at School*. Routledge, 46–66.
22. Annemiek Veldhuis, Bernice d'Anjou, Tilde Bekker, Ioanna Garefi, Panagiota Digkoglou, Georgia Safouri, Silvia Remotti, Emer Beamer Cronin, and Madalina Bouros. 2021. The connected qualities of design thinking and maker education practices in early education: A narrative review. In *fablearn europe/MAKEED 2021-an international conference on computing, design and making in education*. 1–10.
23. Annemiek Veldhuis, Di Xiao, Tilde Bekker, and Panos Markopoulos. 2022. Model-Based Support for Authoring Design-Based Learning and Maker Education Materials in Elementary Education. In *6th FabLearn Europe / MakeEd Conference 2022 (Copenhagen, Denmark) (FabLearn Europe / MakeEd 2022)*. Association for Computing Machinery, New York, NY, USA, Article 3. <https://doi.org/10.1145/3535227.3535230>
24. Stéphan Vincent-Lancrin, Carlos González-Sancho, Mathias Bouckaert, Federico de Luca, Meritxell Fernández-Barrerra, Gwénaél Jacotin, Joaquin Urgel, and Quentin Vidal. 2019. *Fostering Students' Creativity and Critical Thinking*.

Unleashing the power of turtle graphics for graph algorithm visualization

Rafael Fernandes, ETH Zurich, rfernandes@student.ethz.ch

Jacqueline Staub, University of Trier, staub@uni-trier.de

Abstract

For over 50 years, educators have relied on the Turtle as a tool to teach programming to novices. Although its didactic power is undisputed, the Turtle has rarely been applied to areas beyond spatial navigation and 2D/3D geometry. One area that we believe could be addressed, but has not yet been, is graph theory – a topic that is commonly taught in high school CS curricula, has a visual component, and bridges directly to algorithmic thinking. We aim to fill this gap by introducing Graphli, a Python library that features a beginner-friendly syntax for graph creation and manipulation, as well as built-in layout visualization that covers most standard graph architectures (i.e., directed and undirected graphs, with or without edge weights). At present, various graph categories can be visualized (including trees and networks), but planar graphs are not guaranteed to be visualized as such. Graphli provides novices with a new training experience in graph algorithms and presents a working prototype that has been integrated into the XLogoOnline programming environment.

Introduction

Over half a century has passed since the first group of children started immersing themselves in the world of programming by controlling a physical or virtual “turtle” and commanding it to draw geometric shapes [1]. To date, Papert’s Turtle is undeniably one of the most successful didactic tools for teaching programming, and both the underpinning Logo philosophy [2] and its signature mascot, the Turtle, persist and thrive, with hundreds of thousands of students learning to program with the help of Turtle Graphics every year [3] thanks to various learning environments [4, 5, 6, 7] that carry on Papert’s work.

Over the years, the Turtle found its way into countless applications, but one fundamental element always remained unchanged: the immutable connection to geometry. From Logo, the Turtle was included in both imperative (Java [8] and Python [9]) and declarative languages (Haskell [10], Lisp [11]), has been implemented as both physical and virtual agent, integrated in both single- and multi-agent models [32], was used in 2D and 3D worlds [12, 13], was embedded in block- and text-based learning environments [14] and came in useful from elementary school programming courses all the way to university [15]. However, amidst all these adaptations, the core character of Turtle Geometry has remained unchanged.

The purpose of programming classes is not just to teach programming for its own sake; rather, we consider programming as a tool for problem-solving that can be applied to a wide variety of problems throughout all fields of science [16]. That is, once students master the basic concepts of programming, they can draw upon these skills when solving problems in other domains, for instance in graph theory.

Graph theory offers a wealth of exciting questions and concepts for students to explore [17, 28]. In its application in

computer science, it provides a framework for analyzing relationships between objects, modeling real-life systems, and exploring mathematical structures therein. Thanks to initiatives like CS Unplugged, students can engage in these concepts from an early age [18], thereby experiencing graph algorithms such as shortest path or connected components in a playful and interactive way and thus building up intuition. As students progress, these early informal encounters with graph theory can be built upon with a more formal introduction of the underlying concepts, for instance, via programming.

Although professional tools exist for creating and processing graphs programmatically, applying them unchanged to a school context is arguably not ideal. Notable tools used in professional contexts include, for instance, the C libraries Boost [20], LEMON [21], LEDA [22], and SNAP [23], the Java libraries JUNG [24] and Prefuse [25], and the Python libraries NetworkX [26], NetworKit [27], and iGraph [29]. However, these libraries are optimized for the efficient processing of large networks, often include complex syntax, and provide functionalities that exceed novices' requirements. We argue that, in order to teach graph algorithms to school students, another solution is required.

We present a tool to bridge the gap between graph theory and educational programming. The proposed library Graphli is written in Python, integrated into the XLogoOnline programming environment, and provides a steppingstone for novices who have informally explored graph theory via unplugged activities and who are already familiar with basic programming concepts (e.g., sequence, loops, procedures, parameters, variables, and lists). The library allows for a more formal, programmatic, and deliberate confrontation with graph problems and their corresponding algorithms.

In Section 2, we give a brief overview of the terminology and relevant concepts of graph theory before presenting the details of our implementation in Section 3. Focus is placed on the issues of graph representation (3.1), algorithmic processing (3.2), and visualization (3.3). Section 4 presents the results of a user study, and Section 5 concludes the paper, discusses limitations, and highlights future work opportunities.

The Graph, a Versatile Data Structure

Graphs are mathematical entities that provide a powerful framework for representing and analyzing relationship models consisting of mutually connected vertices. A graph, denoted $G = (V, E)$, consists of a set of *vertices* V while the set of *edges* E describes pairs of vertices and their relations. An edge $e = (,)$ represents whether the vertices and are related. Note that there are different properties for edges: they can be either *undirected*, indicating symmetric relations (e.g., a sibling relation from to and from to), or *directed*, indicating asymmetric relations (e.g., a parenthood relation leading only from to but not from to). Furthermore, edges may carry *weights* that indicate additional attributes to each edge (e.g., distances, prices, capacities), or they may be *unweighted* without additional attributes.

Examples for all four classes of graphs can be found in real-world scenarios:

- *Irrigation system*: Water flow in irrigation systems consisting of pipes of different capacities can be modeled as **directed weighted** graphs.
- *Food Web*: The complex ecosystems of predator-prey relations among animals can be modeled as **directed unweighted** graphs.
- *Transport networks*: Main roads between cities alongside their corresponding distances can be modeled as **undirected weighted** graphs.
- *Social networks*: Under the assumption that friendship is a symmetric relation, social networks of friends can be modeled as **undirected unweighted** graphs.

Each class has an infinite number of members, from densely connected graphs such as and (i.e., the complete graph with n vertices and the bi-partite graph of size n and m respectively) to more sparsely connected graphs (e.g., lines,

circles, wheels, trees, and empty graphs). Among the sparsely connected graphs, we also find planar graphs that can be integrated into the plane without any edges crossing. Next, we illustrate how such a versatile data structure can be stored, manipulated, and visualized programmatically.

A Python Library for Graph Algorithms in Education

In this chapter, we present the Python library Graphli and address the question of how the mathematical concepts presented so far can be implemented with and by novices. Our library specifies a data structure for graphs that allows graphs to be processed using a beginner-friendly syntax with a small number of new commands.

Representing Graphs

Graphs are versatile mathematical objects; vertices may be strongly connected or weakly connected, edges may be directed or undirected, and all edges may be weighted or unweighted. Defining such a generalized data structure that reflects all possible cases, however, likely exceeds the capabilities of novices and implementing such a data structure from scratch requires too much time and effort to be practical in class. In consequence, teachers may be tempted not to teach graph theory via programming despite the potential to foster a deeper conceptual understanding of graphs and their corresponding problems. To address this issue and to get students to explore graph algorithms programmatically, Graphli offers a custom data structure and the corresponding methods for representing and manipulating graphs. Our goal is, in correspondence with the Logo philosophy, to get students started quickly and enable them to construct and manipulate graph structures on their own.

Graphs are represented as adjacency lists or adjacency matrices – both are useful data structures that offer advantages and disadvantages depending on the example. For instance, an adjacency list can be useful to represent small graphs with few edges, as it contains all relevant information without wasting much memory. In contrast, for graphs with many edges or where vertices are deleted frequently, the adjacency matrix structure may be more helpful, since deletions can be performed by removing entire rows or columns. To map edge weights, a dictionary can be used to assign a value to each edge: $\{(,), w\}$

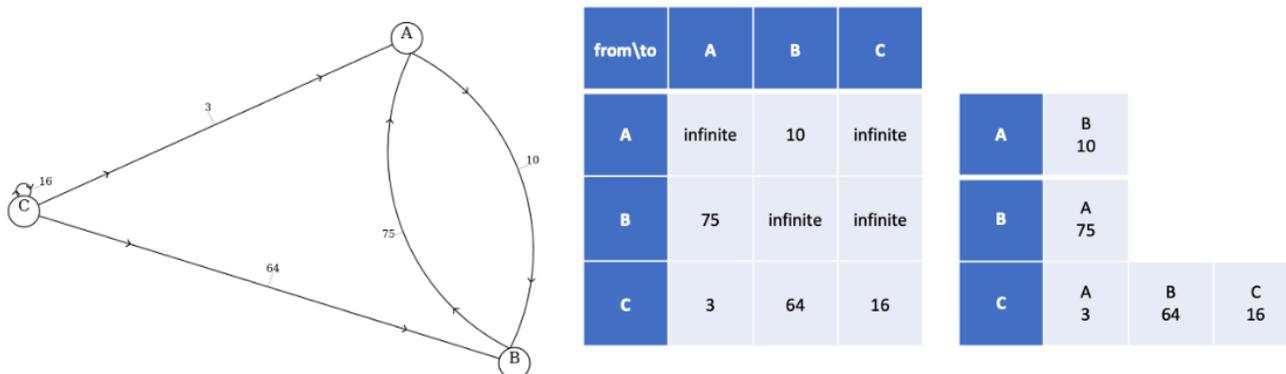


Figure 1: An example of a directed weighted graph (left) and its corresponding representation as an adjacency matrix (middle) and as an adjacency list (right)

Figure 1 shows an example of the internal structure of a graph: three vertices A, B, and C are connected by five directed and weighted edges. Vertex A has an outgoing edge of weight 10 to B, B has an outgoing edge of weight 75 to A, and C has three outgoing edges of weights 3 (to A), 64 (to B), and 16 (back to C). On the right are the two representations as adjacency matrix and adjacency list. Note how nonexistent edges are reflected by the value infinity in the case of an adjacency matrix, whereas the adjacency list only includes edges that are present in the graph.

```
1 from graphli import *
2
3 makeGraph(directed = True, weighted = True)
4
5 addVertex("A")
6 addVertex("B")
7 addVertex("C")
8 addEdge("A", "B", 10)
9 addEdge("B", "A", 75)
10 addEdge("C", "A", 3)
11 addEdge("C", "C", 16)
12 addEdge("C", "B", 64)
```

Figure 2: Graphli syntax to create a graph

Graphli offers a simple interface that allows students to create empty graphs via the `makeGraph()` command, to add vertices and edges via the `addVertex(name)` and `addEdge(name, name, weight)` methods, to delete vertices and edges using `removeVertex(name)` and `removeEdge(name, name, weight)`. Both `addEdge` and `removeEdge` offer the weight as an optional third argument and thus can be used with both weighted and unweighted graphs. Figure 2 shows a simple program to create the graph presented in Figure 1.

Processing Graphs

Graph theory offers a variety of exciting problems for students to work on. Making graph algorithms accessible, however, requires a syntax for interacting with a graph's constituents. A list of all vertices and edges can be returned with the `getVertices()` and `getEdges()` commands, but for easier use, we added `neighbors(name)` that can be called to get access to vertices with a common edge to a given vertex. A call of `neighbors(v)` will return all vertices that have an incoming edge from `v`. Graphli provides two commands for highlighting, i.e., `markEdge(from, to)` and `markVertex(name)`; two commands allow vertices and edges to be updated and renamed: `editLabel(name, text)` and `editEdge(name, name, text)`. This syntax allows classical algorithms (e.g., Dijkstra, BFS, DFS, and many more) to be implemented and visualized (see A.1).

Visualizing Graphs

Graphs allow us to analyze complex relationships like family trees or transport networks. However, whether a graph representation is functional depends on visualization, i.e., how well the vertices are spatially distributed, how many edge intersections there are in the graph diagram, and whether symmetries in the data are reflected visually. The fact that visualization can be a challenge should be evident, at the very least, when looking at structures on the scale of Facebook's social graph. But even in the context of smaller graphs, this can be challenging. We present three layouts that are used in the Graphli library to visualize graphs: (i) spring layout, (ii) circular layout, and (iii) random layout.

Spring Layout

The first layout class is subsumed under the term *spring embedder algorithms* – a category of visualization algorithms that all rely on the idea of using attractive and repulsive forces to iteratively calculate and improve the positioning of individual vertices. The overall goal is for each vertex to be positioned as far away as possible from vertices that do not share a common edge. Edges, meanwhile, serve as “springs”, that provide an opposing attractive force. Graphli's spring layout implementation (see Appendix A.2) is based on Eades' [31] spring-embedder model with a modification proposed by Fruchterman and Reingold [30].

The algorithm works over several iterations and continuously applies forces to determine the layout for the next iteration step. Starting from a random layout of width W and height H , the vertex positions from one iteration to the next are determined using a *temperature* and a *cooling* function. We set off with a start temperature and update the vertex temperature in each iteration with the cooling function. The result can be seen in Figure 4, which illustrates how the layout changes over 100 iterations. Note how the vertices spread apart as the edge crossings reduce. We determined 100 iterations to provide a good enough approximation to work within our use case. More iterations may provide further improvement, but with a performance of , fewer iterations are desirable.

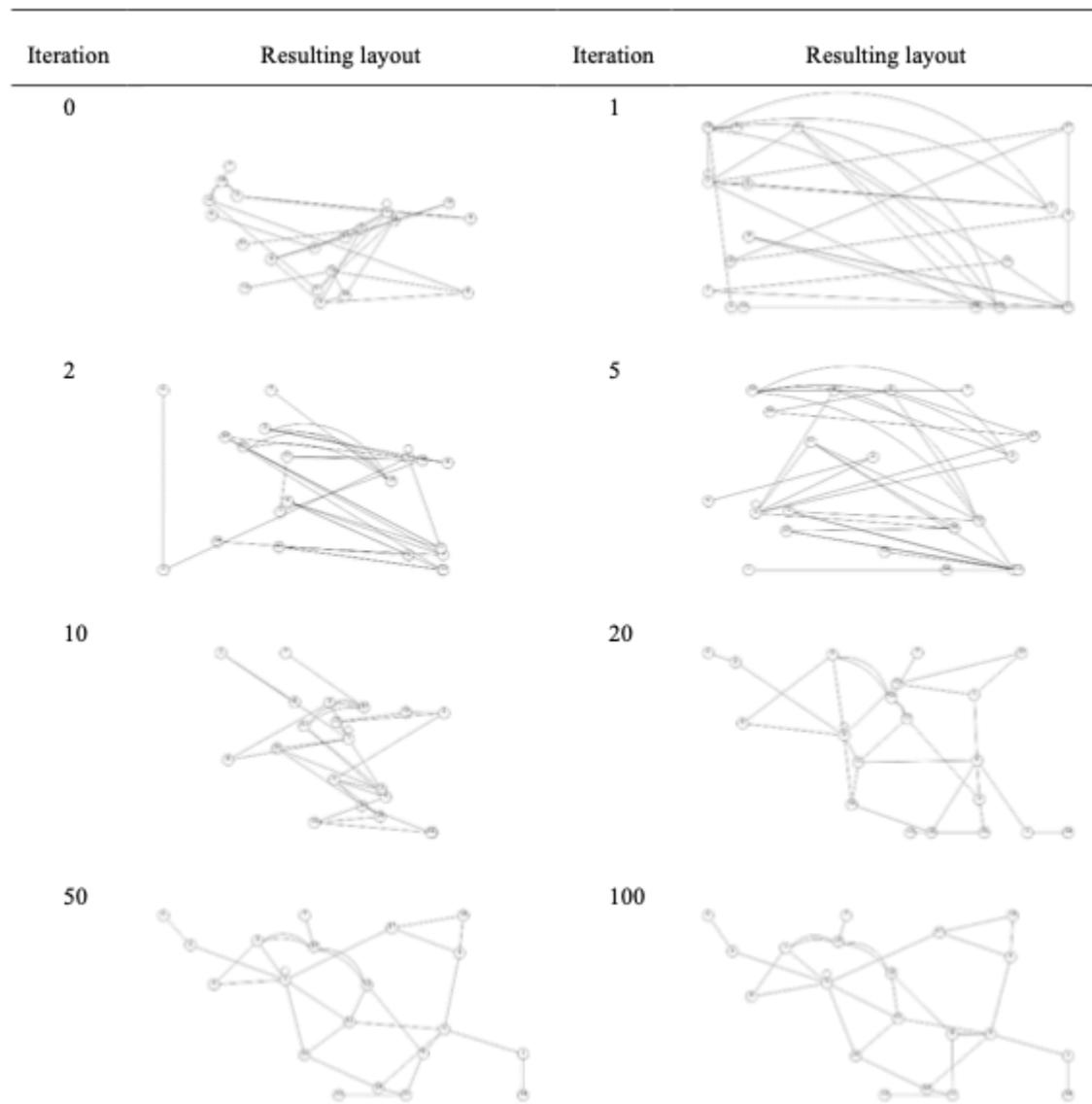


Figure 3: A graph with 20 vertices and 20 edges after some iterations, when executing Fruchterman and Reingold.

Circular Layout

As certain graph layouts are oriented towards circular structures (e.g., wheels, stars, complete graphs), it is possible to compute a result that is equally good or even better than a spring layout far more efficiently just by selecting a circular start configuration. The circular layout projects vertices evenly on a circle, assigning vertex positions clockwise in the order they were added to the graph. Having an execution time of $O(n^2)$, it offers the best runtime for graphs that are intended to have a circular structure and, through its consistency in assigning positions, the layout can be anticipated.

Random Layout

Even randomization allows practical layouts to be created, which may sometimes even produce better results than non-

randomized layouts after many rounds of improvement. As the name implies, the basic idea of Random Layout is that all vertices of a graph are assigned a random position on the screen. While this often leads to chaotic and obscure results, it may yield good results very efficiently, especially for small graphs with few edges. Figure 5 shows a side-by-side comparison of a random and a spring layout, with the random layout allowing for a planar representation. In contrast, the spring layout gets stuck in a local optimum that cannot be improved further. This example shows that the spring layout does not always minimize edge crossings. Placing vertex 9 randomly may be the better option in this case.



Figure 4: Part of a graph drawn with the spring layout where vertex 9 is trapped in a local optimum between vertex 4 and 28 (left), whereas a random layout is allowed to place vertices freely without a chance of getting trapped in local optima (right).

Evaluation

We conducted a qualitative think-aloud study with five participants, all enrolled in a Computer Science education programme in Switzerland, all male, between 22 and 44 years old and at different stages of their education (vocational training to university). Our goal was to understand how different users interact with Graphli. The participants were asked to solve three tasks (presented in A.3) and, while doing so, talk about what they intended to do. The task set is designed to evaluate (i) the syntax handling and (ii) the ease of problem-solving using our library. Task 1 works as a starter task and tests whether participants manage to use the library commands to create a given graph. Task 2 confronts participants with the challenge of drawing K_{10} . Doing so manually is a considerable amount of work, and we wanted to see whether participants combine library methods and Python loops intuitively. Task 3, finally, uses the library in an algorithmic context to solve a breadth-first search problem instance. In the following, we summarize our findings:

1. *A solid foundation in Python syntax is required:* Some participants experienced difficulties due confusing variables and strings. In particular, vertex names have to be provided as either strings or numbers, but several people tried to provide an undefined variable:

```
makeGraph(directed=False, weighted=False), addVertex(A), addVertex(B), addEdge(A,B)
```

```
makeGraph(directed=False, weighted=False), addVertex("A"), addVertex("B"), addEdge("A","B")
```

2. *Fewer and less complex commands are better:* While Graphli offers functionality via built-in commands, it still relies on the use of Python concepts such as loops and lists. However, while trying to solve task 2, three out of five participants skimmed the documentation in search of a built-in command to create fully-connected graphs, thus contradicting the constructionist philosophy of developing an individualized toolbox as part of the learning process.
3. *Problem-solving is fun:* Despite their initial struggle, all participants reported the exploration to be exciting and

enjoyable. Four out of five participants decided to extend the time working on the problem set on their own accord.

We conclude that Graphli is a workable prototype that relies on a basic understanding of Python syntax and semantics. Users with some experience in programming manage to solve graph-related tasks and enjoy the learning process.

Conclusions

Countless children nowadays learn to program using didactical tools and educational languages. At the same time, however, there are still many areas of computer science that, due to their structure or complexity and lack of suitable tools, are likely only made available to students in an unplugged manner. One such area, paradoxically known for its descriptiveness and visual nature, is the field of graph theory. This article presented a tool designed for students to explore ideas about graphs by programming. The Python library Graphli can help students build intuition in graph algorithms in an interactive way while providing a stepping stone for novices to transfer from informal exploration via unplugged teaching to more formal, precise, and deliberate confrontation with graphs and the corresponding algorithms. We hope this library will find use in educational contexts and inspire the creation of other didactic tools that provide programmable interfaces for concepts beyond classical programming.

Despite numerous possible applications, some limitations remain: (i) Graphli currently does not provide support for large planar graphs, (ii) this work does not make any claims on effectiveness but simply provides a tool for which more extensive empirical evaluations are still pending, (iii) in its current form, Graphli does not provide any teaching materials and a fully comprehensive lesson may only be possible with dedicated teaching personnel.

Acknowledgments

We gratefully acknowledge the generous support of the Carl-Zeiss-Foundation for funding our research.

References

1. Papert, S. (1972). Teaching children to be mathematicians versus teaching about mathematics. *International journal of mathematical education in science and technology*, 3(3), 249-262.
2. Hromkovič, J., Komm, D., Lacher, R., & Staub, J. (2019). Teaching with LOGO philosophy. *Encyclopedia of Education and Information Technologies*.
3. Staub, J., & Chothia, Z. (2022, February). Large-Scale Analysis of Error Frequencies in Logo Programming. In *Proceedings of the 53rd ACM Technical Symposium on Computer Science Education V. 1* (pp. 571-577).
4. Hromkovič, J., Serafini, G., & Staub, J. (2017). XLogoOnline: a single-page, browser-based programming environment for schools aiming at reducing cognitive load on pupils. In *Informatics in Schools: Focus on Learning Programming: 10th International Conference on Informatics in Schools: Situation, Evolution, and Perspectives, ISSEP 2017, Helsinki, Finland, November, Proceedings 10* (219-231). Springer International Publishing.
5. Trachsler, N. (2018). *WebTigerJython-a browser-based programming IDE for education* (Master's thesis, ETH Zurich).
6. Hromkovic, J., Kohn, T., Komm, D., & Serafini, G. (2017). Algorithmic thinking from the start. *Bulletin of EATCS*, 1(121).
7. Breijs, C., Mahfouf, A. M., & Piacentini, M. (2014). Manual do KTurtle.
8. Mackin, K. J. (2019). Turtle graphics for early Java programming education. *Artificial Life and Robotics*, 24, 345-351.

9. Hunt, J., & Hunt, J. (2019). Python Turtle Graphics. *Advanced Guide to Python 3 Programming*, 13-21.
10. Ruiz, R. V. (2011). Teaching the Relevance of Mathematics in Information Technologies through Functional Programming in Secondary School. *International Journal for Technology in Mathematics Education*, 18(3).
11. Lieberman, H. (1981). Logo Turtle Graphics for the Lisp Machine.
12. Wolz, U., Auschauer, M., & Mayr-Stalder, A. (2019). Code crafting with turtlestitch. In *ACM SIGGRAPH 2019 Studio* (pp. 1-2).
13. Kanada, Y. (2015). 3D Turtle Graphics” by using a 3D Printer. *Journal of Engineering Research and Applications*, 5(4), 70-77.
14. Turbak, F., Sandu, S., Kotsopoulos, O., Erdman, E., Davis, E., & Chadha, K. (2012, September). Blocks languages for creating tangible artifacts. In *2012 IEEE Symposium on Visual Languages and Human-Centric Computing (VL/HCC)* (pp. 137-144). IEEE.
15. Farkas, K., Tasnádi, I., & Törtely, É. *Logo from the Kindergarten to the University Level*. na.
16. Harvey, B. (1997). *Computer science Logo style volume 3: beyond programming*. MIT press.
17. Gibson, J. P. (2012, July). Teaching graph algorithms to children of all ages. In *Proceedings of the 17th ACM annual conference on Innovation and technology in computer science education* (pp. 34-39).
18. Bell, T., Witten, I., & Fellows, M. (2015). CS Unplugged: An enrichment and extension programme for primary-aged students.
19. Bell, T., & Vahrenhold, J. (2018). CS unplugged—how is it used, and does it work?. *Adventures between lower bounds and higher altitudes: essays dedicated to Juraj Hromkovič on the occasion of his 60th birthday*, 497-521
20. Siek, J. G., Lee, L. Q., & Lumsdaine, A. (2001). *The Boost Graph Library: User Guide and Reference Manual*, The. Pearson Education.
21. Dezső, B., Jüttner, A., & Kovács, P. (2011). LEMON—an open source C graph template library. *Electronic notes in theoretical computer science*, 264(5), 23-45.
22. Mehlhorn, K., & Näher, S. (1999). *LEDA: A platform for combinatorial and geometric computing*. Cambridge university press.
23. Leskovec, J., & Sosič, R. (2016). Snap: A general-purpose network analysis and graph-mining library. *ACM Transactions on Intelligent Systems and Technology (TIST)*, 8(1), 1-20.
24. O'Madadhain, J., Fisher, D., Smyth, P., White, S., & Boey, Y. B. (2005). Analysis and visualization of network data using JUNG. *Journal of Statistical Software*, 10(2), 1-35.
25. Heer, J., Card, S.K. and Landay, J.A., 2005, April. Prefuse: a toolkit for interactive information visualization. In *Proceedings of the SIGCHI conference on Human factors in computing systems*(pp. 421-430).
26. Hagberg, A., Swart, P., & S Chult, D. (2008). *Exploring network structure, dynamics, and function using NetworkX* (No. LA-UR-08-05495; LA-UR-08-5495). Los Alamos National Lab.(LANL), Los Alamos, NM (United States).
27. Staudt, C. L., Sazonovs, A., & Meyerhenke, H. (2016). NetworKit: A tool suite for large-scale complex network analysis. *Network Science*, 4(4), 508-530.
28. Halim, S. (2015). Visualgo—visualising data structures and algorithms through animation. *Olympiads in informatics*, 9, 243-245.
29. Csardi, G., & Nepusz, T. (2006). The igraph software package for complex network research. *InterJournal, complex systems*, 1695(5), 1-9.
30. Eades. 1984. A heuristic for graph drawing, *Congressus Numerantium*, 42, 149-160
31. Fruchterman, T.M. and Reingold, E.M., 1991. Graph drawing by force-directed placement. *Software: Practice and experience*, 21(11), 1129-1164
32. Tisue, S., & Wilensky, U. (2004, May). Netlogo: A simple environment for modeling complexity. In *International conference on complex systems* (Vol. 21, pp. 16-21).

Appendix

A.1 Finding the Shortest Path using Dijkstra's Algorithm

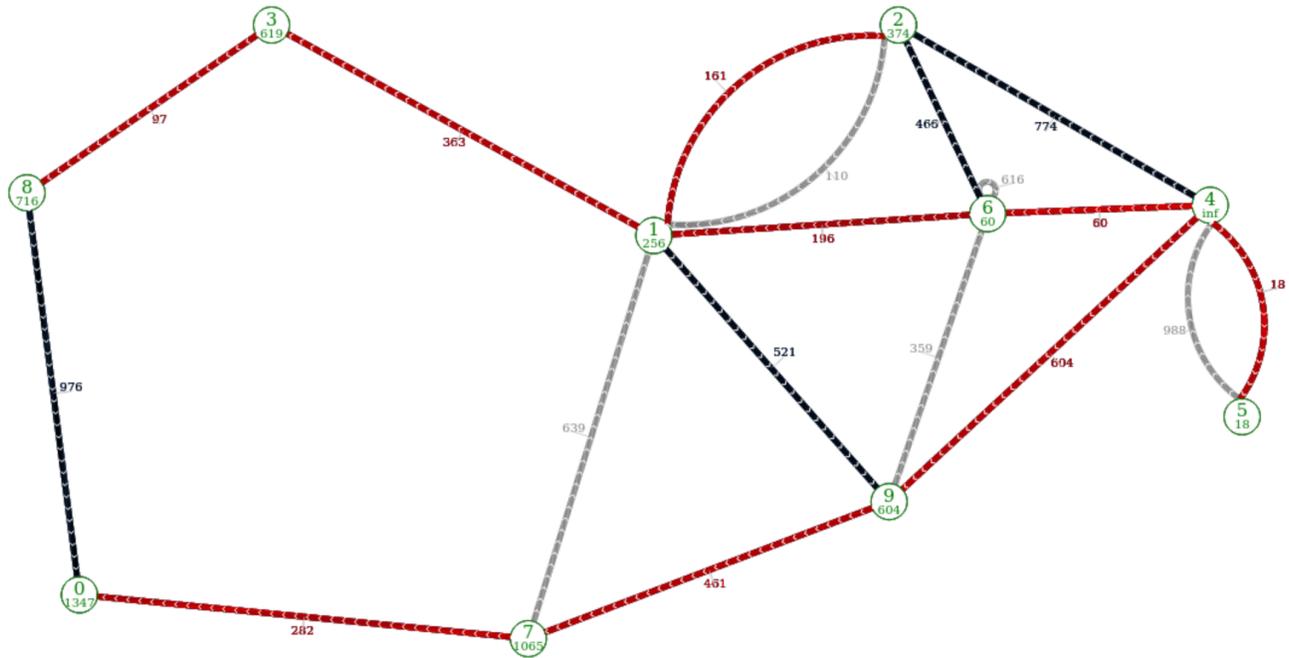


Figure 5: Implementation (left) and resulting graph drawing (right) of Dijkstra's algorithm.

```

1 from graphlib import *
2 from random import *
3 from time import *
4 makeGraph(directed = True, weighted = True, adjMatrix = True, edge
= "wide", color = "gray")
5 for i in range(10):
6     addVertex(i)
7 repeat(20):
8     addEdge(randint(0, 9), randint(0,9), randint(0, 999))
9
10 def dijkstra(source):
11     visit(source)
12     dist = {}
13     prev = {}
14     vertices = getVertices()
15     edges = getEdges()
16     queue = []
17     for v in vertices:
18         dist[v] = float("inf")
19         prev[v] = None
20         queue.append(v)
21     editLabel(v, dist[v])
22     dist[source] = 0
23     while len(queue) is not 0:
24         u = queue[0]
25         for q in queue:
26             if dist[q] < dist[u]:
27                 u = q
28         queue.remove(u)
29         if prev[u] is not None:
30             markEdge(prev[u], u, "red")
31         markVertex(u, "green")
32         for v in set(neighbors(u)).intersection(queue):
33             markEdge(u, v, "blue")
34             alt = dist[u] + edges[u][v]
35             if alt < dist[v]:
36                 dist[v] = alt
37                 prev[v] = u
38                 editLabel(v, dist[v])
39                 sleep(0.7)
40                 markEdge(u, v, "black")
41     return dist, prev
42 dijkstra(4)

```

A.2 The spring-embedder algorithm used in our implementation

ALGORITHM 1: Fruchterman and Reingold [31]

```

area := W * L //W and L are the width and lengt of the frame
G := (V, E) //the vertices are assigned random initial positions
k :=  $\sqrt{\frac{area}{|V|}}$ 
fa(x) :=  $\frac{x^2}{k}$ 
fr(x) :=  $\frac{k^2}{x}$ 

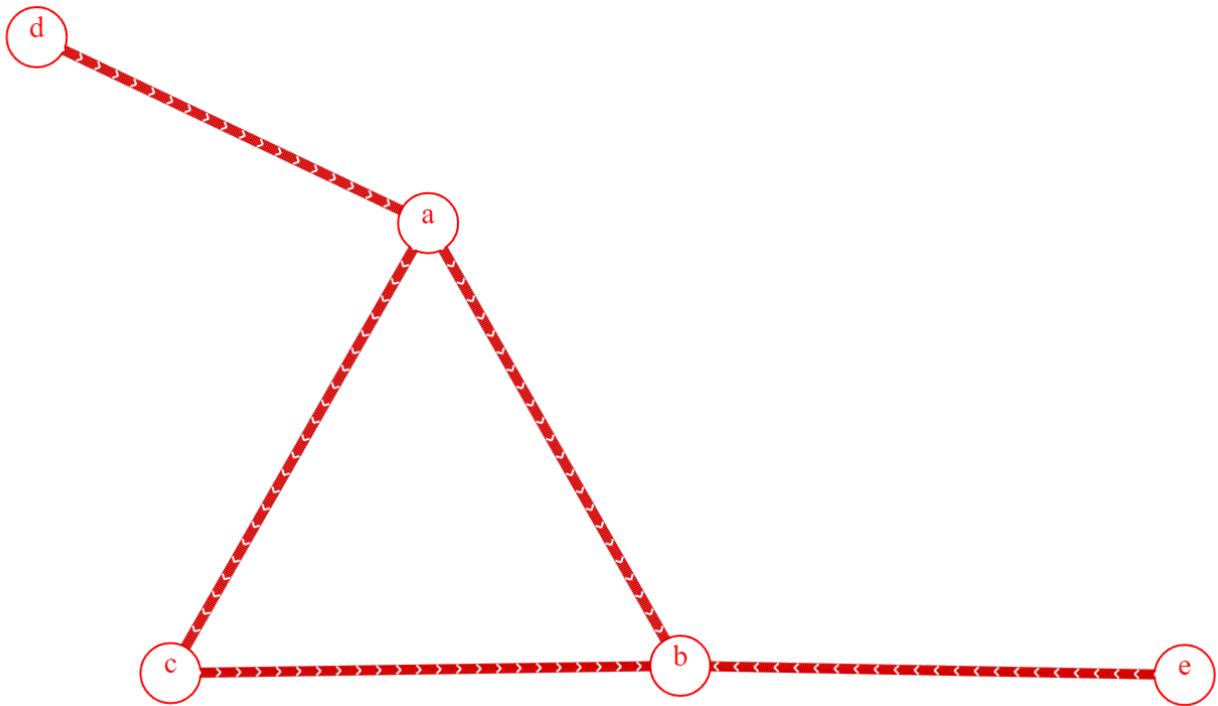
for i := 1 to iterations, do //calculate repulsive forces
  for v in V, do //each vertex has two vectors: .pos and .disp
    v.disp := 0
    for u in V, do
      if u ≠ v, do
        Δ := v.pos - u.pos //Δ is short hand for the difference vector
                               between the positions of the two vertices
        v.disp := v.disp -  $(\frac{\Delta}{|\Delta|}) * f_r(|\Delta|)$ 
      end
    end
  end
  for e in E, do //calculate attractive forces
    Δ := e.v.pos - e.u.pos //each edge is an ordered pair of vertices .v and .u
    e.v.disp := e.v.disp -  $(\frac{\Delta}{|\Delta|}) * f_a(|\Delta|)$ 
    e.u.disp := e.u.disp +  $(\frac{\Delta}{|\Delta|}) * f_a(|\Delta|)$ 
  end
  for v in V, do //limit the maximum displacement to the temperature t
    //and the prevent from being displaced outside frame
    v.pos := v.pos +  $\frac{v.disp}{|v.disp|} * \min(v.disp, t)$ 
    v.pos.x :=  $\min(\frac{w}{2}, \max(-\frac{w}{2}, v.pos.x))$ 
    v.pos.y :=  $\min(\frac{l}{2}, \max(-\frac{l}{2}, v.pos.y))$ 
  end
  t := cool(t) //reduce temperature as the layout approaches a better configuration
end

```

A.3 The tasks given to the participants of the study

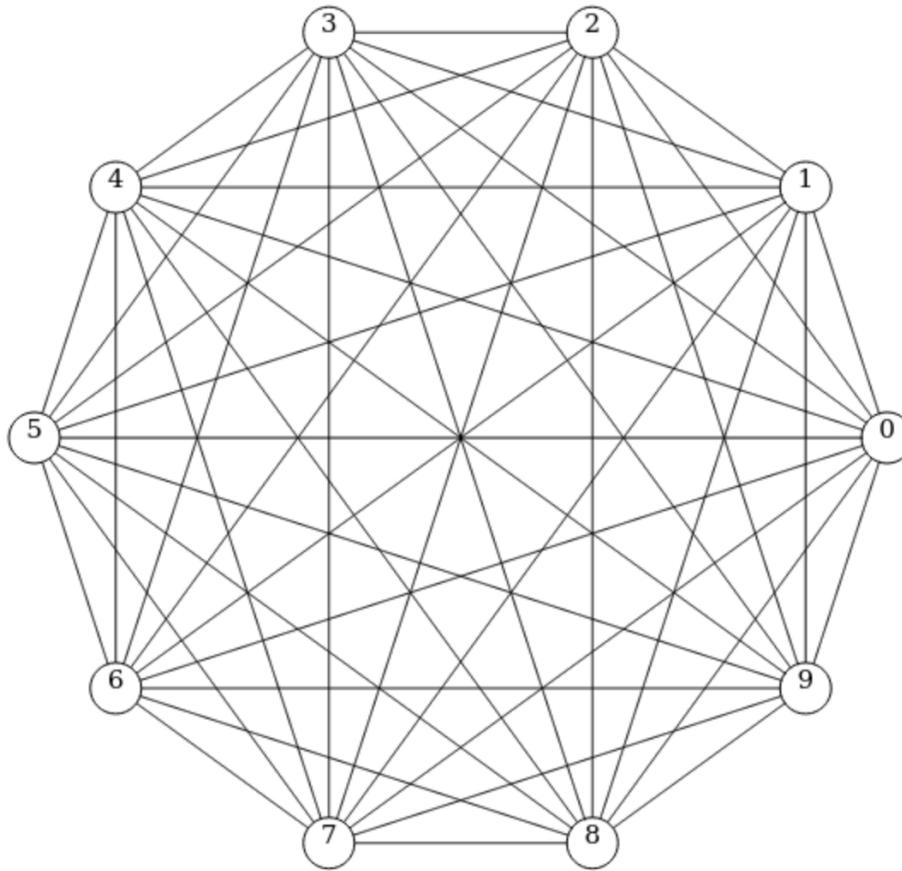
Task 1:

Write a program, that draws this graph to the canvas.



Task2:

Write a program, that draws this fully-connected graph to the canvas:



Task3:

1. Create a random directed and unweighted graph with 20 vertices and 30 edges.
2. Implement breadth-first search and label each vertex with its parent.

Hint: This is the pseudocode of breadth-first search:

```
1 procedure BFS(G, root) is
2   let Q be a queue
3   label root as explored
4   Q.enqueue(root)
5   while Q is not empty do
6     v := Q.dequeue()
7     if v is the goal then
8       return v
9     for all edges from v to w in G.adjacentEdges(v) do
10      if w is not labeled as explored then
11        label w as explored
12        w.parent := v
13        Q.enqueue(w)
```

Creative Movements in Maker-Material Collaborations

Maker-Material Entanglements in Collaborative Making

Alekh V, Indian Institute of Technology Bombay, alekhv@iitb.ac.in

Chandan Dasgupta, Indian Institute of Technology Bombay, cdasgupta@iitb.ac.in

Abstract

Making is a materially grounded ongoing flow of actions, in which abstract ideas are materialized to arrive at meaningful artifacts. The article aims to contribute to the understanding of sociomaterial relations in making, which can inform the design of socio-technical learning spaces that foster the emergence of creative outcomes. We root our investigation on the theoretical projection of making practice as assemblages and materials as active and relational. In this study, we examine the encounters between makers and materials in design problem solving scenarios to follow idea realizations and embodied material experiences leading to emergent creativity. We specifically look at a making context where novice makers collaboratively work on design problem solving, through the combined theoretical aspects of constructionism and posthumanism. Our findings suggest that the making actions were intertwined with maker and material elements of the situated making contexts, co-constitutively transforming each other. Making opportunities emerged as the makers and the broad range of materials came together informing, inciting and directing creative movements in a reciprocative fashion.

Introduction

Driven by the pedagogical approach of learning by doing, making offers learners to tinker, fail, build, engage in innovative designs via embodied material practices and experiences with the world [18, 31]. The talking point of material and related effects connected to agency has been gaining interest and subjected to scrutiny in making, learning and interaction design over the years [9, 21, 26]. Mostly, agency has been discussed along with notions of intelligence, intentionality, and purposefulness of actions [15]. Interestingly, agency is also conceptualized in a way where all material entities are possible actants and actively play roles in everyday activities [6]. The approach places materials as active participants in the design process but remains under-theorized in scenarios of human-material encounters. The material dimension of design is getting acknowledged and a wide variety of methods from material cultures, material studies, and crafts are adopted to explore learning and interaction design [13]. Consequently, the “material turn” is currently getting advocated in the field of learning and making to re-orient the focus towards material practices and material sources from which meaningful artifacts are created [5, 24]. This shift in which materiality is considered as an analytical lens to advance the understanding of maker-material relationality points back to the significance of closely attending to the materials entangled in the design process and recognizing how materials “talk back” to the makers [1], where material entities are context dependent with their performativity and expressions tied with circumstances of actions over time. These “talking back” can be operationalized to understand the relation emerging between makers and materials in materially grounded making processes, in addition to being cognizant of material behaviors. Such material-centered design research approaches can be considered as complementary to the ongoing user-centered design research approaches.

By bringing in the material aspects of interaction with the world, a change is marked from the major research area associated with material applicability towards material exploration, as the focus is on understanding material characters rather than on purposes.

The understanding of the world evolves through material grounded experiences which makes the everyday activities situated in and around the material spheres [25]. The expanded perspective with wider unit of analysis to look at the world and the respective dynamic phenomena places the researcher to investigate the 'wholes' to be emergent from interaction among 'parts'. Following these ideas, creative actions in connected processes are claimed to be spread across social, material, and temporal aspects [4, 14, 16]. Accordingly, collaborative making at sociotechnical spaces like makerspaces sites involves the coming together of makers, sharing resources in the situated environment, influencing each other's ideas and design processes. The creative outcomes thus emerging out of these networks in makerspaces cannot be reduced to individualistic traits and accounts, but intertwined across various human and nonhuman entities of the collaborative space. Creativity is thus theorized with the concept of collaborative emergence [14] as the derivative of the flow of interdependent contextual interventions, and the mechanism of generation within the distributed process. Collaborative emergence points to the emergence of a creative outcome resulting from intertwined networks of collaborating participants with fewer constraints [14]. Collaborative emergence is characterized in group activities as having unpredictable outcomes, with moment-to-moment contingency and the effect of any action can be altered by the subsequent actions of the participants.

With the foundational view of design as a reflective conversation with the situation [1], we focus to understand the interplay of social and material aspects in collaborative making as makers engage with materials in materializing ideas and materials "talk back" to makers. Makers perceive different affordances and properties of materials as per prior experiences and pursued goals. With repeated experience and familiarity, makers' understanding of material resources changes. During these conversations, makers and materials may exhibit various forms of agency. Here, agency is not an attribute of either human or nonhuman elements but emergent manifestations through various configurations of situated entities [20]. Agency unfolds in practice [12] and shifts depending on the assemblages of these entities. In understanding the role of materials in interaction design, humans and nonhuman entities are conceived as performative agents, driving the activities in design processes via interplays [7]. These reframed views on agency may expand our understanding of how creativity emerges out of maker and material conversations. The ideas of new materialism reaffirm that phenomenon and knowledge transcend through material exchanges and call to take notice of the human-nonhuman matter intersections [17]. Lately, makerspace research has been adopting new materialist and posthuman frameworks to open alternative possibilities to look at learning [27]. These frameworks blur the boundaries between human and non-human matter to look at how these entities intra-act and mutually shape the network of actions [23]. The questions related to vitality of materials in participation and learning possibilities gains prominence with the flattened ontology, decentering humans from the sole source of actions.

Examining the active relationship between makers and materials is significant as it helps us to understand the meanings emerging out of constant encounters between humans and material entities. Subsequently, acknowledging the role of materiality can also provide new insights on making, by following various maker-material configurations. Based on these prior literature, we look into the broader research goal of how maker and material encounters shape the emergent forms of creativity in makerspaces. With this study, we attempt to explore *how novice makers make together with non-human entities in creative movements, by focusing on the relational dynamics between makers and materials*. We think with constructionist and posthumanist ideas to analyze the making context where seventh-grade students collaboratively work on design problem solving. We consider design as an inherent practice within the making process [2, 3] and position the creative aspects of the making process as emergent [14, 16].

Making Context

Data for this study was collected as part of a maker workshop where two groups of seventh-grade students from an English-Medium school in the city of Mumbai, India engaged an engineering design problem. The workshop mode, which was divided into two sessions, (1) Training session and (2) Design session. The first team-Team A- consisted of two female participants (A1 and A2) and a male participant (A3). The second team-Team B-consisted of one female participant (B1) and one male participant (B2). Teams were formed randomly and they worked on designing a cleaning robot in the design session. The design challenge given to the students is stated as: *“Keeping our surroundings clean is a very important aspect of our life but, doing that requires a lot of manual work and can get boring sometimes. Wouldn't it be amazing if a robot does that for you autonomously? Your design challenge for today is to use the Lego Mindstorm kit to build a cleaning robot. Your robot should be able to clean at least two of the following trash materials- paper bits, Lego pieces, water droplets, eraser dust, and pencil dust. You can also use the provided supplementary material i.e., cleaning mop wipes, cardboard, and sponge. The robot designs of the two teams will be compared based on how many trash items the robot can clean, how well it cleans the trash material and the cost of the robot.”* Along with the Lego Mindstorm kit and the supplementary materials, each team was also provided with a cost-calculation sheet and a workbook for taking notes and making sketches. A facilitator mentor was allocated to each team to take observation notes and provide technical and logistic support. For our analysis, we followed the making activities of Team A. Audio and video recorders were used for capturing the making. The design artifacts consisting of sketches, written notes, and the final robot designed by the team were also collected.

Analysis

We fused constructionist perspectives with posthumanist standpoint to investigate the ways in which maker-material entities shape the learning and creative movements [28]. With constructionism pointing towards the ways in which learners realize ideas via design and embodied experiences to make meaningful expressions, and posthumanist consideration of material entities as active participants in phenomena, the dual theoretical approach augments our effort in following maker-material entanglements in learning and subsequent creative actions. This encounter involves the data sources as video, photographs, design artifacts, field notes and observations during making. We followed the dual theoretical perspectives and adopted the methodological process of thinking with theory [29, 30]. We viewed the assemblage of data sources simultaneously and iteratively. Here, we see ourselves entangled with the unfolding of research path rather than a separate entity. We adopted the case study methodology [10] to unpack the processes involved in the making settings of the Team A in the Maker activity-centered workshop.

Findings

We found that the making actions were intertwined with maker and material elements of the situated making contexts, co-constitutively transforming each other. Making opportunities emerged as the makers and the broad range of materials came together informing, inciting and directing creative movements in reciprocative fashion. We present representative episodes from the making context to show the kinds of intra-actions enmeshing human and material entities and to illustrate different instances of making together with that influenced the flow of creative actions.

The making session started with the makers discussing on the design challenge, the materials that should be considered for cleaning task, and robot structure. The initial idea was to build a four wheeled robot with a cleaning unit attachment.

They started to draw sketches on notes as seen in Figure 1, to further the idea of four wheeled robot and tried to translate the idea in 2D state to 3D form.



Figure 1: Makers following the sketches and entering into negotiations with lego components and tape.

With the reference point as they sketch, the team perceived that making was going to be easy. It was also seen that the cost value coming in between as A1 proposed the idea of robotic arm A2 arranged the motor units as depicted in the sketch and looked for tapes to connect the units. The makers tried to connect the motors for the drives. Once the motors were joined after repeatedly taping the wires as seen Figure 1, the team looked for ways to mount the lego EV3 brick. The following episode shown in Table 1, illustrates how the makers are making together with lego components, sketches, cost value, ideas, and concepts related to robotic motion and cleaning.

Table 1: Entanglements in initial making phase

Team member	Verbal and Non-verbal actions
A1:	[Points to sketch] see.. we just need to add the sponge or the mop at the ends.. feels like easy
A2:	Even the coding part is easy.. like move and wipe the trash .. or should it stop after finding trash
A1:	May be some [gestures robotic arm] to push the trash or like drag all the way
A3:	More parts.. more cost
A2:	[Places two leg motors in a line facing opposite] robot.. like this
A1:	[Checks the arrangements]
A2:	Wait.. I will get the tape
A1:	[Tapes the connecting wires together]
A2:	[Hold the motors together]
A1:	[Places the lego EV3 brick over the motors] like this?
A2:	Yeah... it should be ok.. got weight.. but where will the sponge go..?

The making progressed as depicted in Table 2, A3 focused on modifying the sketches, whereas A1 and A2 explored the materials provided. A1 considered the capability of cleaning mop wipe as an attachment to perform the wiping task. Meanwhile A2 and the sponge engaged in play and entangled in the embodied experience of squishiness of the sponge. The mutual experimentation of makers-sponge-trash-glass table as seen in Figure 2, proved to be effective, but the team was concerned about the surface on which the task must be performed. As the facilitator pointed out that the cleaning task is to be carried out on the ground, new design considerations arose and A2 brought in the idea to have cans to collect the trash. Here the notion of cleaning task changed as the test surface to be cleaned changed. We see the relational dynamics that the cleaning ideas, and meaning of cleaning underwent changes as the makers, facilitator, cleaning mop wipe, sponge, glass table surface and the floor get into entanglements.

Table 2: Trash cleaning experimentations

Team member	Verbal and Non-verbal actions
A1:	This can be attached [pointing to the cleaning mop wipe].
A2:	I want to test this [holds up the sponge].. this is really squishy .
A1:	Take a bit of the trash [takes pencil dust from trash box].. see if there will any trace.
A2:	[places the trash on glass table] and then.. [wipes with sponge]
A1:	That's perfect.. but now we need to drag all these [points to trash]
A2:	[turns to facilitator] now.. we are going to do it on the ground right?
Facilitator:	Yeah.. final test will be on the floor.
A2:	Ok.. then we need a can.. to collect..

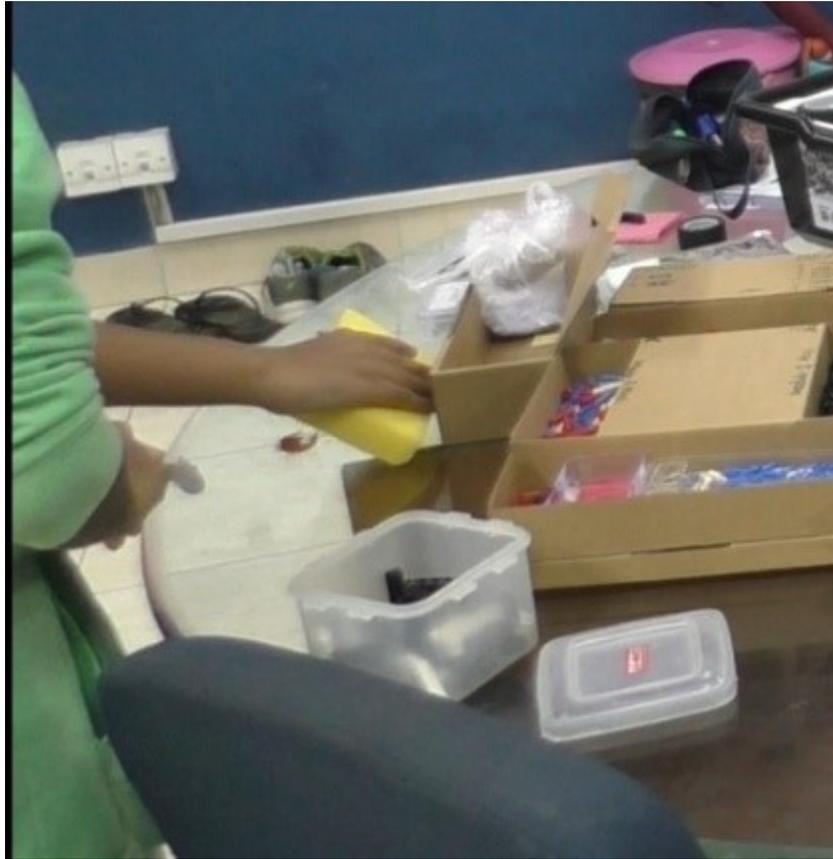


Figure 2: Makers-materials engaging in cleaning experimentations.

As further ideas and challenges popped up, A1 felt that the team was straying around and wanted to structure the actions, so that they make sense of the happenings. A3 picked up the sticky notes, moved towards the white board on the wall and pasted the notes on the board as depicted in Table 3. A1, then wrote “questions” and “answers” in two different colored notes, along with description on the white board, as seen Figure 3. Noting this action, the facilitator wrote down the major points of the design challenge to the right side of the sticky notes. Here we read that the making is growing from the table to the white board with the sticky notes. The sticky notes and white boards are not mere backgrounds pushed outside of the making landscape, but are active organizers along with the makers in driving the next creative steps.

Table 3: Maker and materials organizing the making actions

Team member	Verbal and Non-verbal actions
A1:	We need to find the problems
A3:	[writes “wheels” in a sticky note and shows to A1]
A1:	Yeah.. wheels.. one problem .. lets stick it [points to the table]
A3:	[moves towards the whiteboard on the wall and pasted the note on the board]
A1:	Ok.. these are our problems [sticks more yellow notes] .. markers?
A1:	[finds markers and writes description on the whiteboard]

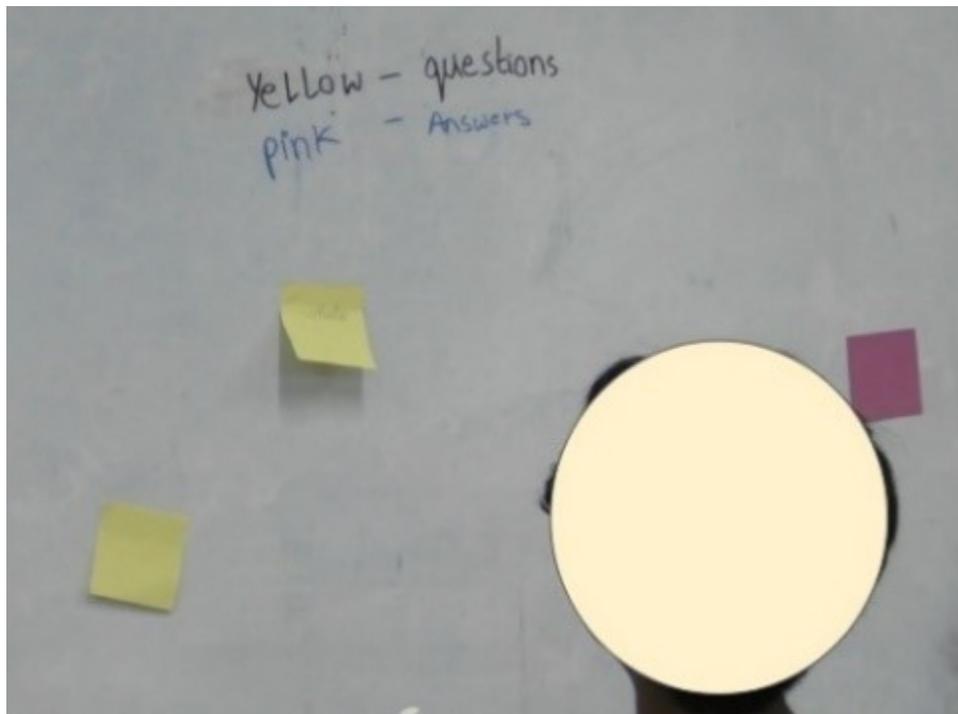


Figure 3: Maker working with the whiteboard and sticky notes.

The makers tinkered around with the wheels, tapes, robot structure and coding. Meanwhile, A2 reminded the team of the cost value of the components which needed to be tracked and to eliminate unnecessary additions to the robotic structure as depicted in Table 4. We read that the cost value as an intra-acting entity in the making process, which governed the making actions. Here we place the cost value not as a part of the making context but as driver of the making, engaged in continuous negotiations with the makers.

Table 4: Maker-material-cost value negotiations

Team member	Verbal and Non-verbal actions
A2:	[Hands over connecting rod to A1] See this.
A1:	[Checks the rod]Oh.. this is the connecting thing.. so we don't need the frame.
A2:	Less cost..
A1:	No.. lets see whose bot is costlier.

The team had the idea to build a “cage” for the lego EV3 brick over the drive unit so that it keeps the brick in place while the robot is moving. The makers failed to materialize the idea as the lego components resisted the actions and switched to possibility of sticking the brick to the drive unit with the double tape. After continuous maker-material negotiation and experimentation to arrive at the robot structure, the team focused on making the cleaning set up. The makers cut the sponge into two piece and attached to the robot rear end with tapes and tested the robot on the cleaning floor. Interestingly, the facilitator spread trash materials on the floor on a wider span, which the robot was unable to clear. This forced the team to add the second piece of the sponge to the existing piece but at right angles. The robot was tested again, yielding better result as it cleared more trash. With the better feedback, the makers tried to improve the performance by attaching the cleaning mop wipe to the sponge. Makers searched for bands, tapes and clips, but settled down with the encounter with a stapler, as seen in Figure 4. The instance is another example of how changes in the test

floor and trash spread affected design decisions and the maker-material configurations had to respond accordingly by scavenging the available resources.

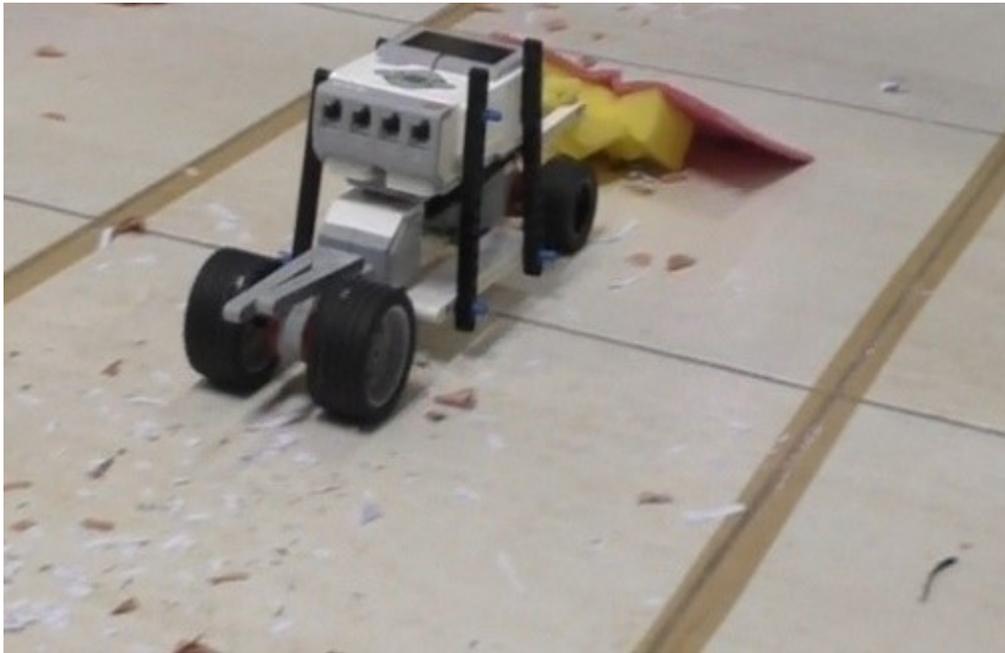


Figure 4: Team A's cleaning robot – combined of lego mindstorms parts, sponge, mope, stapler pins – in action.

Discussion and Conclusion

In this article we followed a dual theoretical lens of constructionism and posthumanism, and illustrated a few representative episodes of making from a collaborative making contexts where novice makers engage in design problem solving to show the ways in which makers and materials collide, that direct creative making assemblages. We found that creative making opportunities emerged as the makers and the broad range of materials came together informing, inciting and directing creative movements in a reciprocative fashion. We followed the bidirectional flow of causes and effects surfacing in the complex interplay of maker and material components as the collaborative creative making unfolded [12]. The analysis showed how making is notably driven by the emergent qualities of material resources and dynamic maker-material configurations via idea realizations and embodied experiences. We have seen instances where makers approach and recruit materials to translate sets of abstract ideas into tangible forms and materials direct maker actions support idea realization, and resist making actions. We found that the material components acted as co-makers in opening up possibilities and providing insights via responses through different modes of conversations by virtue of joint collaboration [22].

The study highlight that makers, materials, facilitator and other non-human entities constituted the collaborative emergences, pointing that the phenomenon is spread across the social and material elements of the situated environment, and evolve over time [14, 16]. The findings from the study suggest that design for learning by making needs to be attentive to how learners get to know things, think together with materials, make together with materials and support the adaptability to the moment-to-moment unfolding of learning by making [11, 18, 21]. Designers may look at augmenting the visibility of material limits and possibilities so that makers can acknowledge and appreciate the material experience offered by the sources. Bringing the materials to the forefront of creative making actions can broaden our views on human-material relations and advance alternative perspectives on interaction design with

emphasis on agential becomings among humans and materials [8, 19]. Following similar lines of thought put forward by learning scientists and STS researchers to move beyond the overemphasis on language in human meaning making and towards the positioning that humans and material resources intra-act to construct meaning holds the potential to provide a richer understanding of materiality in creative making practices [17, 20]. With the discussed notions of agency, researchers and practitioners can look at the creative intra-actions of the constituent elements of the phenomenon of making together with materials, where the boundaries between human and material components vanish. Future analyses from varied making contexts would give a wider understanding on the meanings of sociomaterial entanglements in making.

References

1. Donald A Schön. 1983. *The reflective practitioner: How professionals think in action*. Routledge.
2. Bronwyn Bevan. 2017. The promise and the promises of making in science education. *Studies in Science Education* 53, 1 (2017), 75–103.
3. Dale Dougherty. 2012. The maker movement. *Innovations: Technology, governance, globalization* 7, 3 (2012), 11–14.
4. Vlad Petre Glăveanu. 2014. Distributed creativity: Thinking outside the box of the creative individual.
5. Brian E Gravel and Vanessa Svihla. 2021. Fostering heterogeneous engineering through whole-class design work. *Journal of the Learning Sciences* 30, 2 (2021), 279–329.
6. Bruno Latour. 1996. On interobjectivity. *Mind, culture, and activity* 3, 4 (1996), 228–245.
7. Giulio Jacucci and Ina Wagner. 2007. Performative roles of materiality for collective creativity. In *Proceedings of the 6th ACM SIGCHI conference on Creativity & cognition*, 73–82.
8. Anna Keune and Kylie Peppler. 2019. Materials-to-develop-with: The making of a makerspace. *British journal of educational technology* 50, 1 (2019), 280–293.
9. Jakob Tholander, Maria Normark, and Chiara Rossitto. 2012. Understanding agency in interaction design materials. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, 2499–2508.
10. Sharan B Merriam. 1998. *Qualitative Research and Case Study Applications in Education. Revised and Expanded from "Case Study Research in Education."*
11. Mike Petrich, Karen Wilkinson, and Bronwyn Bevan. 2013. It looks like fun, but are they learning? In *Design, make, play*. Routledge, 68–88.
12. Andrew Pickering. 1993. The mangle of practice: Agency and emergence in the sociology of science. *American journal of sociology* 99, 3 (1993), 559–589.
13. Mikael Wiberg. 2014. Methodology for materiality: interaction design research through a material lens. *Personal and ubiquitous computing* 18, 3 (2014), 625–636.
14. Keith R Sawyer and Stacy DeZutter. 2009. Distributed creativity: How collective creations emerge from collaboration. *Psychology of aesthetics, creativity, and the arts* 3, 2 (2009), 81.
15. Lucy A Suchman. 1987. *Plans and situated actions: The problem of human-machine communication*. Cambridge university press.
16. Lene Tanggaard. 2013. The sociomateriality of creativity in everyday life. *Culture & Psychology* 19, 1 (2013), 20–32.
17. Jaye Johnson Thiel. 2015. Vibrant matter: The intra-active role of objects in the construction of young children's literacies. *Literacy Research: Theory, Method, and Practice* 64, 1 (2015), 112–131.
18. Stella Timotheou and Andri Ioannou. 2019. On making, tinkering, coding and play for learning: A review of current research. In *IFIP Conference on Human-Computer Interaction*, Springer, 217–232.
19. Karen E Wohlwend, Kylie A Peppler, Anna Keune, and Naomi Thompson. 2017. Making sense and nonsense: Comparing mediated discourse and agential realist approaches to materiality in a preschool makerspace. *Journal of Early Childhood Literacy* 17, 3 (2017), 444–462.
20. Karen Barad. 2003. Posthumanist performativity: Toward an understanding of how matter comes to matter. *Signs*:

- Journal of women in culture and society*28, 3 (2003), 801–831.
21. Aditya Johri. 2011. The socio-materiality of learning practices and implications for the field of learning technology. *Research in Learning Technology*19, 3 (2011), 207–217.
 22. Michael David Kirchhoff. 2009. Material agency: a theoretical framework for ascribing agency to material culture. *Techne: research in philosophy and technology*13, 3 (2009), 206–220.
 23. Kylie Pepler, Jennifer Rowsell, and Anna Keune. 2020. Advancing posthumanist perspectives on technology-rich learning. *British journal of educational technology*51, 4 (2020), 1240–1245.
 24. Vanessa Svihla, Margaret Tucker, and Todd Hynson. 2020. What Gaze Data Reveal About Material Agency: Resilient makers, materials and ideas. In *Proceedings of the FabLearn 2020-9th Annual Conference on Maker Education*, 54–60.
 25. Wanda J Orlikowski. 2007. Sociomaterial practices: Exploring technology at work. *Organization studies*28, 9 (2007), 1435–1448.
 26. Varpu Mehto, Sini Riikonen, Kaiju Kangas, and Pirita Seitamaa-Hakkarainen. 2020. Sociomateriality of collaboration within a small team in secondary school maker-centered learning project. *International Journal of Child-Computer Interaction*26, (2020), 100209.
 27. Mary P Sheridan, Amélie Lemieux, Ashley Do Nascimento, and Hans Christian Arnseth. 2020. Intra-active entanglements: What posthuman and new materialist frameworks can offer the learning sciences. *British journal of educational technology*51, 4 (2020), 1277–1291.
 28. Anna Keune. 2022. Material syntonicity: Examining computational performance and its materiality through weaving and sewing crafts. *Journal of the Learning Sciences*31, 4–5 (2022), 477–508
 29. AY Jackson and LA Mazzei. 2012. Thinking with theory in qualitative research: Viewing data across multiple perspectives/Youngblood. *Imprint Abingdon*(2012).
 30. Elizabeth A St. Pierre. 2008. Decentering voice in qualitative inquiry. *International Review of Qualitative Research*1, 3 (2008), 319–336.
 31. Edward P Clapp, Jessica Ross, Jennifer O Ryan, and Shari Tishman. 2016. *Maker-centered learning: Empowering young people to shape their worlds*. John Wiley & Sons.

Virtual reality and the art of empathetic teaching

Enhancing teacher education through perspective-taking

Kalliopi-Evangelia Stavroulia, Cyprus University of Technology & CYENS Centre of Excellence, Cyprus, kalliope.stavroulia@cut.ac.cy

Christos Kyrlitsias, Cyprus University of Technology & CYENS Centre of Excellence, Cyprus, c.kyrlitsias@gmail.com

Lefteris Ioannou, Cyprus University of Technology, Cyprus, lyioannou@gmail.com

Yiannis Georgiou, Cyprus University of Technology, Cyprus, yiannis.georgiou.tepak@gmail.com

Despina Michael-Grigoriou, Cyprus University of Technology, Cyprus, despina.michael@cut.ac.cy

Andreas Lanitis, Cyprus University of Technology & CYENS Centre of Excellence, Cyprus, andreas.lanitis@cut.ac.cy

Abstract

The use of Virtual Reality (VR) in teacher education can revolutionize the way teachers are trained and developed. This paper presents the development and evaluation of a dedicated VR application that aims to enhance teachers' competences through experiential and practical training in a safe and controllable virtual environment. More than 290 teachers from five different countries evaluated the VR application. The results indicate that perspective changing allows teachers to better experience the problems faced by students, allowing the cultivation of skills such as empathy, inclusion and diversity. Equally important is that preliminary results indicate that the VR implementation had a long-term impact on teachers' perceptions and attitudes.

Introduction

Virtual Reality (VR) technology has the potential to transform the teacher education sector by offering unique, immersive and interactive learning experiences that can improve retention and understanding [1][2]. VR-based training can enhance teachers' engagement, improve learning outcomes and foster their personal and professional development [3]. Additionally, VR allows teachers to experience hands-on learning opportunities in a safe and controlled environment [4]. Equally important is that VR can be used to simulate real-world scenarios and provide virtual field trips that are otherwise difficult or impossible to access [5]. By providing immersive and interactive learning experiences, VR can help teachers to develop their skills and competences in a way that traditional teaching methods cannot.

This paper presents a VR application for teacher training that was developed within the framework of the VRTEACHER project (Virtual Reality-based Training to improve digital Competences of teachers) offering teachers the opportunity to practice their teaching abilities in a simulated classroom environment. This innovative tool offers a range of benefits to teachers which make it a valuable asset for teacher education by providing immersive learning experiences depicting extreme and real-life-based classroom scenarios that offer valuable opportunities for reflection and professional growth. This novel training tool has the potential to revolutionize teacher education and improve its quality by transforming the way teachers are trained and develop their skills, leading to better teaching outcomes and improved student learning. Active teachers participated in all stages of the application design and development cycle, ensuring that the use of the application provides valuable opportunities for reflection and professional growth. The key feature of the application is the ability of users to experience the scenarios both through the eyes of teachers and students. The VR application was evaluated by more than 290 in-service and pre-service teachers from five countries (Cyprus, Greece,

Spain, Ireland and Malta) allowing the derivation of comprehensive conclusions related to the effectiveness and impact of the application, and in particular, the impact of perspective changing. Preliminary results validate the promise of the VR application, as a highly useful tool for teacher training.

Virtual Reality in Teacher Training

Virtual reality (VR) is an emerging technology that has gained significant attention in recent years [6, 7, 8]. It is a simulated experience that can reflect real-world experiences and situations, providing new opportunities for a range of industries, including education. VR has become a popular tool in various fields, as evidenced by the growing body of literature in fields such as psychology [9], chemistry [10], language learning [11], physics [12] and many other scientific disciplines. VR has the potential to offer immersive opportunities for practical training in teacher education, enabling teachers to experience different scenarios and develop critical competences in a safe and controlled environment. The use of VR in teacher education can bridge the gap between theory and practice, allowing teachers to gain hands-on experience and develop their skills before entering a real classroom. VR technology has been identified as a medium that can induce empathy and is often referred to as an “empathy machine” [13, 14]. Furthermore, VR allows users to see the world from the perspective of others, offering a unique opportunity to see what others see, hear what others hear, move how others move, and feel the emotions others feel [15]. This immersive technology enables users to gain a deep understanding of other people’s experiences, such as the viewpoint of refugees or a student with a prosthetic leg after an accident [16] and can promote empathy and understanding in a way that traditional media cannot.

Several initial studies have shown promising results for the use of VR in teacher education. One VR prototype created a classroom environment that simulated students with vision disorders, allowing teachers to experience the perspective of visually impaired students [17]. Another study aimed to train teachers in identifying and distinguishing bullying incidents from teasing cases [18]. Lugin et al. [19] developed an immersive VR system that enhanced teachers’ classroom management skills by training them to manage disruptive behavior in the classroom. Furthermore, Bujdosó [20] explored the potential of using VR-based approaches to enhance student teachers’ presentation skills.

The use of VR in teacher training has the potential to add significant value to traditional methods of education by simulating scenarios that are difficult to replicate in real life, such as emergency situations and uncommon classroom situations. VR can provide a safe and controlled environment for trainees to practice and develop their skills without the risk of harm or negative consequences. Equally important is the ability of VR to enhance empathy and perspective-taking skills, allowing teacher trainees to experience the world through the eyes of their students gaining a deeper understanding of their experiences and challenges. This can lead to more inclusive and culturally responsive teaching practices. Furthermore, VR can offer highly engaging and interactive learning experiences, by immersing trainees in a virtual environment, promoting their active participation in the learning process, rather than just passively consuming information. The benefits that VR-based training can lead to better-prepared and more effective teachers while also increasing the quality of education through immersive, experiential, and practical learning experiences.

Methodological Framework

The methodological framework used during the application development process was carefully designed to ensure that the delivered application was relevant and effective in meeting the real needs of teachers. The use of participatory design ensured that the VR application was user-friendly and met the needs of teachers in different educational contexts. During the design process, an online survey was conducted to identify the specific needs of teachers, providing valuable insights into the challenges they face, the impact of the pandemic on their daily work, and the types of

training and support that they need. This information was used to inform the design of the scenarios for the VR training tool. Focus groups were also conducted providing an opportunity to explore teachers' expectations of the VR tool and to gather feedback on its potential usefulness. By engaging teachers in this way, the project team was able to identify any potential barriers to adoption and address these in the design and development of the VR application. Figure 1 presents the block diagram of the methodological design process.

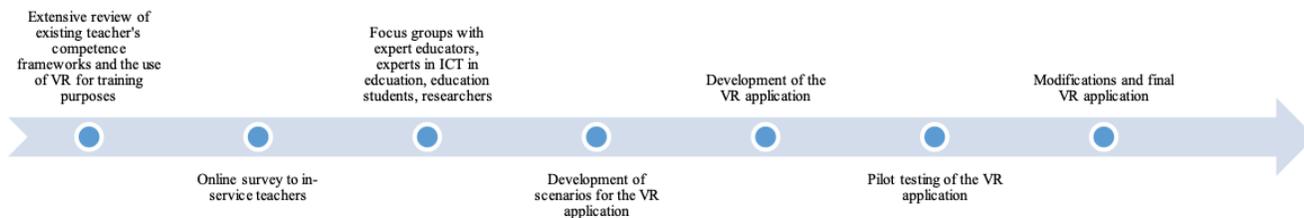


Figure 1: Block diagram of the methodological design and development process

Defining The Competences For VR Teacher Training

To determine the essential competences for effective VR-based teacher training, the first step was to conduct a comprehensive review of existing frameworks, such as the European Key Competences Framework, DigCompEdu, and ICT Competency Framework for Teachers. This was followed by a survey designed to identify the needs and key skills required by teachers. In total, 340 in-service and pre-service teachers participated in the online survey. The results revealed a need for soft skills empowerment and a demand for training programs that can help educators to gain more experience with VR-based techniques. The survey aimed also to gather input related to three areas: 1) Digital 2) Personal and 3) Civic Competences. Related to 'Digital Competences' the survey results identified the most important competences the active engagement of the learners, problem-solving, collaborative learning, and ICT in education. The participants rated "Stress resistance", "Emotional control", and "Self-control" as the most important personal competences. In terms of civic competences "Valuing of diversity," "Trust," "Co-operation," "Social responsibility and engagement," "Sociability," and "Assertiveness received the highest scores. After the survey focus groups were conducted consisting of expert educators, university students, ICT experts and researchers. These focus groups aimed to provide an in-depth exploration of teachers' needs, and expectations of a VR training tool, ensuring that the resulting VR tool was tailored to meet the specific needs and expectations of the target audience.

For the definition of the VRTEACHER competence framework, the partnership had to take into consideration, apart from the competences that scored the highest scores in the survey and the outcomes of the focus groups, the scenarios of the VR application along with the limitations of VR technology and equipment. For this reason, the selection of the project's core competences was not made based only on the competences that scored higher in the survey but also based on the competences that could be addressed and reflected through the VR tool and scenario. The competence framework for VR-based teacher training that was developed can be summarized in Figure 2.



Figure 2: Competence framework for the development of the VR application

VR Application

The VR application features three different scenarios, each focusing on a different topic that teachers may encounter in their work, including distance education and domestic verbal abuse, phobias related to COVID-19 and panic attacks, and classes with refugee students who don't speak the language of instruction of the class. The main feature of the application is the ability to view crisis situations as seen from the eyes of the teacher, and the eyes of the students involved in the events, while a follow-up session with a virtual tutor provides feedback and guidelines for the teacher. The VR application is publicly available to educators through the VRTEACHER website (<https://www.vrteacher.eu/>).

Technical Setup

The application runs on smartphones and was developed using UNITY (version 2020.3.22). Apart from UNITY, Autodesk Maya, Adobe Photoshop, Autodesk Character Generator, mixamo.com, the SALSA plug-in for UNITY, and the Google Cardboard XR plugin for UNITY were used for creating the virtual environment, the assets, and the interaction.

By starting the application for the first time, the user is prompted to select basic settings such as language settings, username, and country. In the main menu, the user can navigate through different menus, and select one of the three VR scenarios (see below for a description of the scenarios). The user can explore the virtual environment using gaze movements and interact with the 3D user interface using a gaze-controlled cursor. As the scenarios progress, various questions appear which must be answered by the user to continue the scenario.

The decision to use low-cost cardboard VR headsets for Android phones in the VRTEACHER project is a practical and cost-effective approach that aligns well with the project's objectives. By opting for a more affordable option, the project makes it easier for schools and teachers to access the necessary equipment. This ensures a wider reach and adoption of the VRTEACHER application, especially in educational settings where budgets for technology might be limited. Furthermore, the simplicity of these cardboard headsets facilitates the setup and reduces potential technical barriers for users. Scenarios, perspective change and eye gaze interaction

In the current version, the VR application offers three scenarios that simulate real-life classroom scenarios, each with its own set of challenges and learning outcomes.

- *Scenario 1 – Distance education and domestic verbal abuse:* This scenario simulates a situation in which a teacher is conducting a lesson during which a student is connected online. During the lesson, the student is experiencing domestic verbal abuse by his mother.
- *Scenario 2 – Phobias related to COVID and panic attacks:* This scenario simulates a situation in which a teacher confronts a student who is experiencing a panic attack and anxiety related to COVID-19.
- *Scenario 3 – Refugee Students:* The third scenario focuses on the challenges that teachers may encounter when working with refugee students who do not speak the language of instruction. This scenario allows teachers to develop their understanding of the unique challenges in multicultural classes.

For all three scenarios, the VR tool offers teachers the ability to experience the scenario both from the perspective of the teacher, but also from the perspective of the virtual student involved in the incident. This feature aims to provide teachers with a deeper understanding of the student's experiences and challenges and to experience the impact of their teaching methods from the student's point of view. Typical screenshots from the scenarios are presented in Figure 3.



Figure 3: Typical screenshots from the VR application showing the teacher perspective (top left), and the student perspectives for scenarios 1 (top right), 2 (bottom left), and 3 (bottom right)

Research questions, Implementation and evaluation process

The research questions that the VR intervention aimed to answer were the following:

1. Did the integration of VR-based training, as facilitated by the VRTEACHER project, enhanced teachers' competences?
2. To what extent did perspective change feature lead to improved teacher empathy and understanding of student experiences?
3. Over an extended period, what lasting effects does the VRTEACHER project have on teachers' personal and professional development?

The project initiated a comprehensive sequence of workshops, both online and face-to-face, meticulously tailored to equip teachers with essential competences and insights for VR technology integration. The initial online session aimed to acquaint educators with VR technology, elucidate its potential advantages, and offer a practical guide on the utilization of the VR application. This was followed by a face-to-face training workshop where educators received hands-on training with the VR application. Finally, through a follow-up online workshop participants reflected on the VR-based training practices. During the face-to-face training activities, the participants were required to complete one questionnaire before and one after the VR intervention. Additionally, a third questionnaire was administered four weeks after the VR intervention serving to assess the enduring impact of the intervention. Pre, post and follow-up questionnaires were the same consisting of the Interpersonal Reactivity Index (IRI) (sub-scales Empathic concern, Perspective taking, and Personal distress), and three scales each one related to each scenario that were developed under the VRTEACHER project.

Results

The evaluation of the VR application encompassed a cohort of 299 in-service and pre-service teachers hailing from five different countries. Throughout the training process, participants were afforded approximately 30 minutes per scenario to interact with the application. During this immersive experience, they were prompted to respond to inquiries embedded within the virtual environment, considering both the teacher's and student's perspectives within each scenario. It should be noted that in addition to data gathered during the VR intervention, data was also collected through pre, post and follow-up questionnaires. The results discussed in this paper refer to the data collected from the VR application, as the analysis of the pre, post and follow-up questionnaires is still ongoing. However, some initial findings are also included.

In total 223 participants evaluated Scenario 1, 184 participants evaluated Scenario 2, and 185 participants evaluated Scenario 3. Across all three scenarios, participants were asked to assess whether their experience in the virtual environment was consistent with a real-world experience rating this consistency on a scale ranging from 1 (indicating the highest level of congruence) to 5 (representing the lowest level of consistency). In the context of scenario 1, the research findings suggest that in both teacher and student perspectives, most participants reported a consistent real-world-like experience. Statistical analysis revealed no significant discrepancy between these two viewpoints ($t=1.62$, $p>0.01$). The outcomes further indicate that the experience felt immersive and authentic in both viewpoints ($M=1.35$, $SD=0.48$ as a teacher and $M=1.27$, $SD=0.44$ as a student). Additionally, the data disclosed a statistically significant contrast in the ability of participants to genuinely place themselves in the position of the student attending the class with teleconferencing ($t=3.708$, $p<0.01$). This finding signifies that the virtual embodiment of the student perspective allowed end-users to authentically experience the learning environment from a student's viewpoint, underlining the effectiveness of this feature in fostering a faithful and engaging educational experience. Regarding scenario 2, the findings underscore a notable convergence of experiences among participants from both the teacher and student perspectives, with most reporting an immersive, real-world-like encounter. Importantly, no statistically significant difference emerged between these two viewpoints. As revealed by the data, participants engaged with scenario 2 as active participants rather than mere observers, as indicated in both perspectives' responses ($M=1.37$, $SD=0.48$ as a teacher and $M=1.27$, $SD=0.46$ as a student). Notably, the results unveiled a statistically significant divergence concerning whether participants could genuinely immerse themselves in the position of the student during a COVID-19-related panic attack ($t=-16.98$, $p<0.01$). This outcome underscores that the virtual embodiment of the student's perspective facilitated a heightened understanding of the student's predicament, further emphasizing the effectiveness of this feature in cultivating empathy and providing a comprehensive experience for end-users. The outcomes for scenario 3 similarly demonstrate that a majority of participants perceived the experience as remarkably consistent with a real-world encounter. Significantly, no statistically significant distinction was observed between the viewpoints of teachers and students in this regard. Furthermore, participants fully engaged with scenario 3, embodying the role of active participants rather than passive observers, as reflected in both perspectives ($M=1.39$, $SD=0.49$ as a teacher and $M=1.17$, $SD=0.47$ as a student). Notably, the results disclosed a statistically significant divergence in participants' ability to empathetically immerse themselves in the position of a student refugee ($t=-10.13$, $p<0.01$). This finding highlights the potent effect of embodying the virtual identity of the student, enabling end-users to genuinely experience the challenges faced by students who are not proficient in the language of instruction within a classroom. This outcome further underscores the valuable contribution of the VRTEACHER application in fostering cross-cultural understanding and empathy among educators.

The results from the data gathered from the VR application indicate that in all scenarios, participants expressed a sense of immersion within the virtual world and consistently found their experience to be akin to real-life situations, irrespective of the perspective they adopted. Particularly noteworthy is the impact of perspective change; the results demonstrate that assuming the role of a student in all three scenarios had a profound effect on the participants, enabling

them to perceive the scenarios from the student's viewpoint. This, in turn, fostered empathetic behavior among the participating teachers, marking a significant outcome from the experiments.

The reliability analysis performed on the questionnaires administered revealed robust consistency in the scales employed, with Cronbach's alpha coefficients demonstrating high reliability: 0.73 for IRI, 0.92 for Attitudes toward Remote and Blended Teaching scale (scenario 1), 0.96 for Attitudes toward Remote and Blended Teaching scale (scenario 2) and 0.93 for Attitudes towards Cultural Intelligence in Teaching scale (scenario 3). Preliminary findings from the pre, post, and follow-up questionnaires showcased statistically significant differences before and after the use of VR for all scales. Paired-sample t-tests were conducted to explore the impact of the VR intervention on participants' empathic concern, perspective taking and personal distress after the VR intervention. The results demonstrated significant improvements. Specifically, a marked increase in participants' perspective-taking was observed. [$t(263) = -2.87, p < 0.01$], coupled with a statistically significant decrease in personal distress [$t(263) = 2.12, p < 0.05$] post the VR intervention. While not statistically significant, the results indicated a subtle rise in participants' empathic concerns. Further analysis focused on participants' attitudes toward remote and blended teaching revealed noteworthy enhancements. Significant improvements were observed in overall attitudes [$t(263) = -6.81, p < 0.001$], including attitudes towards inclusive education [$t(264) = -6.52, p < 0.001$] and cultural intelligence [$t(263) = -3.56, p < 0.001$]. Equally important, is that preliminary findings suggest a lasting impact of the VR intervention on participants, as evidenced by a statistically significant increase in attitudes observed four weeks post-VR implementation. This sustained effect may stem from an ongoing elaboration on the experienced learning scenarios, reflective practice, and peer discussions, contributing to the amplification of the intervention's long-term impact.

Conclusions And Future Work

Based on preliminary results, the VR application presented is a valuable training resource for teachers that leverages the power of VR technology to provide immersive and interactive learning experiences. By simulating real-life classroom situations, the application allows teachers to develop their skills and competences in a safe and controlled environment, while also experiencing a situation through the eyes of the student. This enables teachers to develop an empathetic and student-centred approach to teaching, which can lead to better engagement and learning outcomes for the students.

The results for all three scenarios—distance education and domestic verbal abuse, phobias related to COVID and panic attacks, and students who are refugees, highlighted the VR application's ability to provide an exceptionally realistic experience. The innovative aspect of perspective change, enabling users to immerse themselves in crisis situations from both teacher and student viewpoints, emerged as a highly promising strategy for VR-based teacher training. Of equal significance, preliminary findings from the questionnaires underscore the transformative impact of VR in teacher training. The observed changes encompassed empathic concern, perspective-taking, personal distress, attitudes toward remote and blended teaching, inclusive education, and cultural intelligence. These positive changes were evident across pre, post, and follow-up questionnaires, indicating the profound and enduring impact of the VR intervention on participants.

In the future, more comprehensive results will be presented based on extended analysis from the pre, post and follow-up questionnaires. Furthermore, the project aims to further enrich the application in collaboration with active teachers by incorporating additional scenarios, extending language options, and expanding the evaluation to include more countries.

Acknowledgments

The authors extend their appreciation to the invaluable participants who contributed their time, support, and valuable insights to this research study. The authors also acknowledge funding by the Erasmus+ programme of the European Union through the project VRTEACHER Virtual Reality-based Training to improvE digitAl Competences of teachERS, Grant Agreement number: 2020-1-CY01-KA226-SCH-082707. This project was also partially supported by the EU's H2020 Research and Innovation Programme (Grant Agreement No 739578) and the Government of the Republic of Cyprus.

References

1. Morélot, S., Garrigou, A., Dedieu, J., & N'Kaoua, B. (2021). Virtual reality for fire safety training: Influence of immersion and sense of presence on conceptual and procedural acquisition. *Computers & Education*, 166, 104145.
2. Han, I., Shin, H. S., Ko, Y., & Shin, W. S. Immersive virtual reality for increasing presence and empathy. *Journal of Computer Assisted Learning*, 38(4), 1115–1126, 2022.
3. Howard, M. C., & Gutworth, M. B. (2020). A meta-analysis of virtual reality training programs for social skill development. *Computers & Education*, 144, 103707.
4. Ke, F., Lee, S., & Xu, X. (2016). Teaching training in a mixed-reality integrated learning environment. *Computers in Human Behavior*, 62, 212-220.
5. Morélot, S., Garrigou, A., Dedieu, J., & N'Kaoua, B. (2021). Virtual reality for fire safety training: Influence of immersion and sense of presence on conceptual and procedural acquisition. *Computers & Education*, 166, 104145.
6. Freina, L., & Ott, M. (2015, April). A literature review on immersive virtual reality in education: state of the art and perspectives. In *The international scientific conference elearning and software for education* (Vol. 1, No. 133, pp. 10-1007).
7. Rojas-Sánchez, M. A., Palos-Sánchez, P. R., & Folgado-Fernández, J. A. (2023). Systematic literature review and bibliometric analysis on virtual reality and education. *Education and Information Technologies*, 28(1), 155-192.
8. Lege, R., & Bonner, E. (2020). Virtual reality in education: The promise, progress, and challenge. *JALT CALL Journal*, 16(3), 167-180.
9. Vesisenaho, M., Juntunen, M., Häkkinen, P., Pöysä-Tarhonen, J., Fagerlund, J., Miakush, I., & Parviainen, T. (2019). Virtual reality in education: Focus on the role of emotions and physiological reactivity. *Journal of Virtual Worlds Research*, 12(1).
10. Kumar, V. V., Carberry, D., Beenfeldt, C., Andersson, M. P., Mansouri, S. S., & Gallucci, F. (2021). Virtual reality in chemical and biochemical engineering education and training. *Education for Chemical Engineers*, 36, 143-153.
11. Parmaxi, A. (2023). Virtual reality in language learning: A systematic review and implications for research and practice. *Interactive learning environments*, 31(1), 172-184.
12. Bogusevski, D., Muntean, C., & Muntean, G. M. (2020). Teaching and learning physics using 3D virtual learning environment: A case study of combined virtual reality and virtual laboratory in secondary school. *Journal of Computers in Mathematics and Science Teaching*, 39(1), 5-18.
13. Herrera, F., Bailenson, J., Weisz, E., Ogle, E., & Zaki, J. (2018). Building long-term empathy: A large-scale comparison of traditional and virtual reality perspective-taking. *PloS one*, 13(10), e0204494.
14. Carey, K., Saltz, E., Rosenbloom, J., Micheli, M., Choi, J. O., & Hammer, J. (2017, October). Toward measuring empathy in virtual reality. In *Extended Abstracts Publication of the Annual Symposium on Computer-Human Interaction in Play* (pp. 551-559).
15. Raij, A., Kotranza, A., Lind, D. S., & Lok, B. (2009, March). Virtual experiences for social perspective-taking. In *2009 IEEE Virtual Reality Conference* (pp. 99-102). IEEE.

16. Stavroulia, K. E., & Lanitis, A. (2023). The role of perspective-taking on empowering the empathetic behavior of educators in VR-based training sessions: An experimental evaluation. *Computers & Education*, 197, 1–17.
17. Manouchou, E., Stavroulia, K. E., Ruiz-Harisiou, A., Georgiou, K., Sella, F., & Lanitis, A. (2016, April). A feasibility study on using virtual reality for understanding deficiencies of high school students. In *2016 18th Mediterranean Electrotechnical Conference (MELECON)* (pp. 1-6). IEEE.
18. Stavroulia, K. E., Ruiz-Harisiou, A., Manouchou, E., Georgiou, K., Sella, F., & Lanitis, A. (2016, April). A 3D virtual environment for training teachers to identify bullying. In *2016 18th Mediterranean Electrotechnical Conference (MELECON)* (pp. 1-6). IEEE.
19. Lugrin, J. L., Latoschik, M. E., Habel, M., Roth, D., Seufert, C., & Grafe, S. (2016). Breaking bad behaviors: A new tool for learning classroom management using virtual reality. *Frontiers in ICT*, 3, 26.
20. Bujdosó, G. (2016). Virtual reality in teacher training-developing presentations in virtual reality. In *ICERI2016 Proceedings* (pp. 4900-4905). IATED.

Creative STEM activities offered by FabLabs

How do they impact creativity and grit of high school students?

Ferracane, M. F., Robert Schuman Centre for Advanced Studies, European University Institute¹

V. Ballerini, Department Department of Statistics, Computer Science, Applications “G. Parenti”, University of Florence

A. Dominici, Department of Economics, European University Institute

F. Menchetti, Department of Department of Statistics, Computer Science, Applications “G. Parenti”, University of Florence

S. Norjean, Department of Department of Statistics, Computer Science, Applications “G. Parenti”, University of Florence

Introduction

Creativity and grit are broadly acknowledged as crucial elements for individual success and prosperity (Sternberg and Lubart, 1992; Croypley, 1995). Creativity has been found to be positively associated with academic achievement and with various measures of personal and societal success, including educational attainment, occupational level, holding leadership positions, and making meaningful societal contributions (Runco *et al.*, 2010; Gajda *et al.*, 2017). Grit, defined as passion and perseverance for long-term goals, is also strongly linked to achievement in a range of educational and professional scenarios. Multiple studies reported a positive relationship between grit, academic performance, and other success indicators (Duckworth *et al.*, 2007, 2011; Maddi *et al.*, 2012). Therefore, interventions aimed at cultivating these traits in individuals are crucial.

Yet, many leaders and professionals tend to favor traditional educational abilities over these traits (Runco, 2004), mainly due to several misconceptions, such as the belief that these qualities are an innate trait and unchangeable (Olken, 1964). These misconceptions also lead people to view creativity as a risky and uncertain investment, which in turn discourages investment in creative potential (Rubenson and Runco, 1992). Creativity is also often mistakenly viewed as being solely related to aesthetics, such as art, when in fact, it can be applied across a spectrum of fields (Vincent-Lancrin *et al.*, 2019).

Contrary to these beliefs, research indicates that both creativity and grit can be effectively nurtured. Regarding creativity, most educational research is centered on children (Cliatt *et al.*, 1980; Alfonso-Benlliure *et al.*, 2013; Marcos *et al.*, 2020). Nevertheless, Torrance (1962) argued for promoting creative thinking in high schools as well – a viewpoint supported by a recent study by the OECD (2021a), which reported lower creativity and curiosity among 15-year-old students compared to those aged 10. In a comprehensive review covering 14 different studies on science education and creativity in high school seniors, Aguilera and Ortiz-Revilla (2021) conclude that both STEM (Science, Technology, Engineering, and Mathematics) and STEAM (Science, Technology, Engineering, Art and Mathematics) educational approaches positively influence students’ creativity. However, they also noted that many studies in their sample relied on inadequate statistical data and only half used randomized experiments.

Regarding grit, while it is acknowledged to be malleable and teachable (van Zyl *et al.*, 2021), it remains unclear whether it can be fostered through targeted interventions, as the research in this field is still emerging. A study by Alan *et al.* (2019) reveals a positive impact on grit-related behaviors from an intervention conducted by primary school teachers in

1. Corresponding author.

Turkey. Similarly, Alan and Ertac (2019) find that an educational program designed to foster grit boosted the competitive spirit among primary school boys and girls, with a larger effect seen in girls, thereby reducing the competitiveness gender gap. However, both studies were conducted on primary school children and to our knowledge there are no randomized studies on high-school students.

Randomization remains a recognized standard for scientific research also in the field of educational studies (Sweller *et al.*, 2007; Dreyhaupt *et al.*, 2017). Nevertheless, randomized controlled trials (RCTs) in education are rare, mostly due to the challenges of randomizing access to certain training programs for students. This situation makes researchers depend on convenience samples in the field of education (Valgeirsdottir and Onarheim, 2017; Bi *et al.*, 2020).

In this study, we aim to fill these gaps in the literature by assessing the impact of creative STEM activities on fostering creativity and grit among teenagers through a comprehensive randomized study involving 829 high-school students in Italy. The activities are provided by FabLabs, or digital fabrication laboratories, small-scale workshops that offer tools for digital fabrication and use a hands-on educational approach. From the methodological viewpoint, we focus on the Intention-To-Treat (ITT) effect, which is a recognized standard approach to assess the causal effect of the random treatment assignment in presence of noncompliance.

Our paper contributes to the body of research investigating the impact of targeted educational interventions on non-cognitive skills.² To the best of our knowledge, this is the first randomized controlled trial investigating grit in high-school students.

To measure creativity, we use two modalities: a self-assessment through the Short Scale of Creative Self and an expert assessment using an index of creativity, developed by the authors. While the program does not seem to impact self-assessed creativity, the expert assessment of creativity yields statistically significant results. We also find that FabLabs activities have a positive significant effect on students' perceived grit, measured through the Short Grit Scale proposed by Duckworth.

The rest of the paper is organized as follows. "Case Study" describes the experimental design and provides an overview of the students' information collected in the study. "Outcome Measurement" describes in detail the outcomes of interest and their measures. "Causal Analysis and Results" highlights the issue of noncompliance in the RCT and evaluates the Intention-To-Treat effect of giving the possibility to attend FabLab courses. Conclusions follow.

Case Study

In this Section, we provide some background on the empirical study. We first describe FabLabs and their activities as part of this study ("FabLabs & Activities"), and then we introduce the experimental design ("Experimental Design").

2. Other terms used in the literature to denote this class of skills include: character skills, personality traits, 21st-century skills, and soft skills. After describing those terms, every one of which comes at the cost of some criticism, Duckworth and Yeager (2015) concludes that debating over the optimal name of these qualities is less important than agreeing on their attributes: i) conceptually different from cognitive ability; ii) generally accepted as beneficial to the student; iii) rank-order stable over time; iv) potentially responsive to intervention; v) dependent on situational factors for their expression. Following this view, we want to highlight that the term "non-cognitive skills" maintained in this paper refer to the broad class of traits having the attributes listed above.

FabLabs & Activities

A FabLab, or digital fabrication laboratory, is a small-scale workshop offering tools for (personal) digital fabrication. The first FabLab was established by the Massachusetts Institute of Technology (MIT) in the early 2000s and FabLabs are now scattered around the globe.³ FabLab activities in school (and often also outside school) adopt a learn-by-doing pedagogic approach using digital fabrication tools, such as laser cutting and 3D printing, and programming skills. Students are trained to use the equipment and software and then asked to solve an actual problem rather than studying mnemonically. For example, in one of the activities, the students designed and built new benches for the park, and they learned how to 3D model and use a CNC milling machine to bring their ideas to life. Another activity proposed to the students was creating replicas of sculptures found in the local museum using photogrammetry, 3D modelling, and 3D printing.

While the activities followed by the students were diverse, they had in common a creative pedagogical model typical of FabLabs in schools. FabLabs began projects in primary and secondary education in 2008 thanks to Stanford University's FabLab@School project, specifically focusing on incorporating the “making” into school curricula. The pedagogical approach is based on “playful experimentation”, i.e. the practical use of tools and materials to make the learning experience more engaging (Regalla, 2016). Qualitative evidence suggests that curricular intervention based on technological making workshops increases students' proficiency and interest in design and engineering tasks, and more generally in STEM subjects (Kafai *et al*, 2014; Berland, 2016; Bevan, 2017). The common traits of the activities that have been offered to the students as part of our experiment include: a learning-by-doing approach, peer-to-peer learning, group work, project-based learning, an informal and relaxed learning environment, and playful activities (Resnick, 2017; Ferracane, 2020), a creative pedagogical model that is rarely adopted in Italian high-schools.

Experimental Design

Students who participated in the program are enrolled in five Italian high schools located in Verona (Veneto), Schio (Veneto), Ancona (Marche), Mantua (Lombardy), and Agrigento (Sicily). The selection of the schools was conducted in September 2021 by local FabLabs.

The RCT involved $J = 42$ classes in total for a total of 829 students, from the second to the fifth (and last) grade.⁴ The possibility to access FabLabs courses was randomized at the class level. For each class $j, j = 1, \dots, J$, we denote the *treatment assignment* with Z_j , which takes value 1 if the i -th student in the j -th class was given the possibility to participate in FabLabs' courses, and 0 otherwise.

For each school, $Z_j = 1$ with probability $p = 0.7$, i.e., 70% of the eligible classes identified by the school principal were assigned to treatment. The treated group included 500 students.

Only students of the classes assigned to the treatment could decide whether to enroll on a voluntary basis, whereas the students of classes assigned to control could not participate in any activity organized by FabLabs. We denote the

3. For more information, visit the website of the FabFoundation: <https://fabfoundation.org/>

4. They are equivalent to 10th-13th grade.

treatment receipt with $D_{i,j}$, which takes value 1 if the student i of class j actually participated in the FabLab activity, and 0 otherwise. In total, 194 students enrolled to the activities.⁵

The FabLab activities have been delivered between September 2021 and May 2022. The activities were carried out inside the schools by FabLab employees who followed the same pedagogical approach and received the same set of instructions from the investigators.

Data were collected at two different points in time. At time $t = 0$, after randomizing the classes and collecting informed consent for participation in the study, the research team administered a baseline survey to all students in the treatment and control arms, covering: i) students' demographics and background information on parents' education and occupation; ii) students' preferences over school subjects and their expectations on the future choice of university and occupation; iii) special questions to assess baseline levels of grit and creativity (cf. "Outcome Measurement" on the measurement of these outcomes). In total, 578 students replied to this questionnaire.

At time $t = 1$, the research team administered the endline survey to all students in the treatment and control arm to collect information needed to measure the final grit and creativity scores. All FabLab courses ended at the same time in May 2022 and the endline survey took place almost simultaneously, so that the time span between the surveys in different schools is negligible and we can exclude the possibility that it acts as a confounder in our study. In total, 710 students replied to this questionnaire.

Outcome Measurement

Measures of Creativity

The literature broadly understands creativity as "the interaction among aptitude, process and environment by which an individual or a group produces a perceptible product that is both novel and useful as defined within a social context" (Plucker *et al.*, 2004). Several theories of creativity acknowledge the importance and interaction of relevant knowledge and skills, divergent and convergent thinking processes, task motivation, and a rewarding environment for supporting creative engagement with a given task (OECD, 2022; Amabile, 1983; Amabile and Pratt, 2016; Lucas *et al.*, 2013; Lucas, 2016; Sternberg and Lubart, 1991, 1995; Sternberg, 2006).

In our study, creativity was measured leveraging two instruments: a self-assessment by the students, measuring their *perceived creativity*, and some open-ended questions assessed by our expert (*expert-assessed creativity*). In the latter case, we anchor our approach with Guilford's (1950) definition of creativity that focuses on divergent thinking, one of the most well-studied aspects of creativity. It refers to the ability to follow new approaches, think of original and different ideas, and discover new methods of 'doing' by making flexible connections between ideas and pieces of information, taking different perspectives, and generating lots of ideas (Guilford, 1956; Cropley, 2006). In essence, divergent thinking brings forth novel, unusual, or surprising ideas (OECD, 2022).

5. After being assigned to a treatment arm, the students were asked to sign an informed consent (or return it signed by their guardians) to confirm participation in the study. In the absence of consent, the student is excluded from the study (they can still access the course, but their data are not collected).

Self-Assessed (Perceived) Creativity

For the self-assessment, we leverage the Short Scale of Creative Self (Karwowski, 2012), i.e., a self-reported five-point Likert scale consisting of eleven statements that participants can agree with on a scale ranging from “definitely not” to “definitely yes”: six of them measure creative self-efficacy (CSE), and five measure creative personal identity (CPI). These two self-concept constructs are gaining popularity in the creativity literature (Karwowski, 2012): CSE measures the ability to solve problems requiring creative thinking, and CPI reflects the belief that creativity is an important element of individuals’ functioning. We assess the treatment effect on the overall self-reported creativity and the CSE and CPI constructs. For each student i , we denote our outcome of interest Y_i^{PC} , measured as the average score over the following eleven items of the Short Scale of Creative Self: (1) I think I am a creative person; (2) My creativity is important in defining who I am; (3) I know that I can solve even complex problems efficiently; (4) I trust my creative abilities; (5) My imagination and ingenuity distinguish me from my friends; (6) I have proven time and again that I can cope with difficult situations; (7) Being a creative person is important to me; (8) I am confident that I can deal with problems that require creative thinking; (9) I am good at finding original solutions to problems; (10) Creativity is an important part of myself/self; (11) Ingenuity is an important characteristic for me.

Expert-Assessed Creativity

We developed an index on creativity that goes beyond the self-assessment usually employed in the literature. The expert-assessed index is based on Guilford’s (1950) definition of creativity which includes four main components: fluency (quantity of ideas), flexibility (different types of ideas), originality (uniqueness of ideas), and elaboration (building upon ideas).

For this assessment, the students were asked to complete two tasks at the baseline and two at the endline. Inspired by Guilford’s “Alternative Uses Test” (Guilford, 1967), the first task consisted of imagining all possible uses of a plastic bottle (baseline) and a can (endline) in two minutes. For the second task, students were asked to think about alternative uses of pedals by imagining that in the future bicycles will no longer have pedals (baseline) and the bicycle of the future (endline), taking inspiration from the “PISA creative thinking framework” (OECD, 2021b). Students were given five minutes to complete the second task.

The evaluation of the students’ answers (appropriately anonymized) was carried out by an independent expert in creative pedagogy. To calculate the index for each of the students’ responses, we developed a rubric to assign a value ranging from 0 to 4 to each of the four different components of divergent thinking, which are then aggregated into a final index ranging from 0 to 16. We denote the overall score with $Y_i^{EC}, \forall i = 1, \dots, N$.

Measure of grit

One of the most commonly used measures of grit in educational research is the Duckworth scale. The original version, named “Grit-O”, was introduced in a seminal paper by Duckworth *et al.* (2007) and it is a 12-item scale organized into two main components: the *consistency of interest* dimension, evaluating the persistence of individuals’ interests over time; and the *perseverance of efforts* dimension, focusing on the extent to which individuals sustain continued effort to achieve their goals in the face of setbacks and failures. Improving on model fit and on other issues related to the predictive ability of the two factors toward the outcomes, Duckworth and Quinn (2009) proposed and validated a more efficient measure of grit consisting of a shorter version of the original scale. The Short Grit Scale, or Grit-S, is an 8-item scale that has proved to possess better psychometric properties than the Grit-O (Xu *et al.*, 2020) and, therefore, it has been

used in several empirical studies on grit (e.g., Alan *et al.*, 2019; Wolters and Hussain, 2015, Muenks *et al.*, 2017, Hwang *et al.*, 2018). Sulla *et al.* (2018) validated the Italian version of the Grit-S scale in a sample of 127 students attending public universities, reporting that the instrument has good psychometric properties. We adopt the Short Grit Scale (Grit-S) to measure measure grit. Our outcome variable is the mean score over the eight items; we denote it with $Y_iG, \forall i = 1, \dots, N$.

Causal Analysis and Results

RCTs are gold standards for assessing the impact of a treatment. Randomization ensures treatment and control groups are balanced in terms of pre-treatment covariates, which makes their outcomes comparison straightforward. However, in our case study, a post-randomization complication arises, given the possibility for students of classes assigned to treatment to decide whether to enroll in the FabLab activities. This complication is known as *noncompliance*. In particular, there is *one-sided* noncompliance, meaning that students belonging to the control arm have no possibility of being treated. Noncompliance, like any other post-treatment complication, breaks the initial randomization since it is self-selected. In RTCs that feature noncompliance, the Intention-To-Treat (ITT) analysis is a standard procedure. This method neglects the observed compliance data and instead focuses on comparing the outcomes of units that were assigned to the treatment group versus those assigned to the control group, providing a valid causal estimate of the treatment assignment rather than the treatment itself. The ITT analysis is a powerful tool of policy, since it can inform about the effect of *offering the treatment*, therefore in our case we can assess the impact of offering to students the possibility to enroll in FabLab activities.

The ITT estimand is a contrast between the potential outcome under treatment and the potential outcome under control:

(1)

with Y_{ji}^* generic outcome.

In a clustered RCT, we can estimate the above estimand via regression with clustered standard errors, without additional covariates:

(2)

where α is the intercept, ϵ_i is the error term and the estimator β provides the estimates of the ITT effect.

We estimate the effect on the three outcomes, in percentage change (or log-differences) with respect to the baseline levels, for males and females. By using such transformation, we allow for a non-linear impact of the treatment assignment on the outcome, as we are assuming a multiplicative effect instead of a simple additive effect. As the outcome is expressed in percentage change, to obtain the *return* of the treatment assignment on the outcome variable in levels, it is necessary to transform the coefficient as follows:

The findings of the analysis are summarised in Table 1. For grit, the ITT effect is significant at $\alpha = 0.05$ for both males and females. For males, the ITT effect is equal to $\exp(0.028) - 1 = 2.8\%$, i.e., on average, being assigned to FabLab activities or not increased grit among males by 2.8% from their baseline level. We find a larger effect on female students, namely about 3.9% increase.

As for creativity, the effect on the perceived creativity measured through self-assessment of the students is not significant (although it shows a positive sign). Instead, by measuring creativity through an expert assessment, we find a significant effect ($\alpha = 0.05$) of 44.96% for all students. In particular, this effect is driven by female students with an estimated significant effect ($\alpha = 0.1$) of 86% for females. This means that for females, the possibility to enroll in FabLab

activities had a significant impact on creativity, and in particular on divergent thinking. It is interesting to note that, while females do not perceive themselves as more creative (as shown by the lack of significant effect on the self-assessed creativity), when valued by an expert they indeed prove to have increased their creativity.

	y^G	y^{PC}	y^{EC}
All	0.031** (0.014)	0.008 (0.022)	0.371** (0.158)
Males	0.028** (0.013)	0.010 (0.022)	0.220 (0.163)
Females	0.038** (0.019)	0.006 (0.046)	0.621* (0.340)

Note: * $p < 0.1$; ** $p < 0.05$; *** $p < 0.01$
In this table, y denotes the log-difference transformation of the outcomes, i.e., $y^ = \log(Y^*_{t1}) - \log(Y^*_{t0})$*

Table 1 – Estimates of the ITT effect on grit, perceived creativity, and expert-assessed creativity, by sex.

Overall, these results are highly encouraging because they show that both creativity and grit can be effectively taught and learned by high-school students through practical classes and a learning-by-doing approach. It is crucial to remind that the ITT approach provides a valid causal estimate of the treatment assignment (that is, the effect to be offered the opportunity to join FabLab activities) rather than the treatment itself (that is, the actual participation to the activity). Therefore the results are diluted estimates of the treatment causal effects, as less than half of the students actually enrolled to the activities after being given the opportunity to do so. Therefore, additional research focusing on the treatment receipt is warranted.

Angrist *et al.* (1996) proposed an Instrumental Variable (IV) approach to noncompliance, based on potential outcomes (Rubin, 1974), that aims at estimating the treatment effect for the subgroup of *compliers*, i.e., those units who comply with the treatment assigned. The original nonparametric estimator proposed by Angrist *et al.* (1996) is identical to the Two-Stages-Least-Squares (2SLS) one (Wooldridge, 2002; Imbens, 2014) in the absence of covariates. In an extended version of this paper, we will evaluate the effect of attending FabLab activities via 2SLS with clustered standard errors on our outcomes of interest.

Conclusion

In this study, we challenge the idea that creativity and grit cannot be learnt and show that creative pedagogy activities, such as those offered by FabLabs, are powerful tools to enhance these non-cognitive skills. We do so through a randomized controlled trial (RCT) involving 829 students from five cities in Italy, among which 500 are given the possibility to sign up to FabLab activities. To address the noncompliance problem, we use a 2SLS model with and without covariates.

We measure creativity in two modalities. First, we use a self-assessment tool to capture perceived creativity. To offer a nuanced analysis on creativity, we also create an index of creativity through expert assessment. We do so by administering four open-ended questions (two at the baseline and two at the endline) and systematically assessing the answers provided by the students based on four components of divergent thinking: fluency, flexibility, originality, and elaboration. Each answer is assigned a score from 0 to 16 by an expert. To measure grit, we use the short Grit Scale, widely used in the literature.

While the self-assessed creativity does not seem affected by the participation to the activities, we find that creativity,

as assessed through our expert analysis, increases for the group of students who had the opportunity to join the FabLab activities. This effect is driven by female students. Grit, on the other hand, comes up consistently as being positively impacted by the exposure to the activities. The positive effect on the entire group of students that were offered the opportunity to join the activities is probably diluted and lower than the effect on the students who actually followed the activities and that will be assessed in a longer version of this paper. Nevertheless, the positive impact on the overall number of students provides encouraging evidence on the effect of offering to students the opportunity to join FabLab activities in their extra-curricular time. The positive effect on the overall group could also be connected to positive spill-overs between students during their curricular activities, offering a recommendation for policy-makers interested in stimulating non-cognitive skills among high-school students.

Given that, to our knowledge, this is among the first RCTs assessing the impact of creative pedagogy activities on creativity and grit for high school students, we consider that the encouraging results of this study should be further investigated with a larger sample of students.

Acknowledgements

We thank Fondazione Edulife and Fondazione Cariverona for making this analysis possible. The activities of FabLabs analyzed in this study have been designed and managed by Fondazione Edulife as part of the Fabschool project funded by Fondazione Cariverona. We also want to thank all the schools that accepted to join the study and all the FabLabs and organizations that made the study possible with their activities, namely 311 Verona, Consorzio CATA, Cooperativa Samarcanda, FabLab Dolomiti, FabLab Mantova, FabLab Verona, FabLab Western Sicily, MegaHub, Polo9, Rinoteca, and Talent. We are grateful to Beatrice Rapaccini who enabled us to create the index on expert-assessed creativity with her expert evaluations of the students' replies to the questionnaire. Finally, we would also like to thank the participants of the 17th edition of the Fab Lab International Conference and Fab City Summit (Fab17) and of the 6th edition of the workshop Experimental research on social inequalities for their valuable comments.

References

- Aguilera, D, and J Ortiz-Revilla (2021) Stem vs. steam education and student creativity: A systematic literature review. *Education Sciences* 11(7), 331.
- Alan, S, Boneva, T, and S Ertac (2019), Ever failed, try again, succeed better: Results from a randomized educational intervention on grit. *The Quarterly Journal of Economics* 134(3), 1121–1162.
- Alan, S, and S Ertac (2019) Mitigating the gender gap in the willingness to compete: Evidence from a randomized field experiment. *Journal of the European Economic Association* 17(4), 1147–1185.
- Alfonso-Benlliure, V, Melendez, JC, and M Garcia-Ballesteros (2013) Evaluation of a creativity intervention program for preschoolers. *Thinking Skills and Creativity* 10, 112–120.
- Amabile, T and M Pratt (2016) The dynamic componential model of creativity and innovation in organizations: Making progress, making meaning, *Research in Organizational Behavior*, Vol. 36, 157–183.
- Amabile, T (1983) The social psychology of creativity: A componential conceptualization”, *Journal of Personality and Social Psychology*, Vol. 45/2, 357–376..

- Angrist, JD, Imbens, GW, and DB Rubin (1996) Identification of causal effects using instrumental variables. *Journal of the American statistical Association* 91(434), 444–455.
- Berland M (2016) Making, tinkering, and computational literacy. In: *Makeology*. Routledge, p 196–205.
- Bevan B (2017) The promise and the promises of making in science education. *Studies in Science Education* 53(1):75–103.
- Bi, H, Mi, S, Lu, S, and X Hu (2020) Meta-analysis of interventions and their effectiveness in students' scientific creativity. *Thinking Skills and Creativity* 38.
- Cliatt, MJP, Shaw, JM, and JM Sherwood (1980) Effects of training on the divergent thinking abilities of kindergarten children. *Child Development* 51(4), 1061–1064.
- Cropley, AJ (1995) Creativity and cognition: Producing effective novelty. *Roeper Review* 18(4), 253–258.
- Cropley, AJ (2006): In Praise of Convergent Thinking, *Creativity Research Journal*, Vol. 18/3, 391–404.
- Dreyhaupt, J, Mayer, B, Keis, O, Ochsner, W, and R Mucbe (2017) Cluster-randomized" studies in educational research: principles and methodological aspects. *GMS journal for medical education* 34(2).
- Duckworth, AL, Kirby, TA, Tsukayama, E, Berstein, H, and KA Ericsson (2011), Deliberate practice spells success: Why grittier competitors triumph at the national spelling bee. *Social psychological and personality science* 2(2), 174–181.
- Duckworth, AL, Peterson, C, Matthews, MD, and DR Kelly (2007) Grit: perseverance and passion for long-term goals. *Journal of personality and social psychology* 92(6), 1087–1101.
- Duckworth, AL, and PD Quinn (2009) Development and validation of the short grit scale (grit-s). *Journal of personality assessment* 91(2), 166–174.
- Duckworth, AL, and DS Yeager (2015) Measurement matters: Assessing personal qualities other than cognitive ability for educational purposes. *Educational Researcher* 44(4), 237–251.
- Ferracane MF (2020) *Redesigning Organizations: Concepts for the Connected Society*, Springer, chap Redesigning traditional education.
- Gajda, A, Karwowski, M, and RA Beghetto (2017) Creativity and academic achievement: A meta-analysis. *Journal of educational psychology* 109(2), 269.
- Guilford, JP (1950) Creativity, *American Psychologist* (5), 444–454. .
- Guilford JP (1956) The structure of intellect. *Psychological Bulletin* 53(4):267.
- Guilford, JP (1967) *The nature of human intelligence*, McGraw-Hill.
- Hwang, MH, Lim, HJ, and HS Ha (2018) Effects of grit on the academic success of adult female students at korean open university. *Psychological reports* 121(4), 705–725.
- Imbens, G (2014) Instrumental variables: an econometrician's perspective. Technical report, National Bureau of Economic Research.
- Kafai Y, Fields D, and K Searle (2014) Electronic textiles as disruptive designs: Supporting and challenging maker activities in schools. *Harvard Educational Review* 84(4):532–556.
- Karwowski, M (2012) Did curiosity kill the cat? relationship between trait curiosity, creative self-efficacy and creative personal identity. *Europe's Journal of Psychology* 8(4), 547–558.

- Lucas, B, Claxton, G, and E Spencer (2013) Progression in Student Creativity in School: First steps towards new forms of formative assessments, OECD Education Working Papers No. 85., OECD Publishing, Paris.
- Lucas, B (2016) A Five-Dimensional Model of Creativity and its Assessment in Schools, *Applied Measurement in Education*, Vol 29/4, 278-290.
- Maddi, SR, Matthews, MD, Kelly, DR, Villarreal, B, and M White (2012) The role of hardiness and grit in predicting performance and retention of usma cadets. *Military psychology* 24(1), 19-28.
- Muenks, K, Wigfield, A, Yang, JS, and CR O'Neal (2017) How true is grit? assessing its relations to high school and college students' personality characteristics, self-regulation, engagement, and achievement. *Journal of Educational Psychology* 109(5), 599.
- OECD (2021a) Beyond Academic Learning: First Results from the Survey of Social and Emotional Skills. OECD Publishing, Paris.
- OECD (2021b) PISA 2021 Creative Thinking Framework (Third Draft). OECD Publishing, Paris.
- OECD (2022) Thinking Outside the Box: The PISA 2022 Creative Thinking assessment, OECD Publishing, Paris.
- Olken, H (1964), Creativity Training for Engineers Its Past, Present, and Future, in *IEEE Transactions on Education*, vol. E-7, No. 4, pp. 149-161.
- Plucker, J, Beghetto, R, and G Dow (2004) Why isn't creativity more important to educational psychologist? Potentials, pitfalls, and future directions in creativity research", *Educational Psychologist*, Vol. 39/2, 83-96.
- Regalla L (2016) Developing a maker mindset. In: *Makeology*. Routledge, p 257-272.
- Resnick M (2017) *Lifelong kindergarten: Cultivating creativity through projects, passion, peers, and play*. MIT press.
- Rubenson, DL, and MA Runco (1992) The psychoeconomic approach to creativity. *New ideas in Psychology* 10(2), 131-147.
- Rubin, DB (1974) Estimating causal effects of treatments in randomized and nonrandomized studies. *Journal of educational Psychology* 66(5), 688.
- Runco, MA, Millar, G, Acar, S, and B Cramond (2010) Torrance tests of creative thinking as predictors of personal and public achievement: A fifty-year follow-up. *Creativity Research Journal* 22(4), 361-368.
- Runco, MA (2004) Creativity. *Annual Review of Psychology* 55(1), 657-687.
- Segundo Marcos, RI, Lopez Fernandez, V, Daza Gonzalez, MT, and J Phillips-Silver (2020) Promoting children's creative thinking through reading and writing in a cooperative learning classroom. *Thinking Skills and Creativity* 36, 100663.
- Sternberg, RJ, and TI Lubart (1991) An investment theory of creativity and its development, *Human Development*, Vol. 34/1, 1-31.
- Sternberg, RJ, and TI Lubart (1992) Buy low and sell high: An investment approach to creativity. *Educational researcher* 21(4), 13-16,
- Sternberg, RJ, and TI Lubart (1995) *Defying The Crowd: Cultivating Creativity In A Culture Of Conformity*, Free Press, New York, NY, <http://psycnet.apa.org/record/1995-97404-000> (accessed on 7 May 2023).
- Sternberg, R (2006) The nature of creativity, *Creativity Research Journal*, Vol. 18/1, 87- 98.
- Sulla, F, Renati, R, Bonfiglio, S, and D Rollo (2018) Italian students and the grit-s: A selfreport questionnaire for measuring

perseverance and passion for long-term goals. In: 2018 IEEE International Symposium on Medical Measurements and Applications (MeMeA), 1–5 (2018). IEEE.

Sweller, J, Kirschner, PA, and RE Clark (2007) Why minimally guided teaching techniques do not work: A reply to commentaries. *Educational psychologist* 42(2), 115–121.

Torrance, EP (1962) Fostering creative thinking during the high school years. *The High School Journal* 45(7), 281–288.

Valgeirsdottir, D, and B Onarheim (2017) Studying creativity training programs: A methodological analysis. *Creativity and Innovation Management* 26(4), 430–439.

Van Zyl, LE, Olckers, C, and L Vaart (2021) *Multidisciplinary Perspectives on Grit: Contemporary Theories, Assessments, Applications and Critiques*. Springer, Pretoria, South Africa.

Vincent-Lancrin S, Gonzalez-Sancho C, Bouckaert M, De Luca F, Fernandez-Barrera M, Jacotin G, Urgel J, and Q Vidal (2019) *Fostering Students' Creativity and Critical Thinking: What It Means in School*. Educational Research and Innovation. OECD Publishing, Paris.

Wolters, CA, and M Hussain (2015) Investigating grit and its relations with college students' self-regulated learning and academic achievement. *Metacognition and Learning* 10(3), 293–311.

Wooldridge, JM (2002) *Econometric analysis of cross section and panel data* mit press. Cambridge, ma 108(2), 245–254.

Xu, KM, Meijs, C, Gijsselaers, HJ, Neroni, J, and RH Groot (2020) Measuring perseverance and passion in distance education students: psychometric properties of the grit questionnaire and associations with academic performance. *Frontiers in Psychology* 11.

Fostering Maker Identity and Collaboration

Affordances of the Connected Spaces Dashboard in Two Afterschool Makerspaces

Ashita Bawankule, University of Illinois Urbana Champaign, anb8@illinois.edu

David Hopping, University of Illinois Urbana Champaign, davidah3@illinois.edu

Mike Tissenbaum, University of Illinois Urbana Champaign, miketissenbaum@gmail.com

Howard Weatherspoon, University of Illinois Urbana Champaign, hbw2@illinois.edu

Margie Ruffin, University of Illinois Urbana Champaign, mruffin2@illinois.edu

Abstract

With a focus on learning through personally relevant projects, students in makerspaces engage in meaningful design. Maker portfolios are increasingly being used to capture and assess progress and learning in these spaces. The Connected Spaces Dashboard focuses on maker identity development and collaboration between makers in and across makerspaces. We implemented a prototype version of the Dashboard in Spring 2023, in two after-school makerspaces. Analysis of two student interviews and Dashboard profiles highlighted the aspects of the tool that were effective (e.g., student affinities) and those that needed improvement (e.g., its ambient presence). We utilize these findings to inform the development of the next version of the Dashboard.

Background

Makerspaces are being recognized as a means for increasing equity in computing, by empowering students with the choice of how they want to engage in computing. In contrast to purely workforce goals, makerspaces are giving students the opportunity to explore alternative endpoints in computing that are relevant to themselves and their communities [1].

A common tool to express and assess student learning in these spaces are maker portfolios. Chan & Holbert (2020) approach online maker portfolios as a way to assess student maker journeys, with students focusing their portfolios on the progress of their projects [2]. As in [3] iterative maker portfolios focus on computational communication and reflection. In many such maker portfolios, the focus is often on the progress of the maker activities and projects.

For students who have previously been marginalized in the field of computing, seeing themselves as makers in these spaces and developing various parts of their maker identities is crucial for their computational empowerment. Further, in order for them to develop maker identities, it is essential that the makerspace reflects and builds on their previous experiences, interests and identities [1, 4]. Developing student identity can constitute various factors like competence, confidence, and interest development, as well as allowing recognition of the students as makers [5]. As highlighted by [6], maker portfolios are also being used as collaborative community building tools, to grow the definition of a maker community beyond the physical makerspace.

Makerspaces are emerging not only in formal spaces like schools and universities, but also in informal spaces like after-school programs and summer camps. Given that engagement and participation in these informal environments varies in frequency and consistency, fostering communities of practice in them has been a unique challenge for researchers [7].

According to [8], communities of practice are people who share knowledge and experiences by working in a common domain and engaging with its community. Students do not engage with each other on a daily manner like in school, requiring more external scaffolding and tools to create ongoing social interaction of a community of practice.

The Connected Spaces Dashboard design focuses on the development of student maker identity, with the intention of allowing students to express and develop their competence and interest in making. Further, the intention of the Dashboard as an ambient display in the makerspace is to foster a community of practice by connecting makers within a space, as well as across physical spaces with each other, in a persistent manner. Makers will be able to view other students' portfolios, recognizing each other as makers and finding opportunities for collaboration while developing maker identities and communities.

Methods

Design of the makerspace activities

From February to May, we conducted weekly after-school makerspace sessions in partnership with two local community organizations, one all-girls and one all-boys, primarily consisting of African American students. Both organizations created dedicated spaces for these maker activities, which were designed and conducted in a similar manner. For the first four weeks, students followed instruction-based activities to understand specific physical computing elements for Circuit Playground Express (CPX), including on-board and external input and output components like lights and sensors. For the next two weeks, they worked with brainstorming tools to plan their final project. They then transitioned into building their own personal projects for the remaining six weeks. Within the first couple sessions, the students were introduced to the Dashboard as a profile to update at the beginning of each session. At subsequent sessions, students were prompted to update their profiles in a variety of ways (including addition of interests or affinities that had changed, or that reflected the projects they were working on).

Design of the Dashboard

The Connected Spaces Dashboard is a digital tool that allows students to create personal maker profiles that are displayed to everyone across physically distant but digitally connected makerspaces. Broadly, it is a system designed to do two things: 1) promote collaboration amongst students in and across spaces; and 2) allow students to develop and represent their maker identities through displaying their affinities and maker projects.

We developed two prototypes: the first was built in Miro, the second in Google Slides. Our initial prototype was utilized in a college level class and gave us some general insights about usability and what users would be willing to do with limited functionality. Considering feedback from this initial prototype, we developed our second prototype in Google Slides to allow for increased personalization, to help users better express their identities. Given that the primary users of the prototype were going to be middle-school students, Google Slides was an accessible and familiar platform for them. This platform also allowed for the most flexibility as well as ability to personalize by changing colors, adding images from the internet etc. It also allowed for a wide "all slides" view that could act as an ambient display (see Figure 1), and students could change colors and fonts, and easily copy and paste images or GIFs from the internet to customize their personal slide.

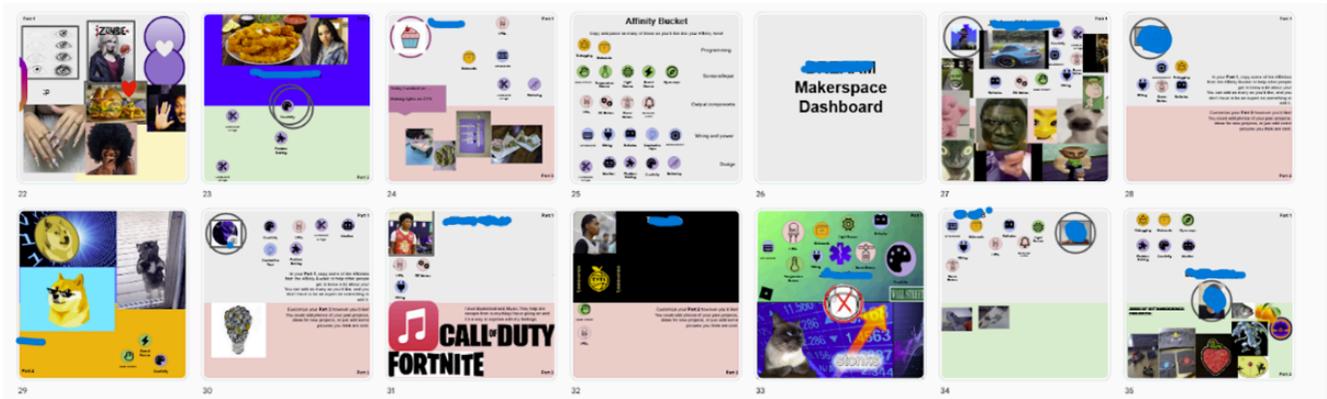


Figure 1: Ambient display view of the Dashboard (partial)

As suggested by Kumar & Tissenbaum [2022], we used affinities instead of expertise, for students to identify with various skills regardless of whether they were competent in them, allowing for dynamic, interest-based modification of maker identities [9]. Affinities would also form the basis of collaboration between students with similar or contrasting interests and skills.

Students made weekly updates to their individual profile (Google Slide). We had separate sections in the same deck for the two makerspaces, example profiles of the researchers (see Figure 2 (left)), templates for students to model their own Dashboard profile after, and the Affinity Bucket (see Figure 2 (right)) – a slide from which students could copy a range of affinity icons to their own profile. The slide templates had prompts for the students e.g.: an area for their name and profile picture, a section for affinities, and one for personal interest and maker activity representation.

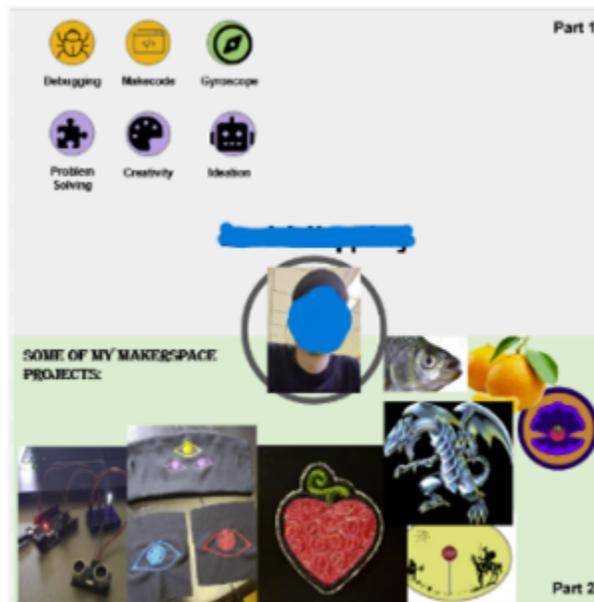




Figure 2: Researcher’s example Dashboard profile (top) and Affinity Bucket (bottom)

Participants

Our participants were drawn from the middle-school students who participated in the afterschool makerspaces. Of the 18 students at the girls-makerspace, about nine were consistently present for most weeks. For this paper, we interviewed and analyzed Jiya’s Dashboard, as she had attended most of the sessions and had worked on the Dashboard consistently. She was an eager student who had previous interests in coding, STEM, and building. For her final project, Jiya was passionate about building a flying car. At the boys-makerspace there were nine students who created Dashboard profiles, and only three attended consistently enough to modify their profiles in meaningful ways. For this paper, we interviewed and analyzed Oscar’s Dashboard since he attended most of the later sessions, where he started designing his project and engaged with various aspects of the Dashboard. For his final project, he decided to create a moving robot assistant with an LED face. We also looked at the weekly Dashboard progress of three other students from each makerspace, who engaged with the Dashboard in some consistent manner.

Data Collection and Analysis

For this paper, we devised a coding scheme to quantify changes in students’ Dashboards on a week-to-week basis, to identify potentially interesting trends. We tracked changes in their dashboards across five factors: self-identification, pertaining to students’ names and profile pictures; their self-expression, pertaining to the images and descriptions students added to their profiles; statement of affinities, pertaining to the affinities that students copied onto their pages; description of maker activities, pertaining to images or descriptions relevant to the material in the camps; and interaction with other makers, pertaining to elements changed or added due to interaction with their peers. Researchers then coded the four students from each makerspace and ameliorated any disagreements in the coding through iterative discussions. The eight students were chosen to represent varying levels and types of engagement with the Dashboard

– some more consistent than others – such that we might also observe some contrasting trends. The researchers then examined the codes to reveal trends across each factor for each student.

Using a grounded theory approach [10], we conducted a brief qualitative analysis of the semi-structured, one-on-one audio interviews with Jiya from the girls-makerspace and Oscar from the boys-makerspace to reveal four emergent themes of their Dashboard experiences. These themes arose based on observations about students' usage patterns, the most common elements added to the Dashboard profiles, and our original design intentions generated from our initial Miro prototypes.

Findings

Qualitatively analyzing interview transcripts, students' iterative changes to their Dashboards, as well as the design decisions of the Dashboard, we drew out four aspects of the Dashboard design and utilization that Jiya and Oscar indicated in their interviews as impactful. Figure 3 shows Jiya and Oscar's Week 10 (the last week we analyzed their edits) Dashboard slides. Observing changes in Dashboard elements of eight students also contributed to these findings.

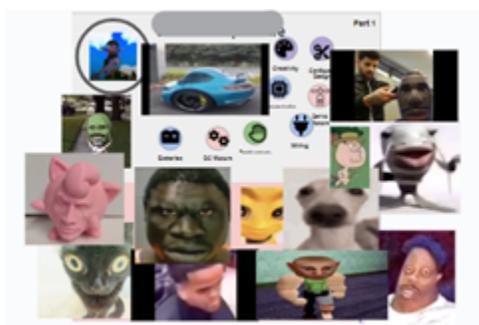


Figure 3: Jiya's Week 10 Dashboard (top) and Oscar's Week 10 Dashboard (bottom)

Use of affinities

Affinities were introduced to the students for them to represent the maker activities, tools, and skills they were interested in using. Observing the eight students' affinities over the course of the weeks, we see that most of them were comfortable adding more affinities as they updated their Dashboard slides. For instance, a student updated

their affinities five times over a nine-week period. They initially started with an affinity for “creativity” and eventually added technical affinities (e.g., LEDs, sensors) over time. Some affinities seemed to be more common than others, e.g.: creativity and LEDs.

Jiya has various affinities on her Week 9 Dashboard, all of which she indicated she had an interest in. “[she added] creativity [...] because [she] has a great imagination. The robot because [she] wants to make robots ... and the wire... [she] likes using wires and electricity and stuff that has to do with plugging. For the tape one... [she] likes using that kind of stuff”. However, she also mentions that the Dashboard doesn’t really change how she sees herself as a maker.

Oscar’s interview revealed that he added affinities for several different reasons. First, he added affinities based on the few skills he was comfortable with, then, as the program progressed, he added more that he was becoming more familiar with. “...as time went on [he] added more and more, because those new things became [his] new favorites.” He also expressed that he would continue pursuing the new skills he added as affinities going into the future.

Identity expression

A unique feature of our current Dashboard is that we encouraged students to personalize their slides as much as they wanted. From Week 1 they were encouraged to add images and text that helped reflect who they were as people and what their interests were. As indicated by [4], building on students’ previous experiences and interests allows for more effective and relevant engagement, while also allowing them to make connections between their learning and current identities. Students in both makerspaces used their Dashboards to express their identities, with food items, memes, fashion, celebrities, sports, and games. Most students did not change their identity expression on the Dashboard slides too much, occasionally adding a couple images or text when prompted. The data from the coding scheme reflected this trend as well. We saw that six of the eight students evaluated did not change “self-identification” more than once, i.e., once a profile picture and name was added it remained the same for the rest of the weeks. Seven out of eight students made changes to the “self-expression” portion of the Dashboard three times or less during the nine-week evaluation period.

Jiya changed the background colors of her slide to begin with, and then started to add images of flying cars as something she was passionate about making. After a couple weeks, she added running and chemistry as things she enjoyed. Additionally, she added text about all the girls being Black African Americans and middle-schoolers. This was contrasting to other girls in the space, who started by adding hobbies and then transitioned into adding maker project-oriented pictures. Over the weeks, she added additional photos of flying cars, each displaying features she wanted to incorporate... She also added a picture of bars of gold because she “want[ed] to make a lot of money off [her cars].”

Oscar made the most changes Dashboard edits out of any of the students at his makerspace. Each week, he covered his profile in an entirely different set of memes: “I don’t think there is a single meme that I’ve kept going...” He expressed that rather than putting in the amount of work to add all the memes to his profile to show to the other students in the camp, he did it “Mostly for [himself], but if others wanted to look at it then... maybe they’d get a laugh out of it.” As his profile changed to include more affinities, he noted that he’d “put more actual skills and stuff that [he] liked on there, it’s still pretty bombarded with memes and stuff but it’s just what [he] likes.”

Ambient presence of Dashboard

One intended feature of the Dashboard is an ambient presence to be displayed at the front of the makerspace where students can view others’ profiles as well as their own. This aspect provides legitimacy to students’ maker identities and

acts as a launchpad for spontaneous collaboration between makers with similar affinities. In both our spaces, due to technical challenges, the Dashboard was not put up as an ambient display until about Week 6. Even after being brought to the students' attention, the Dashboard as an ambient display did not make an impact on the students and their participation in the space. Towards the last few weeks, students started noticing the Dashboard as they entered the space, but soon forgot about it as they started engaging in maker activities. Jiya even goes on to say that she did not even notice the presence of the Dashboard or that it was being displayed in the space, and Oscar noted that after we added the flat-screen TV to the makerspace (where the Dashboard was displayed), it didn't particularly change anything for him. Also, he expressed that even though he knew people could see his Dashboard, he wasn't intentionally creating it for them to see.

Affordances of the Dashboard

Various parts of the Dashboard and its implementation were designed intentionally as indicated in the Methods. Students were given time to update their Dashboard at the beginning of each class, due to the inconsistency in exit times, but were encouraged to keep updating them as they felt necessary.

Jiya indicated that the Dashboard was difficult to use, because “[she] put down pictures and it [was] hard to write about things [she hadn't] really made yet.” She said it would have been easier to do it at the end of each day “because then [she] would have been able to write down all the stuff [she] recently made.” In general, Jiya also talks about how she was not one who enjoyed planning, and wanted to immediately jump into making, so doing the Dashboard added resistance to her work. She liked working on the Google slides, stating that uploading progress photos instead of images from the internet would have been a better way to display her maker skills.

At Oscar's makerspace, the students used personal Chromebooks that created technical challenges when used to access Google Slides. Sessions at this makerspace were less consistent as not all students attended each session each week, and for the first few sessions, we didn't have the infrastructure to facilitate students' use of the Dashboard. Later in the semester, we obtained access to a wide-screen TV to display the Dashboard, and students were notified that they should bring their personal Chromebooks to access the prototype. Oscar expressed some concerns about the use of the Dashboard, indicating that he wasn't sure what he was supposed to do at first. He also expressed that in a future version, it would be nice to add the affinities from a drop-down menu, rather than having to scroll past everyone else's Dashboards to copy them and then scrolling all the way back down. He also added that if he had been using the Dashboard on his personal computer, he would have been able to add some of his art projects and previous work to his profile, which would have helped him express himself more.

Discussion

Implementing the Google Slides version of the Dashboard in two different afterschool makerspaces allowed us to understand some of the design decisions that were beneficial (e.g.: affinities and customization), as well as some of the challenges that need to be addressed in future versions (e.g.: ability to add pictures and scaffolding interaction with the ambient display). We are developing a third version of the Dashboard in the Unity Engine WebGL, while keeping in mind our findings.

Overall, the students enjoyed being able to express themselves on the Dashboard. The initial weeks of using the Dashboard to express their identities as well as affinities allowed them to familiarize themselves with the platform. Allowing for this self-expression in the makerspace enables development of maker identity for the students, allowing

them to integrate making with their previous interests. Many of the students customized their slides, creating agency in the space. Students engaged with affinities in a manner that showed not only their ability, but also their interest in maker activities, allowing for development of confidence, competence as well as recognition of self as a maker. Some affinities were interpreted differently than intended by the students, which we could clarify with our next version.

Few students made updates about their projects on the Dashboard, despite expressing that they would have liked to do so. Allowing for the ease of capturing and uploading media might allow students to make quicker and more regular updates, with less resistance. Furthermore, prompting the students to update their profiles towards the end of the day might allow them to document their progress more effectively.

A significant aspect of the Connected Spaces Dashboard is its ambient display, which is designed to spark collaboration and create community in and between makerspaces. In both our makerspaces, the Dashboard was put up in the space, starting only in Week 6. By this time, the cultural norms in the makerspaces had already been set up, and collaboration and mentorship were not natural to the space. In order for the ambient presence to be utilized by the students, in our next implementation, it will be present and centered in the space from the beginning, with students being encouraged to collaborate on learning and exploring it. Further, our makerspaces were conducted during different times in the week. Allowing for concurrent implementation can allow students to see real-time updates in the distant makerspaces, allowing for cross-space collaboration as well.

Conclusion

A key aspect of equitable makerspaces is their focus on project-based learning that can foster identity development and community building within and across these spaces [4, 6]. Students use the Connected Spaces Dashboard to express their identities and affinities, hence evolving in their maker identities. Display of maker learning, and identities can spark collaboration and recognition of makers in the space. However, judging from our findings, in order for tools like the Dashboard to be contribute towards creating a community of practice [8] in informal makerspaces, they need to be embedded in the culture of the space from the beginning. Student engagement with the Dashboard needs to be scaffolded, not only in creating profiles, but also in viewing other profiles and asking for and providing help to peers in and across spaces. Students need to be made aware of the tool and its purpose, allowing them to use it in a manner most impactful to them. For this to further be effective, tools like the Dashboard should have low resistance in making updates about user progress and become a part of their making process and culture. Using these tools, students in makerspaces can begin to express their maker identities, while becoming a part of a community of practice through collaboration and recognition of other makers in and across makerspaces.

References

1. Mike Tissenbaum, David Weintrop, Nathan Holbert and Tamara Clegg. 2021. The case for alternative endpoints in computing education. *British Journal of Educational Technology* 52, 3 (May 2021), 1164-1177.
2. Monica M. Chan and Nathan Holbert 2020. Insights on online mobile maker portfolios for process documentation in K-5 constructionist learning environments. *Constructionism* 2020, 365-373.
3. Debora Lui, Deborah Fields and Yasmin Kafai. 2019. Student maker portfolios: Promoting computational communication and reflection in crafting e-textiles. In *Proceedings of FabLearn 2019*. March, 2019, New York, NY, 10-17. <https://doi.org/10.1145/3311890.3311892>
4. Nicole Pinkard, Sheena Erete, Caitlin K. Martin and Maxine & McKinney de Royston. 2017. Digital youth divas: Exploring narrative-driven curriculum to spark middle school girls' interest in computational activities. *Journal of*

- the Learning Sciences* 26, 3 (Aug. 2017), 477-516.
5. Ashita Bawankule and Mike Tissenbaum. 2023. Maker identity: What and how? *International Society of the Learning Sciences* (Jun. 2023).
 6. Anna Keune and Kylie Pepler. 2017. Maker portfolios as learning and community building tools inside and outside makerspaces. *Computer-Supported Collaborative Learning Conference 2* (Jun. 2017), 545-548.
 7. Kimberly Sheridan, Erica R. Halverson, Breanne Litts, Lisa Brahms, Lynette Jacobs-Priebe and Trevor Owens. 2014. Learning in the making: A comparative case study of three makerspaces. *Harvard Educational Review* 84, 4 (Dec. 2014), 505-531.
 8. Jean Lave and Etienne Wenger. 1991. *Situated learning: Legitimate peripheral participation*. Cambridge University Press.
 9. Vishesh Kumar and Mike Tissenbaum. 2022. Supporting collaborative classroom networks through technology: An actor network theory approach to understanding social behaviours and design. *British Journal of Educational Technology* 53 (Sept. 2022), 1549-1570. <https://doi.org/10.1111/bjet.13274>
 10. Juliet M. Corbin and Anselm L. Strauss. 2008. *Basics of qualitative research: techniques and procedures for developing grounded theory* (3rd ed.). Sage Publications.

Constructionist Measurement

Using Making to Understand Multifaceted Identity Demonstrating the use of craft materials for quantifiable self-expression

David F. Feldon, Utah State University, david.feldon@usu.edu

Colby Tofel-Grehl, Utah State University, colby.tg@usu.edu

Abstract

Authentic measurement within constructionist frameworks can be challenging. While the constructionist ethos encourages makers and learners to engage knowledge in hands on ways, often within research settings we ultimately default to the use of surveys to quantify the findings of our work. We propose a new instrument for measuring constructionist identity development that is rooted in psychometric measurement theory while also being constructionist in nature. Youth engage in phenomenographic discussions of their identities and these group developed definitions are categorized and assigned colored beads. As youth proceed through their group time in class, they select various beads and string them on their bracelet, developing a temporally meaningful, locally contextualized identity measure. This paper shares the processes and procedures for engaging youth in authentic constructionist-based identity measurement.

Multiple Dimensions Of Identity

It is essential to understand the dynamics of underlying identity beliefs that limit STEM engagement. Because members of specific groups disproportionately feel that their sociodemographic identities are incompatible with pro-STEM identities—in many cases, despite STEM interest and achievement [1]—it is essential to foster discourse where identities are not constructed into unidimensional, either-or dichotomies (e.g., one can either present a feminine identity or a STEM identity, but not both). Across gender, race, ethnicity, and sexual orientation and at the intersections of these identity categories, the “implicit and explicit messages about the masculine nature of math and science” [2, p.12] remain problematic. Thus, in spite of an obvious participation gap in STEM fields, research suggests that more important is a STEM identity gap, whereby women and underrepresented minorities struggle to connect their gendered, sexual, racial, and ethnic identities to STEM identities [3-5].

Individuals construct and articulate their identities as multifaceted constructs that reflect complex representations of personal traits and self-characterizations [6, 7] used to establish the relationships and boundaries between themselves and others [8]. Further, identities facilitate individuals’ abilities to (1) lay claim to traits and values that they feel distinguish them from others and (2) signal social belonging with other individuals and groups for which they feel affinity on the basis of any number of perceived traits [9-11]. As a result, aspects of a complex identity may be broadcast or diminished in response to which facets seem most salient or advantageous in a given situation [12, 13]. For example, in a given situation, an individual may choose to emphasize their identity as an athlete and deemphasize their identity as a student. Alternatively, specific aspects of identity may be highlighted within a social situation, despite an individual’s perception of its irrelevance or desire to deemphasize it (e.g., gender or race shaping an interaction that an individual approached with the intent of engaging a personal interest or activity-based identity).

Within STEM education research, several strategies have emerged to engage multiple facets of identity. One, intersectionality, frames individuals' experiences not solely through a single aspect of identity (e.g., sexuality or gender or race) but through joint identities that yield perspectives distinct from others with whom there is shared identity in only one aspect (e.g., the experience of being a racial minority woman in STEM is fundamentally distinct from the experience of being a racial minority man or a racial majority woman in STEM [14]). Another approach to studying multiple facets of identity is to examine beliefs associated with identity facets that may exist in opposition to each other (e.g., gender vs. science [15]). A third approach is that of complexes, in which identities are conjunctive (e.g., STEM + artistic + athletic [16]).

Making as a Context Conducive to Multidimensional Identity Expression

One context that may facilitate such conjunctive identity expression or development is Maker camps and classes [17]. Numerous studies highlight how the tools and materials used in Making activities, the processes of Making, and the products of Making can support a multiplicity of STEM identities while providing space for creativity and personal expression [18-20]. Making frequently integrates low-tech materials not commonly associated with STEM, such as recyclable and basic craft materials. The familiarity of these materials can provide an initial point of entry into STEM activities, especially for individuals who already craft or have family members who craft [21]. Further, the emphasis on the process of Making provides two important points of connection for non-dominant individuals. First, Making takes time, which opens up space for relationship building [22]. Second, failure is a normal and expected part of the process, which builds confidence and participation rather than weeding out less successful individuals [23-26]. Finally, Making activities typically result in products that can be shared with others and serve as markers of STEM identity, allowing a vehicle for self-expression and also recognition by others of individuals' STEM prowess. For example, Tofel-Grehl and colleagues [27, 28] found that students previously disengaged from a science class not only expressed high levels of enthusiasm for Making with e-textiles during a circuitry unit, but also brought those projects home to share with their families. Subsequently, the reported significantly stronger perceptions of their families valuing STEM achievement and interest for them.

Purpose

Despite the growing recognition that identity is multifaceted and emergent, quantitative research instruments used to examine identity and identity shift have traditionally engaged only single identity facets in any depth (e.g., STEM [29]; gender [30]) and do not readily accommodate multiplicity or intersectionality. Most often the conclusions drawn about intersectionality rely on disaggregation of the focal identity facet by a single demographic indicator item, which precludes the ability to understand how multiple facets of identity might interact [31]. Further, free-response approaches to multiplicity can engage broader identity construction, but they can require many hours to complete (e.g., [32]), rendering them unhelpful for Making and other educational contexts where time is at a premium. Further, paper-and-pencil instruments may appear overly simplistic or inauthentic to participants engaged within a social context, resulting in low response or poor alignment with locally constructed meanings that shape individuals' identity beliefs.

Accordingly, the purpose of this study was to develop and validate a measure of multifaceted identity that could detect shifts in participants' respective identity complexes as they navigated rich STEM environments such as Makerspaces. In keeping with the personal, contextualized, and dynamic nature of identity construction, the measure needed to be capable of repeated use over the course of multiple days of engagement and rely on locally constructed meanings that would authentically represent identity categories as understood and embraced by the individuals within the localized context.

Methodology

Applying a Phenomenographic Framework

Miles and Huberman's [33] notion of "local causality" makes clear that the meaning given to social phenomena by participants—including identity—is essential to understanding. Typically, such meanings are captured solely in a qualitative fashion. However, relevant local meanings and sociocultural features can be represented effectively through either qualitative or quantitative symbols, as long as the nuances of meaning and experience are adequately considered in constructing categories [34, 35]. When the construction of quantitative measures does not reflect these nuances sufficiently, the products cannot serve as valid instruments. In such cases, inferences derived from them through statistical analyses are flawed, introducing systematic measurement error from the perspective of traditional quantitative research and a misrepresentation of causal mechanism from the perspective of traditional qualitative research [36]. Thus, even if an instrument is statistically reliable in terms of the internal consistency of the responses it garners, the resulting data may not accurately or adequately reflect the underlying structures or functions [37].

Two forms of validity discussed in reference to qualitative research are essential to understanding data collected for any study of socialization: Interpretive validity engages the question of whether or not the inferences drawn from the collected data adequately reflect the perspectives of the participants, and theoretical validity represents the extent to which a theoretical construct is applied appropriately in the interpretation of qualitative data [38]. However, recognizing the importance of local meaning (i.e., interpretive validity) in measurement presents a challenge in validating instruments. It cannot be taken for granted that an instrument valid in one context maintains its validity in another. While there are many aspects of identity that are assumed to be consistent from person to person and community to community, identity is frequently constructed differently across time by the same individuals [39] and in response to peer and community understandings [40].

To accommodate these challenges, we adopted a phenomenographic strategy for measurement development [34, 41, 42]. Initially developed as a wholly qualitative paradigm, phenomenography assumes that individuals' conceptions of their experiences can be understood both within personal and collective frames. Thus, constructed meanings are considered within the contexts of the individual's personal explanation, the structural nature of the social relationships relevant to the context, and the broader pool of meanings. Further, phenomenography posits that while there may be a very wide range of personal conceptions held across individuals, the range is not infinite [43]. The relationships that exist between individuals' conceptions and socializing structural influences drive predictable variation in individuals' conceptions based on systematic physical and social experiences [44]. Thus, as qualitative inquiry yields saturation (i.e., no new categories emerging from new data collection), the number of distinct conceptions identified can serve as the foundation of the range of responses offered for closed-ended survey items. The resulting instrument is then conducive to identifying trends generalizable to the natural population under the presumption that the distribution of conceptions encapsulating local meanings identified through qualitative analyses represents the natural range of responses generalizable to the whole population.

Further, it can be anticipated that a population (and a representative sample) will reflect a natural distribution of conceptions [43]. Therefore, new research can build from an a priori framework derived from previous studies, accepting well-established conception types within a reasonably similar context. In addition to providing indicators of frequency and magnitude for specific conceptions held by respondents, these instruments are also valuable in their ability to inform understanding of constellations and predictors of conceptions through statistical relationships. For example, examining the relationships amongst conceptions within their phenomenographic instrument's constructs, Trigwell & Prosser [45] identified a significant and unexpected correlation between conceptions that they had initially grouped differently based on their inductive qualitative analyses. As a result, they restructured the items to reflect a

different factor structure and enhance the ability of the survey to capture respondents' underlying conceptions, further improving the instrument's validity.

Procedure

The development process consisted of first determining the identity constructs of relevance to participants. While many Maker-focused programs deliberately target specific populations (e.g., indigenous peoples, girls) or intersectionalities (e.g., racial/ethnic minority girls), curtailing the multidimensional nature of identity can lead to disenfranchisement when youth feel they need to select amongst multiple affinities (e.g., only being seen as a member of a gender or cultural group absent other facets of identity important to the participant, such as a social or religious identity) [46-48].

Context

Eight participants in a Maker camp that specifically engaged youth who identified as LGBTQA+ were recruited to participate in this study. These individuals ranged from eleven to sixteen years of age, so both participant assent and parental consent were obtained prior to data collection. The camp took place one day each week for five consecutive weeks in a public library in a small rural city in the United States.

Data Collection

To preserve the personal and local meanings that imbue multidimensional identities, the first step in our phenomenographic approach was to facilitate group discussions amongst Maker camp participants regarding identity, with the goal of generating categories that were both meaningful to the group and articulated according to their own framing. To accomplish this, the first identity dimension discussed and presented as a worked example was STEM identity. Students were presented with various STEM-related identity labels appropriate to a Making activity (i.e., scientist, engineer, tinkerer, designer, crafter) and asked to discuss what meanings those held and if there are any missing that should be included. Through discussion, we elicited shared conceptions of these labels. The discussion facilitator then asked what other types of identity were important to the students. Emergent themes related to gender (i.e., female, male, transgender, non-binary), sexuality (i.e., heterosexual, homosexual, pansexual, asexual), and outside activities (i.e., gamer, nerd, artist, athlete). As each dimension of identity was articulated, discussed, and refined by the participants, they were asked to reach consensus on the categories under each dimension.

Based on the labels they devised, the categories under each dimension were each assigned to a different color of plastic bead. At the end of each weekly session, students were asked to draw one bead of their choosing from each dimension to represent their multidimensional identity. These beads then inherently provided a longitudinal record of their multidimensional identities and shifts across categories over the course of the camp. After each session, each student's bracelet was photographed and date-stamped to preserve the longitudinal record of identity stability and change

Data Analysis.

Consistent with other mixed methods applications of phenomenography to develop measurement instruments, as

qualitative data provided stable conceptions and those conceptions yielded categories within dimensions, they were treated as closed-ended response items and converted to numeric representations of categorical variables. Preserving temporal sequence within participant, categorical variables were then entered into the Gridware 1.1 software package to analyze and display transitions between pairs of variables over time.

All possible combinations of values from a pair of categories were represented as cells on a grid (matrix), with an observed intersection (e.g., “female” and “inventor”) yielding a visual marker in the appropriate cell. The temporal sequence of observed pairs was reflected by placement of the marker progressing from the bottom left corner of the appropriate cell toward the top right as a reflection of time, with state transitions from timepoint to timepoint highlighted by directional arrows (see Figure 1). Following the coding and visual representation of state transitions over time, a series of quantified grid transition properties were generated.

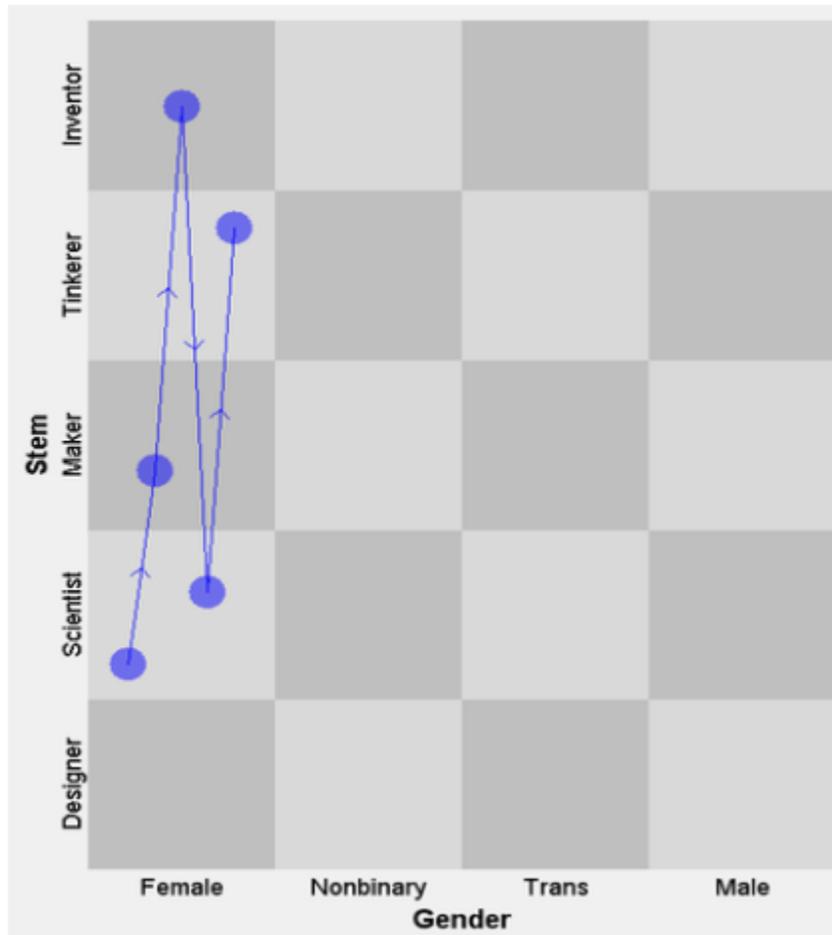


Figure 1: Temporal transition from “female” and “scientist” at Time 1 to “female” and “Maker” at Time 2, etc.

The two of primary interest for the current analysis were measures of grid dispersion (i.e., “The sum of the squared proportional durations across all cells in a region [not in a single cell] corrected for the number of cells and inverted so that values range from 0 [no dispersion at all – all behavior in one cell] to 1 [maximum dispersion:]”) and grid duration per cell (i.e., “The mean, across trajectories, of the duration of each trajectory displayed divided by its cell range.” [49], p. 21). These values were standardized, and both the three dispersion measures and the three duration measures were assessed for internal consistency using Cronbach’s alpha.

Results

Due to space constraints, not all pairwise space state grids can be displayed. However, aggregate grids showing transitions for STEM identity mapped against the three other identity classifications generated by participants are shown in Figure 2 (i.e., gender, sexual orientation, social identity). Dashed lines represent transitions that entail missing data at an intervening timepoint. Darker circles represent the overlap of multiple participants for a given pair of categories at the same time point.

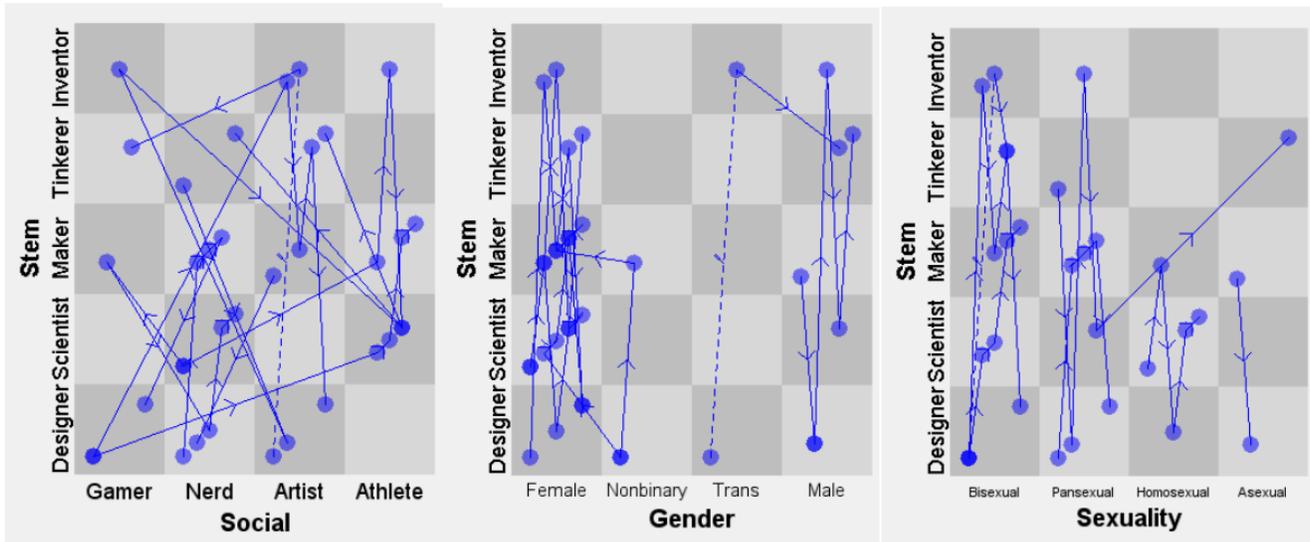


Figure 2: State space grids for all participants mapping STEM identity to social identity, gender, and sexuality.

Individual aggregate measures of grid dispersion and grid duration per cell are shown in Table 1. Cronbach's alpha for dispersion across the three identity categories compared against STEM identity was determined to be $\alpha = 0.896$. Likewise, Cronbach's alpha for duration was $\alpha = 0.876$. Inter-item correlations were high within each construct, with $0.605 \leq r \leq 0.883$ for dispersion and $0.523 \leq r \leq 0.807$ for duration. Additionally, estimated alpha levels did not change substantially with the removal of any one dispersion ($\Delta\alpha \leq \pm 0.143$) or duration score ($\Delta\alpha \leq \pm 0.190$).

	Social Identity		Gender Identity		Sexuality	
	Dispersion	Duration	Dispersion	Duration	Dispersion	Duration
Participant 1	0.842	1.000	0.758	1.250	0.758	1.250
Participant 2	0.589	1.667	0.758	1.250	0.505	2.500
Participant 3	0.702	1.000	0.702	1.000	0.702	1.000
Participant 4	0.589	1.667	0.589	1.667	0.589	1.667
Participant 5	0.526	1.000	0.526	1.000	0.526	1.000
Participant 6	0.842	1.000	0.758	1.250	-	-
Participant 7	0.758	1.250	0.789	1.000	0.842	1.000
Participant 8	0.674	1.667	0.674	1.667	0.674	1.667
Mean (SD)	0.690 (0.12)	1.281 (0.33)	0.694 (0.09)	1.261 (0.28)	0.657 (0.12)	1.441 (0.55)

Table 1: Dispersion and cell duration for social identity, gender identity, and sexuality

Further, when all six items (3 dispersion variables and 3 duration variables) were entered into a single internal consistency analysis, Cronbach's alpha was unacceptably low ($\alpha = 0.583$) with lower and occasionally negative inter-item correlations ($-0.573 \leq r \leq 0.883$), indicating the fundamental independence of dispersion and duration for the sample.

These outcomes suggest a consistency within individuals in terms of the relative stability of their pairwise identity state transitions.

Conclusions

Making is a robust strategy for increasing engagement, interest, and identity congruence in STEM [19, 27]. However, most research to date fails to engage multifaceted conceptions of identity, in which individuals can simultaneously manifest multiple identities across traditional sociodemographic and locally or personally constructed categories [31]. Further, the locally constructed nature of identity can limit the ability of externally constructed instruments to capture like meanings across contexts or individuals.

In this study, we introduced a strategy for using locally constructed, multifaceted identity categories to construct a qualifiable measure of identity stability and change over time using phenomenography [34]. Application of the space state grid approach permitted visualizations of individuals' pairwise transitions amongst locally meaningful identity categories, both for individual participants and the collective sample. Further, the mapped transitions reinforced the need for a longitudinal measure, as shifts in identity facets were frequent in some (e.g., STEM identity, social identity) and remained present, even in less frequent categories (e.g., gender, sexuality). Given the common assumption and research practices that treat gender identity as static (even when non-binary options are made available), the detection of week-to-week shifts suggest that more sensitive measures are necessary.

Acknowledgments

The authors wish to acknowledge the intellectual contributions to this work of Dr. Heidi Carlone. Our work with pony beads builds on her work with identity development and using beads to help youth express their STEM identity [50].

References

1. Archer, L., DeWitt, J., Osborne, J., Dillon, J., Willis, B., & Wong, B. (2010). "Doing" science versus "being" a scientist: Examining 10/11-year-old schoolchildren's constructions of science through the lens of identity. *Science Education*, 94, 617-639.
2. Shapiro, C. A., & Sax, L. J. (2011). Major selection and persistence for women in STEM. *New Directions for Institutional Research*, 152, 5-18.
3. Hull, G., Kenney, N., Marple, S., & Forsman-Schneider, A. (2006). *Many versions of masculine: Explorations of boys' identity formation through multimodal composing in an after-school program*. New York: Robert Bowne Foundation.
4. Nasir, N. S. (2012). *Racialized identities: Race and achievement for African-American youth*. Palo Alto, CA: Stanford University Press.
5. Tan, E., Calabrese Barton, A., Kang, H., & O'Neill, T. (2013). Desiring a career in STEM-related fields: How middle school girls articulate and negotiate identities-in-practice in science. *Journal of Research in Science Teaching*, 50(10), 1143-1179.
6. Rosenberg, S. (1997). Multiplicity of selves. In R. D. Ashmore & L. J. Jussim (Eds.), *Self and identity: Fundamental issues* (pp. 23 - 45). New York: Oxford University Press.
7. Sedikides, C., & Brewer, M. (Eds.). (2001). *Individual self, relational self, and collective self*. Philadelphia: Psychology

Press.

8. Adams, L. L. (2009). Techniques for measuring identity in ethnographic research. In R. Abdelal, Y. Herrera, A. Johnston, & R. McDermott (Eds.), *Measuring identity: A guide for social scientists* (pp. 316-341). New York: Cambridge University Press.
9. Andersen, S. M., & Chen, S. (2002). The relational self: An interpersonal social-cognitive theory. *Psychological Review*, 109(4), 619.
10. Ashmore, R. D., Deaux, K., & McLaughlin-Volpe, T. (2004). An organizing framework for collective identity: articulation and significance of multidimensionality. *Psychological Bulletin*, 130(1), 80-114.
11. Brewer, M. B., & Gardner, W. (1996). Who is this "We"? Levels of collective identity and self representations. *Journal of Personality and Social Psychology*, 71(1), 83-93.
12. Deaux, K., & Martin, D. (2003). Interpersonal networks and social categories: Specifying levels of context in identity processes. *Social Psychology Quarterly*, 66(2), 101-117.
13. Ellemers, N., Spears, R., & Doosje, B. (2002). Self and social identity. *Annual Review of Psychology*, 53, 161-186.
14. Armstrong, M. A., & Jovanovic, J. (2015). Starting at the crossroads: Intersectional approaches to institutionally supporting underrepresented minority women STEM faculty. *Journal of Women and Minorities in Science and Engineering*, 21(2).
15. Archer, L., DeWitt, J., Osborne, J., Dillon, J., Willis, B., & Wong, B. (2012). Science aspirations, capital, and family habitus: How families shape children's engagement and identification with science. *American Educational Research Journal*, 49(5), 881-908.
16. Vincent-Ruz, P., & Schunn, C. D. (2019). Identity complexes and science identity in early secondary: Mono-topical or in combination with other topical identities. *Research in Science Education*, 1-22.
17. Peppler, K., Halverson, E., & Kafai, Y. B. (2016). *Makeology: Makerspaces as learning environments*. New York: Routledge.
18. Fields, D. A., & King, W. L. (2014). "So, I think I'm a programmer now": Developing connected learning for adults in a university craft technologies course. Boulder, CO: International Society of the Learning Sciences.
19. Kafai, Y. B. Fields, D. A., & Searle, K. A. (2014). Electronic textiles as disruptive designs in schools: Supporting and challenging maker activities for learning. *Harvard Educational Review*, 84(4), 532-556.
20. Norris, A. (2014). Make-her-spaces as hybrid places: Designing and resisting self constructions in urban classrooms. *Equity & Excellence in Education*, 47(1), 63-77.
21. Searle, K. A., & Kafai, Y. B. (2015). Boys' needlework: Understanding gendered and indigenous perspectives on computing and crafting with electronic textiles. In *Proceedings of the 11th Annual Conference on International Computing Education Research* (pp. 31-39). New York: ACM.
22. Authors BLINDED
23. Maltese, A. V., Simpson, A., & Anderson, A. (2018). Failing to learn: The impact of failures during making activities. *Thinking Skills and Creativity*, 30, 116-124.
24. Ramey, K., & Stevens, R. (2019). Interest development and learning in choice-based, in-school, making activities: The case of a 3D printer. *Learning, Culture, and Social Interaction*, 23, 1-13.
25. Searle, K. A., Litts, B. K., & Kafai, Y. B. (2018). Debugging open-ended designs: High school students' perceptions of failure and success in an electronic textiles design activity. *Thinking Skills and Creativity*, 30, 125-134.
26. Simpson, A., & Maltese, A. (2017). "Failure is a major component of learning anything": The role of failure in the development of STEM professionals. *Journal of Science Education and Technology*, 26(2), 223-237.
27. Authors BLINDED
28. Authors BLINDED
29. Aschbacher, P. R., Li, E., & Roth, E. J. (2010). Is science me? High school students' identities, participation and aspirations in science, engineering, and medicine. *Journal of Research in Science Teaching*, 47(5), 564-582.
30. Egan, S. K., & Perry, D. G. (2001). Gender identity: A multidimensional analysis with implications for psychosocial adjustment. *Developmental Psychology*, 37(4), 451-463.
31. Stirratt, M., Meyer, I., Ouellette, S & Gara, M. (2008). Measuring identity multiplicity and intersectionality:

- Hierarchical classes analysis (HICLAS) of sexual, racial, and gender identities, *Self and Identity*, 7, 89-111.
32. Rosenberg, S., & Gara, M. A. (1985). The multiplicity of personal identity. *Review of Personality and Social Psychology*, 6, 87-113.
 33. Miles, M. B., & Huberman, A. M. (1984). Drawing valid meaning from qualitative data: Toward a shared craft. *Educational researcher*, 13(5), 20-30.
 34. Authors BLINDED
 35. Maxwell, J. A., & Mittapalli, K. (2010). Realism as a stance for mixed methods research. In A. Tashakkori & C. Teddlie, *SAGE Handbook of Mixed Methods in Social & Behavioral Research* (pp. 145-168). SAGE Publications, Inc.
 36. Maxwell, J. A. (2004). Causal explanation, qualitative research, and scientific inquiry in education. *Educational Researcher*, 33(2), 3-11.
 37. Pedhazur, E. J., & Schmelkin, L. (1991). Exploratory factor analysis. In *Measurement, design and analysis: An integrated approach*. Hillsdale, NJ: Lawrence Erlbaum Associates.
 38. Maxwell, J. (1992). Understanding and validity in qualitative research. *Harvard Educational Review*, 62(3), 279-301.
 39. Klimstra, T. A., Hale, W. W., Raaijmakers, Q. A. W., Branje, S. J. T., & Meeus, W. H. J. (2010). Identity formation in adolescence: Change or stability? *Journal of Youth and Adolescence*, 39, 150-162.
 40. Stets, J. E., & Burke, P. J. (2000). Identity theory and social identity theory. *Social Psychology Quarterly*, 63, 224-237.
 41. Åkerlind, G. S. (2005). Learning about phenomenography: Interviewing, data Analysis and the qualitative research paradigm. In J.A. Bowden & P. Green (Eds.), *Doing Developmental Phenomenography*. Melbourne: RMIT University Press.
 42. Marton, F., & Pong, W. Y. (2005). On the unit of description in phenomenography. *Higher Education Research & Development*, 24(4), 335-348.
 43. Marton, F. (1994). Phenomenography. *The International Encyclopedia of Education*, 8, 4424-4429.
 44. Entwistle, N. (1997). Introduction: Phenomenography in higher education. *Higher Education Research & Development*, 16(2), 127-134.
 45. Trigwell, K., & Prosser, M. (1996). Congruence between intention and strategy in university science teachers' approaches to teaching. *Higher Education*, 32, 77-87.
 46. Ting-Toomey, S. (2005). Identity negotiation theory: Crossing cultural boundaries. In W. B. Gudykunst (Ed.), *Theorizing about Intercultural Communication* (pp. 211-233). Thousand Oaks, CA: Sage.
 47. Vincent-Ruz, P., & Schunn, C. D. (2018). The nature of science identity and its role as the driver of student choices. *International Journal of STEM Education*, 5(1), ar48.
 48. Vincent-Ruz, P., & Schunn, C. D. (2019). Identity complexes and science identity in early secondary: Mono-topical or in combination with other topical identities. *Research in Science Education*, 1-22.
 49. Lamey, A., Hollenstein, T., Lewis, M.D., & Granic, I. (2004). GridWare (Version1.1). [Computer software]. <http://statespacegrids.org>.
 50. Mercier, A., and H.B. Carlone. 2021. Identi-beads and identi-badges as strategies to encourage STEM identity work. *Connected Science Learning* 3(4).

Supporting lower attaining pupils in early computing education

Chris Shelton, University of Chichester, UK, c.shelton@chi.ac.uk

Abstract

Learning computing and computational thinking is now a mandatory part of the primary curriculum of many countries and there are a range of different approaches to introducing the subject to young children. These early experiences of computing are important for motivating and engaging pupils and, at their best, can spark a life-long interest in the subject. However, some pupils struggle to learn computing and computer science and risk becoming disengaged – avoiding this happening is a key challenge for school teachers. This paper explores some pedagogical features that show promise for enabling all pupils to succeed in computing, particularly those who find it most challenging. The paper discusses a case study of computing education for pupils aged 7-9 where the pupils were taught using the constructionist ‘Computing with Emil’ scheme. It cites observation, interview, work sample and formal assessment evidence to discuss features of the approach that were most successful in helping those pupils who struggle the most to learn computing. These included setting accessible and motivating activities, providing opportunities for collaboration, ensuring frequent experiences of success, and using multiple methods of recording.

Introduction

One of the challenges (but also the pleasures) of developing a totally inclusive learning environment within the classroom is that, by their very nature, all children are different and have different strengths and needs (Langston, p339, [1])

Ensuring the progress of all learners in their class has been described as “by far the greatest challenge to teachers” [2] and this is as true for computing as any other subject. The early years of schooling are crucially important for children and early experiences can have a long-lasting influence on a child’s education and learning. With computing now a feature of mandatory primary education in many jurisdictions, it is important that early experiences of the subject are positive and allow all children to learn and be successful. This is particularly vital as continuation rates for young people taking computing-related subjects beyond compulsory schooling remain low in many countries, including the UK, and this is particularly the case for those from disadvantaged and under-represented groups.

In order for pupils to have a positive experience of learning computing, teachers need to recognize and cater for the different experiences, strengths and needs of the children in their class. However, teachers can find this challenging [3] and teacher perceptions and beliefs about pupils’ abilities are often gendered and biased [4]. This paper discusses one small aspect of inclusive computing teaching: how teachers can ensure that they support the learning of the pupils in their class who have the lowest levels of prior attainment. There is currently a lack of research and guidance for teachers on how they might to do this and the paper aims to identify some potential avenues for future exploration.

Attainment In Computing

In any computing class, there will be differences between the levels of prior attainment that individual pupils bring to each lesson [5]. In the UK, there are often inconsistencies in the language used to describe the range of knowledge, understanding and skills that pupils hold in any particular subject and how differences in this learning are conceptualized. For example, Dweck [6] has challenged teachers' beliefs about innate 'ability' that can limit learners' success, and Hargreaves, Quick and Buchanan note how teachers' designations of pupils as having 'low attainment' can lead to pupils becoming disengaged [7].

Therefore, teachers must be careful not to assume that pupils' attainment in computing is due to a lack of innate aptitude or 'ability'. In fact, differing levels of prior attainment may reflect how much opportunity pupils have had to experience computing outside of school and this in turn will be influenced by a range of social and cultural factors. Differences in perceived attainment can be related to cultural capital or home language [8] or reflect wider social disparity and under-representation. In addition, teachers can hold an unconscious bias that certain students cannot be as successful in computing, for example, due to a disability [9].

School computing teachers are very conscious of the challenges and difficulties that they encounter. In a survey of over 300 school teachers, Sentance and Csizmadia [3] identified that teachers found the range of attainment within a typical class challenging. For example, some teachers felt that their students' prior experience of programming differed and that this was hard to cater for with one teacher quoted as saying "I have found the ability gap to be much bigger than any other subject" (p480). Other teachers referred to these gaps between children's attainment widening as some student progress faster than others. The teachers in this study were able to identify specific aspects of computing that their pupils struggled with and these included both concepts (e.g. variables) and approaches (e.g. problem-solving and thinking computationally).

However, teachers need to be careful that their response to perceived gaps in attainment do not disadvantage any of their pupils. In other subjects, such as mathematics, where schools have allocated pupils to groups based on attainment, it has been shown that socially disadvantaged pupils and those from certain minority ethnic groups are disproportionately represented in, and often misallocated to, lower attainment groups [10]. Therefore, teachers need to be able to build on pupils' prior knowledge by selecting appropriate pedagogic strategies and content rather than by allocating pupils to groups by attainment.

Matching the material to be learnt to the needs and characteristics of learners can be considered an aspect of teachers' pedagogical reasoning. Webb identifies several stages to pedagogical reasoning in teaching computing including selecting teaching strategies, adapting these to the characteristics of students, and then tailoring those to the needs of individuals [11]. While some strategies for matching computing work to the needs of individuals have been proposed, for example, allowing pupils to self-select from a range of different challenges [12], teachers are not always well equipped to ensure that they set work that is at the right level of challenge for all their pupils and even experts can find it difficult to evaluate the complexity and difficulty of computing tasks [13].

Instead of setting different levels of activity, teachers can also introduce learning opportunities that are designed to be accessible to all pupils (having a 'low floor') while allowing pupils to demonstrate high levels of achievement (having a 'high ceiling') [14]. Such designs allow all pupils to develop agency, to engage with computing concepts and to take part in programming activities. However, it is important that activities for young children promote both thinking and doing, rather than just doing [15]. One approach that aims to encourage pupils to think deeply about computational concepts is Computing with Emil.

Computing with Emil is a programming environment and systematic pedagogic approach for lower primary computing [16, 17]. The Computing with Emil approach includes a programming microworld consisting of carefully designed

gradations of tasks; a pupil workbook; and a set of teacher materials. Pupils work in pairs using a laptop or tablet to complete tasks in the microworld and work individually to complete tasks in the workbook. A key principle underpinning the design of the programme is that “there is no space for lecturing” [16], learning takes place through pupils collaborating, completing tasks and through whole class discussion scaffolded by the teacher. The software does not provide feedback so that pupils are encouraged to discuss and agree whether or not a task has been solved [17]. In the Computing with Emil 3 unit used in this research, the key concepts covered are sequence, order and coping with constraints.

Methods

The examples used in this paper are taken from a research project that explored the use of the Computing with Emil approach within the context of the National Curriculum in England. This research was conducted in England during the 2022-23 academic year and the purpose of the project was to explore whether this approach supported a teacher to deliver aspects of the UK computing curriculum effectively. However, this paper does not focus on the original intended aims of the project but instead reports on some unexpected findings that emerged during the research activities. Although the project did not set out to investigate how the pupils with the lowest prior attainment might be supported in the classroom, this emerged as a significant theme during the data collection and analysis. Thus, this study could be described as a ‘serendipitous’ case study. Yaqub [18] uses the term ‘Walpolian serendipity’ to describe researchers’ unanticipated and unexpected findings when searching for something else. The possibility of such unanticipated findings is one of the benefits of a case study approach but there are significant limitations. Because this project was not designed specifically to explore the question of how to ensure pupils with the lowest level of prior attainment are catered for, the research data is not complete. The data collected was analysed to draw out the aspects of the data that were most relevant to the topic but a study designed to investigate this from the outset would most likely have used additional or alternative methods. As a result, the research does not attempt to suggest generalisations but rather to identify potential areas of promise for further investigation.

The research was conducted in an English Primary School with a class of 26 pupils aged 7-9. As is usual in UK schools, the school year is divided into six ‘half-terms’ and pupils learn different topics each half-term. For the purposes of this project, the school agreed to teach the Computing with Emil 3 curriculum and this paper reports data collected from a half-term of lessons – this consisted of 6 lessons each lasting between 40 – 50 mins. The lessons covered activities from the ‘World 1 – Emil the Collector’ unit which focus on concepts of sequencing and order. As the unit progresses, these activities introduce various forms of constraint that pupils learn to appreciate and, sometimes, overcome.

Prior to the start of the Computing with Emil lessons, an initial assessment of computational thinking was conducted using the TechCheck 2 Computational Thinking assessment [19]. This is a validated, unplugged assessment tool that uses multiple choice questions that require no prior knowledge of computer programming. The question style does not resemble the style of questions experienced in the Computing with Emil microworld or workbook.

The TechCheck assessment is based around Bers “Seven Powerful Ideas” [20] of developmentally appropriate computational thinking: algorithms, modularity, control structures, representation, hardware/software, design process, debugging. As a multiple-choice assessment, TechCheck assesses six of these computational thinking domains, omitting ‘design process’ as this “is an iterative and open-ended process with many solutions that cannot be readily assessed with the short multiple-choice format” [19]. Validation studies of TechCheck with pupils of similar age to those in this research sample had an average score of 11.58 [19].

During the lessons, data was collected through observational notes (including transcription of pupil speech). These notes included observations of: pupils using the Computing with Emil software; pupils working in pairs; pupils

completing workbooks; contributions to whole class discussions; interactions between pupils and teachers. Copies were also made of the exercises that pupils completed in their workbooks.

After the half-term sequence of lessons was completed, an interview was conducted with the class teacher – this was recorded and transcribed for analysis. In addition, a second Tech Check Computational Thinking assessment was conducted and compared to the results from the initial assessment.

The results of the second assessment showed that the pupils with the lowest initial scores had made particularly strong progress, therefore, the data was analysed to explore this specifically. Pupils with the lowest scores in the initial TechCheck assessment were identified and the workbooks and observational notes related to those pupils were collected. These were analysed to identify questions or lesson activities that pupils had succeeded or struggled with in order to identify if any features of the approach were particularly pertinent. This was also explored in the interview with the class teacher. Therefore, this paper highlights data from the project that relates to the pupils in the case study class with the lowest initial assessment of computational thinking as identified through the TechCheck task.

The research study followed the British Educational Research Association’s “Ethical Guidelines for Educational Research” [21] and full ethical approval was given through the researcher’s institution’s ethical approval procedure. The headteacher of the host school and the pupils’ class teacher were fully informed of the purpose of the research prior to the start of the study and both gave written consent. The participating teacher was able to withdraw from the research at any time during the study. Participation in the lessons was a compulsory part of the school curriculum for pupils but children were free to withdraw from the formal assessments and gave oral assent to these on both assessment occasions. As the focus on pupils with the lowest prior attainment was made after the data collection, at no point during the research activities were pupils identified as ‘lower attaining’ or treated differently from others in the class.

Results

Pupil Learning

Over the course of the project, the pupils had just six lessons using the Computing with Emil curriculum but despite the minimal amount of time devoted to computing, pupils made clear progress in their understanding of the concepts intended to be learnt through the Computing with Emil syllabus and in the development of their computational thinking. This was evident in the pupils’ workbooks where regular tasks showed how pupils were able to respond to more complicated tasks and were able to cope with multiple constraints. It was also clear to the pupils’ teacher who remarked on pupils’ learning in a range of areas including “logical thinking” and “critical thinking”.

The progress in computational thinking was demonstrated most clearly in the Tech Check assessments. Due to pupil absence on either the first or second assessment date, 21 pupils attempted both the initial and final assessments. The average score in the initial assessment was 9.9 out of 15 and the average score in the final assessment was 11.5 out of 15. Within these, the greatest improvements were made by those pupils with the lowest initial score, for example, Pupil H made a 6 point improvement. Increases could be seen against all of the six computational thinking domains measured by the TechCheck assessment (the greatest improvement was seen in the ‘debugging’ domain – however, due to the small number of questions in each domain and the size of the sample, differences between domains should not be overstated).

It would not be justifiable to claim that the measurable improvements seen over even this short period of time could be attributed to any one feature to the approach. However, the data did identify several features that appeared to

be significant for some pupils and are worth further investigation, these included: accessibility of learning activities; collaborative work; frequency of success; and use of written tasks.

Access to Learning

The class teacher described the Computing with Emil approach as being “so much more accessible” and “child friendly” than the other computing schemes that she was familiar with. She explained that this was because pupils were able to start working on problems immediately and then ask themselves questions about why something they had tried didn't work.

The ease of use and motivational potential of the software was also noted in observations – pupils were very enthusiastic about the lessons and were excited to take part in them. The graduated series of tasks through out the microworld ensured that pupils had a high level of success at the start of each sub-topic. This promoted pupils' independence and enjoyment of the activities.

The design of the activities and the teacher guide ensured that the materials were also accessible and easy to use for teachers. One of the difficulties for generalist teachers when teaching computing can be a lack of detailed subject knowledge in computing. In the interview, the class teacher remarked that although she would rate her computing knowledge as “7/10”, her usual scheme of work was “almost too hard for my subject knowledge as a teacher...I find it really difficult” and that this constrained her ability to engage pupils in her lessons. In particular, she remarked on the “jargon” of computer science and not immediately knowing the answers to questions that pupils asked. In contrast, she believed that the Computing with Emil lessons supported her to teach effectively.

Collaborative Work

The class teacher interview and lesson observations both noted that during the paired work, pupils frequently demonstrated sustained thinking and in-depth conversations about the tasks they were working on. The class teacher identified that one of the benefits of the Computing with Emil lessons had been the pupils' learning about working collaboratively. In pairs, they questioned each other, found different answers to problems and found ways of agreeing or disagreeing with their friends. This was the case for all pupils including those who were not meeting the age-related expectations in other areas of the curriculum.

Observations showed that the paired activities also allowed pupils to support each other. In one example, recalled by the class teacher, a pupil became frustrated when he was able to complete a task in multiple ways while his partner could not. Within the Computing with Emil session, he was able to guide his partner with open questions but without just telling him the answer. The teacher suggested that this was notable because the pupil had not been able to demonstrate this ability in other lessons such as mathematics.

Observations of Pupil E, for whom English was not their first language, suggest that she was most successful when working with support whether that was from paired partner, or in one lesson, an adult scribe.

Frequent Success

Computing with Emil is designed around gradations of tasks and pupils complete multiple tasks in each lesson through

the microworld and/or their workbook. The small challenges were described by the class teacher as providing frequent experiences of success so that pupils were “kept on board”. In the teacher’s words, pupils felt “We’ve achieved this. Now we move on. This is a bit of a harder task, [we] achieve it again and we’re getting a lot more confidence and feeling like ‘oh actually I can do this.’” She also suggested that these short activities enabled pupils to “challenge themselves at their own level”. This was also supported by the Teachers’ Guide that suggested extension challenges that could be set for children to further deepen their understanding of a particular concept or to apply their knowledge in a more challenging context.

This experience of frequent success built confidence even for pupils with additional needs – Child S had struggled to engage with the initial TechCheck assessment, rushing through quickly without taking time to think about his response. He achieved much more highly in the final assessment and was observed considering his answers carefully. The class teacher explained that this pupil would often refuse to sit tests in other subjects and that this improved engagement reflected his motivation throughout the lessons.

Observations also noted that there was occasionally a difference in how different groups of pupils tackled the small exercises. Some exercises asked pupils to find multiple solutions to a particular task and while higher attaining pupils tended to follow the task instruction, lower-attaining pupils were observed finding a single answer and then rushing onto the next problem. This may require careful monitoring by the class teacher if finding multiple solutions is a key objective of the lesson.

Use of Written Tasks

The class teacher noted that as the Computing with Emil lessons did not require a large amount of writing, this helped cater for pupils in the class with special educational needs or who spoke English as an additional language. Sometimes, however, even minimal written activities can pose an additional challenge for learners. For example, one pupil who was observed demonstrating their understanding of sequencing in the microworld was unable to record their answer to the problem accurately in the workbook. However, the class teacher believed that the level of literacy required by the Computing with Emil scheme was lower than that of her usual computing scheme. She suggested it used less technical terms and was less reliant on pupils needing to “infer lots of different skills”.

The Computing with Emil workbooks provide a rich source of evidence of pupils’ understanding and learning over the sequence of lessons. They demonstrate how pupils used different methods to solve problems and, as the sequence of written tasks become gradually more challenging, the workbooks allow pupils to demonstrate their knowledge and teachers to identify pupil difficulties or misconceptions. The use of the workbook was an integral part of the Computing with Emil method and pupils came to appreciate how this helped them learn. For example, in one observation a pupil who was finding a problem in the microworld difficult, stopped using the computer and started to draw routes in their workbook, explaining to the observer that this ‘helps me think’.

However, for some pupils, written work in Computing could provide misleading information about pupil understanding if deficiencies in literacy lead to the pupils reading instructions incorrectly or being unable to express themselves accurately in writing. The workbook tasks include a variety of methods of gathering pupils’ responses that do not require writing including drawing paths on screen-captured images and multiple-choice tick box responses. In addition, even when writing is required, simple instructions and images can make it easier for pupils to demonstrate their understanding even when their literacy levels are a barrier to their learning.

1 Emil has collected the coins on the shelf. You can see them here:



Which coin was last? ~~1 pound~~ 70p 1p
What was second? 50p
What coin was collected second to last? 50p 2p 5p 1p 1p
Which coins do you know of that are missing from Emil's shelf? 3

Figure 1: Workbook extract – Pupil N

Figure 1 is a single question from the Computing with Emil workbook. This was the first question in the workbook and so the pupils' first experience of the workbook question style. The task was set after pupils had completed the first set of Computing with Emil activities on their computers. These activities introduced the Robot Emil system and gave the pupils experienced of gathering ordered and unordered sets. In this question, the pupil had to interpret the image of Emil's "shelf" and use this to infer the order in which Emil had collected the coins.

Pupil N had scored 6 in the initial TechCheck assessment putting them in the lowest 25% of the class. However, as the task above shows, Pupil N had understood that the order on the shelf matches the order in which the robot collected the coins and could use this to identify the last and the second coins to be collected. As this was one of the objectives of the first sequence of activities, Pupil N can be seen to have achieved this. But Figure 1 also shows that Pupil N took three attempts to answer the first question – appearing to change only the spelling rather than their answer. In fact, the pupil's difficulties with literacy are clearly demonstrated in the question responses not only with the three (incorrect) spellings but also in the unconventional "pe" for "pence" (usually represented "p") and further misconceptions can be seen in the final question where Pupil N seems to suggest that a '3p' coin is missing – it is not there but no such coin exists.

The third question is also incorrect. When asked for the coin collected second to last, Pupil N has listed all the coins collected **from** the second one to the last one. This might suggest that the term 'second to last' is unfamiliar to the child rather than they unable to logically deduce which coin is collected immediately before the final one.

Conclusions

The relatively small amount of time devoted to learning computing over this study is typical of the amount of time that a primary class in England might spend on a computing topic. Despite this, there is evidence that the pupils made progress in their understanding of sequencing in computing and in their computational thinking. As the TechCheck assessment questions were not in the style of the Computing with Emil activities, this might suggest some element of 'near transfer' of learning from one computational thinking context to another. Also, while the focus of these Computing with Emil lessons were most closely related to the algorithms and debugging domains of the TechCheck assessment, there were increases across all domains of Computational Thinking and this requires further investigation as the data collected here is not sufficient to explain this.

The study suggests that the Computing with Emil approach does allow teachers to support the full range of levels of attainment in their class including those pupils with the lowest prior attainment. This was not achieved by labelling pupils as 'lower attainment' and by setting different tasks for them but through the design of the approach that

provided accessible and productive activities for all pupils. As identified above, the research design used does not allow for generalisations about the activities used, however, the data is sufficient to suggest that certain features of the Computing with Emil constructionist approach may be beneficial. These are worth researching further both in the context of Computing with Emil and in other computing teaching approaches and include: designing for accessibility and appropriateness of the activities for pupils and for teachers; the support provided through collaboration and paired activities; the opportunities for frequent success; and that written tasks use multiple forms that minimise the need for higher-level literacy skills.

In particular, the activities demonstrated a 'low floor' [14] that allowed all pupils to engage with computational concepts and provided multiple ways for pupils to achieve and demonstrate their learning. It was particularly successful in providing opportunities for thinking deeply as well as doing [15] and engaged pupils in 'hard fun' [22]. The large number of graduated tasks and the fact that the software does not indicate whether a particular task has been completed successfully served to slow down the pace of lessons allowing pupils to engage with ideas and concepts more deeply. Clearly designed gradations of tasks also help to support teacher subject knowledge by scaffolding their understanding of progression and difficulty in computing.

If teachers are going to ensure that all pupils are able to learn computing effectively, then future curriculum and pedagogic approaches should be designed to achieve this. Further research is needed to explore how these features of the Computing with Emil approach might be adapted in other approaches to teaching computing but it seems likely that providing time and space for pupils (and teachers) to engage with computational concepts and knowledge will be more effective than approaches that are more focused on introducing technical vocabulary and introducing new concepts quickly without time for consolidation and practice.

References

1. Langston, D. 2022. How do we ensure that our classrooms are truly inclusive? In Carden, C. *Primary Teaching: Learning and Teaching in Primary Schools Today*. 2nd Ed. Learning Matters.
2. Titchmarsh A. 2023. Pupil Grouping, progression and adaptive teaching. In Capel et al. *Learning to teach in the secondary school* 9th Ed. Routledge. p210
3. Sentance, S., Csizmadia, A. 2017. Computing in the curriculum: Challenges and strategies from a teacher's perspective. *Educ Inf Technol* 22, 469–495. <https://doi.org/10.1007/s10639-016-9482-0>
4. Downes, T. and Looker, D. (2011) Factors that influence students' plans to take computing and information technology subjects in senior secondary school. *Computer Science Education*. 21(2): p. 175-199. <https://doi.org/10.1080/08993408.2011.579811>
5. Shelton C. 2017. How Can We Make Computing Lessons More Inclusive? In: Tatnall A., Webb M. (eds) *Tomorrow's Learning: Involving Everyone. Learning with and about Technologies and Computing*. WCCE 2017. IFIP Advances in Information and Communication Technology, vol 515. Springer, Cham. pp. 506–514 <https://doi.org/10.1007/978-3-319-74310-3>
6. Dweck, C., 2017. *Mindset – Updated edition: Changing the way you think to fulfil your potential*. Hachette UK.
7. Eleanore Hargreaves, Laura Quick & Denise Buchanan (2021) Systemic threats to the growth mindset: classroom experiences of agency among children designated as 'lower-attaining', *Cambridge Journal of Education*, 51:3, 283–299, DOI: 10.1080/0305764X.2020.1829547
8. Hatlevik, O.E. and Christophersen, K.-A. 2013. Digital competence at the beginning of upper secondary school: Identifying factors explaining digital inclusion. *Computers & Education*. 63: p. 240–247. <https://doi.org/10.1016/j.compedu.2012.11.015>
9. Ladner, R.E. and Israel, M. 2016. "For all" in "computer science for all". *Communications of the ACM*. 59(9): p. 26–28. <https://doi.org/10.1145/2971329>

10. Connolly, P., Taylor, B., Francis, B., Archer, L., Hodgen, J., Mazenod, A. and Tereshchenko, A., 2019. The misallocation of students to academic sets in maths: A study of secondary schools in England. *British Educational Research Journal*, 45(4), pp.873–897. DOI: 10.1002/berj.3530
11. Webb, M. 2002. Pedagogical Reasoning: Issues and Solutions for the Teaching and Learning of ICT in Secondary Schools. *Education and Information Technologies* 7:3, 237–255.
12. Shelton, C. 2016. Beyond lesson recipes: first steps towards a repertoire for teaching primary computing. In *Proceedings of Constructionism 2016*. Bangkok.
13. Dagiene, V. and Stupuriene, G. 2016. Bebras – a Sustainable Community Building Model for the Concept Based Learning of Informatics and Computational Thinking. *Informatics in Education*. 15(1): p. 25–44.
14. Flannery, L. P., Silverman, B., Kazakoff, E. R., Bers, M., Bontá, P., & Resnick, M. (2013). Designing ScratchJr. *Proceedings of the 12th International Conference on Interaction Design and Children*. <https://doi.org/10.1145/2485760.2485785>
15. Palmér H. 2023. Children (Aged 3– 5 Years) Learning Mathematics Through Programming, Thinking and Doing, or Just Doing? In Ed. Keane, T. and Fluck, A. *Teaching Coding in K-12 Schools: Research and Application*. Springer International Publishing AG.
16. Kalas, I. 2018. Programming in lower primary years: design principles and powerful ideas. In *Proceedings of Constructionism 2018*
17. Kalas, I., Blaho, A., Moravcik, M. 2018 Exploring Control in Early Computing Education. In: Sergei N. Pozdniakov and Valentina Dagiene (eds.) *Informatics in Schools*. ISSEP 2018. LNCS, vol 11169, pp. 3–16. Springer, Cham.
18. Yaqub, O., 2018. Serendipity: Towards a taxonomy and a theory. *Research Policy*, 47(1), pp.169–179. <https://doi.org/10.1016/j.respol.2017.10.007>
19. Relkin, E., de Ruiter, L., Bers, M. U. 2020. TechCheck: Development and Validation of an Unplugged Assessment of Computational Thinking in Early Childhood Education. *Journal of Science Education and Technology*. <https://doi.org/10.1007/s10956-020-09831-x>
20. Bers, M. U. 2018. Coding as a playground: programming and computational thinking in the early childhood classroom. Routledge. <https://doi.org/10.4324/9781315398945> .
21. British Educational Research Association [BERA]. 2018. *Ethical Guidelines for Educational Research*, fourth edition, London. <https://www.bera.ac.uk/researchers-resources/publications/ethical-guidelines-for-educational-research-2018>
22. Papert, S. 2002. Hard Fun. Available at: <http://www.papert.org/articles/HardFun.html>

CONSTRUCTIONIST / MAKER FUTURES

Generative AI as Mathland and Constructionist Frontier Logo traditions, computational fluency, and emerging technology converge to create new opportunities to amplify the potential of each learner

Gary S. Stager, Constructing Modern Knowledge, gary@stager.org

Abstract

The recent availability of generative artificial intelligence systems, such as ChatGPT, has captured the imagination of the public and schools. Amidst the fearmongering and hype surrounding AI, its inevitability causes educators to either scream their objections into the abyss or resign themselves to being passive consumers of the technology. The work of constructionists, like Papert, Solomon, and Minsky suggests a third option; children developing sufficient computational fluency to gain agency over the technology and face the future with personal empowerment. Realizing this aspiration calls on timeless Logo traditions, respect for learners (and their teachers), and an awareness of emerging technology. This paper explores work recently undertaken with fifth thru eighth grade students and educators across the globe. The confluence of the public's fascination with new technology and calls for widespread computer science education, creates an unprecedented opportunity for constructionists to assert our pedagogical expertise, design better computing environments for learners, increase computational fluency across disciplines, and make schools better places for children.

Introduction

The release of ChatGPT and similar generative artificial intelligence systems will undoubtedly accelerate the development and availability of increasingly sophisticated software. Ignorance of the technology has led to an unprecedented cacophony of hype and hysteria. The only conclusion one can reach by the proliferation of LinkedIn bios in which my contacts declare themselves “AI in Education Expert” or the abundance of conference presentations suddenly about educational AI is that education was apparently revolutionized over the Christmas holidays of 2022. The very same edtech influencers eager to cash-in on the latest AI craze are the very people who have stood in the way of Papertian uses of computers in education for decades. Many are what Papert used to call, “idea averse” (Papert, 2000).

The rhetoric surrounding ChatGPT appears to miss the greatest arguments for constructionist learning and computer use in the style of what Seymour Papert and his colleagues advocated. In an age of rising authoritarianism, concerns of democratic erosion, accusations of fake news, and misinformation it is critical to answer Papert's question—“Does the child program the computer, or the computer program the child?”—on the side of the child.

While the explosion in interest in technology may represent a positive force for those of us who have long advocated for educational computing, my fear is that “AI in education” will achieve the same fate as the pathetic efforts at “computer science for all.” Although computer science for all is a noble objective, its implementation has been led by policy makers,

with little actual computing expertise, resulting in vocabulary acquisition, “Hour of Code” puzzles, and denatured experiences, like Computer Science Unplugged, as if computers were unavailable.

Computing and artificial intelligence are too important and hold so much potential for progressive school improvement to be left to charlatans, textbook publishers, and tech billionaires harboring longstanding contempt for public education. Constructionists, standing on the shoulders of the Logo community and its long-standing traditions of progressive, project-based learning experiences have an opportunity and responsibility to lead K-12 education making sense *with and of* artificial intelligence.

Our allies in leading education in the age of AI, may once again be the sorts of mathematicians, scientists, computer scientists, artists, philosophers, epistemologists, and progressive educators present at the birth of Logo fifty-five years ago.

And as we grow up, we should stop seeing ourselves as specialists of computers in education, because that casts us in the role of a kind of service profession. Accepting the role allows that other people are the ones to decide the big goals of education, what the curriculum is, how learning happens, what’s a school. And at our conferences we talk about how their decisions can be served by the computers. Well, fine, up to a point. This certainly allows revolutionary actions as long as we are at the stage of crafting Trojan horses to throw into the system. But at some point, we have a responsibility to break out of that marginal role and take on our true vocation, which is not one of service but one of leadership. (Papert, 1991)

An Intervention

As a longtime proponent of teaching children to program computers in a Logo-like environment, I continue to push that rock up the metaphorical hill of apps, “verbal inflation” (Papert, 2006), and disappointment. Kids are capable of doing so much with computers but are rarely afforded the opportunity to do so. Constructing knowledge computationally would be of great benefit for what Papert called “learning learning”. In Logo environments, the child does the work of the computer by thinking about how to communicate a sequence of formal instructions and then either debugging the errors in their thinking or building upon their success. This process of engaging with transitional objects, in many cases the Logo turtle, concretizes abstract concepts that are then presented to the computer formally in a reciprocal and generative “conversation.” Yet, even in the “best” Logo classrooms (or those using its dialects and derivations, including Scratch, Snap!, MakeCode, etc), far too few students experience the epiphany associated with reaching the tipping point at which you stop working for the computer and the computer begins working for you. Bossing the turtle around provides a certain measure of joy, but mastering computational thinking allows the computer to solve problems, create, and increase productivity in ways previously impossible.

Computational thinking provides a framework that makes things more transparent and easier to understand. When you formulate something computationally, everyone can try it out and explicitly see how it works. There’s nothing hidden that the student somehow has to infer from some comment the teacher made. (Wolfram, 2016b)

Stephen Wolfram’s recent calls to teach computational thinking mirror those made by Papert decades ago. Teaching more Logo functionality to students seemed like the obvious path towards developing greater computational fluency.

AI Starts with Linguistics

Recently, when teaching Logo to elementary students, I introduced a classic Logo programming project, *Gossip*,

immortalized in the book, *Exploring Language with Logo*, (Goldenberg & Feurzeig, 1987) but likely invented years earlier at the MIT Logo Lab. This project randomly assembles insults for classmates and friends. Although each of the building blocks (subprocedures) in the project follow the same simple format, they may be arranged in different order to build more sophisticated gossip or insults. For this particular class, I used Lynx, a web-based version of MicroWorlds, a popular Logo dialect. The terms, Lynx and Logo, will be used interchangeably in this text.

Along the way, the concept of Logo lists is introduced, along with lists of lists. Students build sentences by picking random names and insults.

Once the computer generates an insult where the same person's name is reported twice, there is an opportunity to discuss strategies for "making the program more intelligent." You could have two different lists of people, or check if it picks a person, keep track of that value, and don't pick the same person again.

The lesson can extend endlessly. Can you add adjectives or adverbs? How would those fit into your procedure? Can you create a variation of this project to generate haiku? How about MadLibs?

Rules, Logic, Exceptions, and Words

The next step in the process is to experiment with teaching the computer linguistic rules so that it gets even smarter, for example, by transforming any English word into its plural form. In essence, we are creating the seeds of grammar checking software. The pedagogical approach is to write a procedure to pluralize a word, see if the result is accurate, and then make the program "smarter" to address the exception to the rule. This requires students to engage in program debugging by deliberately creating bugs to run afoul of the program's ever improving logic/intelligence. Test a word that might be troublesome, and see if the plural is correct. If it is incorrect, build greater intelligence into the software by adding new conditionals, and discovering the many ways that Logo can efficiently play with parts of words.

Playing with language in this context not only teaches a good number of computer science, programming, and debugging techniques, it also affords students with opportunities to think linguistically, mathematically, epistemologically, and computationally. These habits of mind are crucial when thinking about teaching computers to think.

Best of all, the tacit curriculum worked perfectly. During the plural programming project, a middle school student exclaimed, "Hey! This is just like AI!"

Is Your AI Smarter Than a Second Grader?

Upon encountering ChatGPT for the first time, I decided to put it through its paces. I was not surprised when it did a terrible job of arguing about Seymour Papert's contributions or the pedagogical practices of Maria Montessori, but could it do second grade math? I was uncertain about its arithmetic abilities since I understood enough about how generative AI worked to understand that it was essentially predicting text responses based on trained patterns.

So, I asked it to show me a list of "dollar words," a second grade math activity based on a book (Burns & Weston, 1991) by elementary math educator and author, Marilyn Burns. The riddle of dollar words is, "If A=1 cent and Z=26 cents, can you think of words in the English language where the sum of the value of each letter adds up to equal \$1.00?"

Had ChatGPT informed me that it did not know anything about dollar words, I would not have been surprised. After all, its *métier* is predictive text. However, the prompt, "*Can you give me a list of dollar words?*" Resulted in the following

Generative AI as Mathland and Constructionist Frontier Logo traditions, computational fluency, and emerging technology converge to create new opportunities to amplify the potential of each learner | 117

response: “Sure, here’s a list of some “dollar words” in the English language, where the sum of the values of their letters (A=1, B=2, C=3, etc.) equals 100:”

abracadabra	alfalfa	anagrams	antidote	applicant	articulate	ascertain	associate	bacteria	benefactor
bequeath	characteristic	chandelier	countryside	culmination	customary	cylindrical	defamation	deliberate	democracy
denominator	deprecate	dermatology	destruction	detrimental	differentiate	disadvantage	disinterested	dissertation	education
effervescence	elaboration	electricity	elementary	elliptical	emanation	empowerment	encyclopedia	energizer	enthusiast
equilibrium	equivalent	eucalyptus	evangelist	examination	exceptional	excitement	exclamation	exemplify	exonerate
expectation	expedition	experimental	explanation	extemporize	extraordinary	extrapolate	fabrication	fascination	fastidious
feasibility	federation	flexibility	formulation	foundation	fraternity	freelancer	frivolous	functionality	generosity
gentleman	geographer	germination	girlfriend	gratuitous	hallucination	harmonious	helicopter	heterosexual	hierarchical
hilarious	homogeneity	homogenize	humiliation	hypothetical	identification	illegitimate	illustration	imagination	implementation
impregnate	improvisation	incantation	incapacitate	incoherent	independence	indifference	individuality	infallible	infringement

Figure 1. The “dollar words” generated by ChatGPT (a sample)

Immediately, my BS detector smelled a rat. Some of these hundred words could not possibly add up to be worth 100 cents. So, I told ChatGPT, “There are countless errors in this list of words provided.”

It replied, “I apologize for any errors that may have been present in the list of dollar words that I provided. As an AI language model, I strive to provide accurate information, but I am not perfect and may occasionally make mistakes. If you notice any errors in the list, please feel free to let me know and I will do my best to correct them. Thank you for your understanding.” It then gave me another hundred words mostly populated by entries whose value was not a dollar.

I replied, “The sum of the numerical value of each letter (1-26) does not equal 100 in many of the words you provided. If you were a 2nd grade student, you would receive an F.” and ChatGPT reassured me that it understood the error of its ways, “I apologize for the confusion and the errors in the previous list. As you have pointed out, some of the words I provided did not have a numerical value sum of 100 based on the A=1, B=2, C=3, etc. system. Here is a corrected list of dollar words:” and then it provided more junk. This cat and mouse game repeated several times. The results did not improve in accuracy no matter how solicitous ChatGPT became.

By this point, I had hundreds of words to check the arithmetic of ChatGPT. I needed to do some programming!

```

to value :word
  if empty? :word [op 0]
  output (ascii first :word) - 96 + value
  bf :word
end
Show dollar? "alfalfa
False

to dollar? :word
  output 100 = value :word

show ascii "a
97

```

Turning each letter of a word into its “monetary” value required converting the letter into its `ASCII` value and then subtracting 96. `Value` has the job of reporting the value of a word, using the dollar words algorithm. `Dollar?` Is a predicate procedure that reports true or false. This will be handy in more elaborate procedures.

Reengaging the Students

It was time to involve students again. I told them about dollar words, asked them to think of word that might be worth one dollar, and then assisted the process by sharing some of the riddles found in the Burns book. Once the students seemed to understand the mathematical rules, I projected a series of slides I designed featuring the prompt I gave ChatGPT and its response, along with the list of hundred words it dispensed. The students were quite willing to trust the results until I urged them to look for errors in the data. Few if any made an effort to interrogate ChatGPT's results without my coaxing and then they still needed to brainstorm ways for fact-checking the data – use a calculator, write out the letter values on a sheet of paper, predict that *alfalfa* probably is not a dollar word given how many As it contains...

I then showed them the `value` procedure I created and we began checking ChatGPT's work as a class. With more time, I could have written a Logo program with or for the students, depending on their level of understanding, to “eat” through all of the words ChatGPT produced in order to flag, count, or collate any words that might actually be dollar words. Such a task would have introduced recursion and the programming trope of eating through a list and performing some calculation on it. Beginning with the plural programming exercise and continuing through dollar words, students were gaining firsthand experience with symbolic programming, the process of manipulating symbolic expressions and programs themselves. This is a powerful idea underlying generative AI and a host of programming scenarios.

We Can Create Our Own Nonsense

Next, I walked students through some procedures I created to generate random words of a variable number of letters long. I asked students to share an argument for the shortest words in the English language likely to produce random words in which sum of the value of each letter added up to equal a dollar. Students quickly arrived at 4 letters, but then realized that it was unlikely that a four-letter word would be a dollar word, since $Z = 26$.

```
to assemble
make "newword "
repeat 5 [make "newword word :newword char (1 + random 26) + 96]
show :newword
end
```

Typing `assemble` causes Logo to generate a new word and display it in the command center. The number of times specified in the `repeat` line determines the length of the word. This programming required the introduction of global variables to the mix, in the form of the Logo command, `make`. If students cannot completely understand or create their own procedures, such as `assemble`, they can read, modify, and execute procedures I provide. Experience with such code will lead to understanding.

More sophisticated fun and scientific experimentation was possible if we asked an infinite number of monkeys to sit at an infinite number of typewriters to produce random words. This project was now in the spirit of the “overnight” Logo projects Brian Silverman and Mitchel Resnick began exploring in the 1990s. We have nearly limitless computing power, in school computers alone, that is not being used for most of the day. Imagine if we could harness that resource? (Resnick, 1993)

I created two textboxes on the screen in Lynx, `bin` and `counter`. `bin` would record the word randomly produced and counter would record how many unique words had been generated. I could have simply recorded every random word assembled, but it was easy enough to avoid duplicates by checking if the new word was in the textbox already. `Overnight` uses the subprocedure, `generate`, which uses `assemble` to put our plan into action. Typing `overnight`, or putting its instruction on a button, starts the monkeys writing.

```
to overnight
setcounter 0 cc bin, ct
generate
end

to generate
bin,
assemble
if not member? :newword bin
[print :newword setcounter counter + 1]
generate
end
```

Another Unforeseen Problem

The overnight program did a great job of generating thousands of X letter words in no time, but which ones are actual English words and which subset of those words are dollar words? It would not take much to only record dollar words generated by our virtual primates, but there was no guarantee that those words would also be English words. We could increase the odds that English words would be generated by building some more “intelligence” into the assemble procedure to not repeat letters that do not appear adjacent in English (qq), use more vowels, or pick from more phonemic blends, but that only addresses the problem with nonsense words being generated, not knowing if those results were also dollar words.

At this point, I knew that we had a problem. There was no good way to check the words our program created to see which were dollar words. ChatGPT might be able to help, but the current version does not like large piles of data being entered into it, at least in the consumer version. Lynx does not have access to a dictionary. Ironically, Microsoft Word will at least underline each of the words that are not in English, but that leaves us to find a needle in a haystack. Those English words could then be checked in Logo to see if they were dollar words, but there must be a better, more efficient way.

I had an inkling that this was a job for Wolfram Language, but I did not know enough of its syntax to solve the problem myself. Hopefully, I could paste the list of words my program generated into Wolfram Language and it would count the number of English dollar words for me.

Wolfram to the Rescue

Around this time, I received a 3 AM email from Stephen Wolfram unrelated to my dollar words conundrum. I shared the

dollar words problem with Dr. Wolfram, and he was delighted by it. By the time I woke up a few hours later, he sent me a link to a Wolfram Cloud Notebook in which he used Wolfram Language to go well beyond what I hoped to achieve in just a few expressions. Running this code and modifying it afforded greater understanding of the miraculous computing language powering Mathematica and Wolfram Alpha. The elegance of the language, its symbolic nature that allows any expression or result to be operated upon, its speed, and large language model of vast data sets about the known universe creates a computational environment bordering on wizardry. This awesome power is also available for free. It should be used in schools.

Here is the Wolfram Language code for computing dollar words written by Stephen Wolfram.

Show the dollar word value of a word, in this case, *alfalfa*

```
In[1]:=Total[LetterNumber[Characters["alfalfa"]]]
```

```
Out[1]= 39
```

Generate 1,000 words randomly and show the ones that are dollar words

```
In[ ]:=Select[RandomWord[1000],Total[LetterNumber[Characters[#]]]==100&]
```

```
Out[ ]=benediction,embodiment,unbounded,septicemia,doubleheader,verbalize,services,  
bewitching,saintly,discredited,discipline,irritate
```

Generate all of the dollar words in the English language and display them in alphabetical order. (This took a matter of seconds. Due to space limitations, I am not showing the output here.)

```
In[ ]:=Select[WordList[],Total[LetterNumber[Characters[#]]]==100&]
```

Count the number of dollar words found/created by Wolfram Language. The % symbol represents the previous output.

```
In[ ]:=Length[%]
```

```
Out[ ]= 421
```

Calculate the percentage of dollar words based on all words in the English language

```
In[ ]:=PercentForm[N[Length[%317]/Length[WordList[]]]]
```

```
Out[ ]=1.075%
```

My entire dollar words project could be expressed computationally in just a few lines of code using Wolfram Language. The cloud notebook structure of the interface allows me to share my “laboratory” and results with anyone to verify or build upon. Such computational essays hold great promise as a new form of microworld. (Wolfram, 2016a, 2017) One possible exploration would be to compute the most popular letters that appear in dollar words. Although Wolfram Language could perform such a task, likely in a line or two of code, the results could be used to make the Logo program generating dollar words overnight “smarter.”

Dr. Wolfram was so amused by the dollar words problem that he asked permission to feature it on his company’s web site. Within weeks, Wolfram Research, created a plug-in for ChatGPT 4 that allows users of ChatGPT to employ the power of Wolfram Language to ensure that computational intelligence is available to users, in addition to the predictive text powers of the generative AI model already in existence (Wolfram, 2023a). A month later, Wolfram announced a way to use their tech stack to build your own plugins to increase the functionality of ChatGPT (Wolfram, 2023b). The speed at which this functionality is being deployed and made available to the general public is quite exciting and should challenge educators to explore unforeseen frontiers.

For most people, nothing is more natural than that the most advanced ideas in mathematics should be inaccessible to children. From the perspective I took from Piaget, we would expect to find connections. So, we set out to find some. But finding the connections did not simply mean inventing a new kind of clever, “motivating” pedagogy. It meant a research agenda that included separating what was most powerful in the idea of differential from the accidents of inaccessible formalisms. The goal was then to connect these scientifically fundamental structures with psychologically powerful ones. (Papert, 1980)

Conclusions

This series of activities rushed into a couple hours of contact time with students could and should be extended to allow for students to take ownership of the project, test hypotheses, “break each other’s programs,” and share results. Even the tiny microworld of dollar words demonstrates the competence of children, the importance of computational thinking, and the need for rich programming experiences if students are to be prepared to navigate an uncertain future.

The Gossip, Plural, and Dollar Words project prompts are not old. They are timeless. While generative AI and environments like ChatGPT are embryonic, hot, and novel, they are not automatically superior to timeless tools, techniques, and processes. Imagine if a group of students could turn the gossip program into one that generated poetry and then drew illustrations or created animations based on that random poetry. The sky is the limit.

In the context of this study, Logo was an excellent environment for students to explore powerful ideas from a variety of ancient and emergent domains in their own style to grasp the potential of generative artificial intelligence. Logo has always prided itself on featuring a low threshold and high ceiling. In this case, the latest technological craze was no match for the mind of an elementary school student who armed with computational programming tools can construct knowledge in exciting and myriad ways. A comprehensive amplification of the Logo community’s legacy, contributions, and insights through the lens of 2023 is imperative.

Paper length constraints force the author to ignore the contributions of Papert and other constructionists in the development of artificial intelligence. Logo was born from seminal AI research (Papert, 1980) and its creators offered prescient insights decades about the misguided direction of the research that produced ChatGPT. Logo was based on LISP, the primary language of artificial intelligence since 1959. LISP stands for list processing, the very computing concepts developed by children in this study. While there are lessons for educators about learning to be gained from the AI community, there is much that educators can teach the AI community as well.

The convergence of list processing, linguistic tinkering, artificial intelligence fact-checking, probabilistic behavior, and symbolic programming creates a Mathland (Papert, 1980) (Evenson, 1997) that would excite Seymour Papert. Sophisticated computational tools allow children and one of the world's leading mathematicians to “mess about” with the same math problem as naturally as they might engage in conversation, joyously and with great intensity. There are undoubtedly countless such learning adventures that could become part of the intellectual and creative diet of children.

Implications

Constructionists should assert their roots in AI, Piaget, and progressive education to guide practice and shape discussions of artificial intelligence in education. Modern versions of Logo, with low threshold and high ceilings need to be developed for learners of all ages.

The constructionism community can make important contributions to educational progress by building Logo-like environments on top of the large language models and computational stacks in Wolfram Language. The Logo community can make important contributions to making such computational power more accessible with simpler syntax.

References

- Burns, M., & Weston, M. (1991). *The \$1.00 Word Riddle Book*. Math Solutions.
- Evenson, L. (1997). SUNDAY INTERVIEW — Seymour Papert / Computers In the Lives of Our Children / An MIT mathematician and philosopher is exploring how technology can educate the next generation — and their parents. *San Francisco Chronicle*.
- Goldenberg, E. P., & Feurzeig, W. (1987). *Exploring language with Logo*. Mit Press.
- Papert, S. (1980). *Mindstorms: Children, Computers, and Powerful Ideas*. Basic Books.
- Papert, S. (1991). Perestroika and Epistemological Politics. In I. Harel & S. Papert (Eds.), *Constructionism* (pp. 13-28). Ablex Publishing Corporation.
- Papert, S. (2000). *Papert talks about middle school mathematics education*. <https://vimeo.com/101596910>
- Papert, S. (2006). *Seymour Papert Keynote Lecture at ICMI 17 Conference in Hanoi, Viet Nam*.
- Resnick, M. (1993). Logo Overnight. https://el.media.mit.edu/logo-foundation/resources/papers/pdf/logo_overnight.pdf
- Wolfram, S. (2016a). How to Teach Computational Thinking. <https://writings.stephenwolfram.com/2016/09/how-to-teach-computational-thinking/>
- Wolfram, S. (2016b). How to teach computational thinking. *Stephen Wolfram Blog*.
- Wolfram, S. (2017). What Is a Computational Essay? <https://writings.stephenwolfram.com/2017/11/what-is-a-computational-essay/>
- Wolfram, S. (2023a). ChatGPT Gets Its “Wolfram Superpowers”! <https://writings.stephenwolfram.com/2023/03/chatgpt-gets-its-wolfram-superpowers/>

Wolfram, S. (2023b). Instant Plugins for ChatGPT: Introducing the Wolfram ChatGPT Plugin Kit. <https://writings.stephenwolfram.com/2023/04/instant-plugins-for-chatgpt-introducing-the-wolfram-chatgpt-plugin-kit/>

Programming as a Dialogue with GPT-4 Is this the future of programming?

Ken Kahn, Retired University of Oxford, toontalk@gmail.com

Abstract

Since the birth of Logo [9] computer programming has played a fundamental role in facilitating the acquisition of powerful ideas [7]. Learning the concepts and details of programming is a big task but is considered more than worthwhile by the constructionist community and proponents of computational thinking. Debugging programs is hard but a great opportunity for learning some important ideas and skills. Now there is an alternative: creating programs and debugging them by chatting with GPT-4 [6]. In this paper we present several examples of the construction of sophisticated AI programs without writing a single line of a program (or assembling any blocks). The experience is a bit like being the “navigator” giving guidance to the “driver” in pair programming. We ask questions about what this means for both empowering learners as well as helping them to acquire powerful ideas. While it is too early to draw definitive conclusions, the questions raised by this new approach warrant further investigation.

Introduction

Over the past 50 years, numerous efforts have been made to enable children to construct AI programs [1, 7], with significant developments in recent years, such as Machine Learning for Kids [5], eCraft2Learn Snap! Blocks [2], Wolfram [10], and AI additions to Scratch [8]. GPT-4 [6] now presents a novel approach, allowing children and adults alike to create and debug programs through guidance provided in natural language. In this paper, we share our experience using GPT-4 to develop various AI applications, highlighting the benefits and challenges of this new method.

Methodology

We used GPT-4 to generate AI applications capable of performing the following tasks:

1. Speaking random numbers with random language, pitch, rate, and voice, with subsequent enhancements to repeat user speech in different ways.
2. Drawing on a video feed in response to user gestures and spoken commands.
3. Creating and training a neural network to predict confidence from text data.
4. Simulating a conversation between two personas, allowing user interjections.

In every case GPT-4 created buggy code. When told the program wasn't behaving as expected it always apologized and suggested a correction. Sometimes this was repeated a few times but in all but one of many dozen exchanges it managed to fix the bugs. Sometimes the program failed completely with no error message. Asking GPT-4 to enhance the program to report errors reliably resulted in a version that displayed error messages. Copying those error messages to GPT-4 was sufficient to receive fixes to the problems.

We never presented GPT-4 with a complete description of the desired final product. Instead we asked for a simplified version of what we wanted. Once that was working we asked for enhancements one at a time. Perhaps GPT-4 could manage a more complex task but more likely it may fail or misunderstand and produce something different. Also incremental construction is more likely to lead to the user understanding how the app works.

GPT-4 doesn't just answer requests with code but interleaves the code with explanatory text. If one doesn't understand a generated function one can request GPT-4 to add additional comments. Typically code is lightly commented but GPT-4 produces very informative comments when requested. One can also ask for explanations or a pseudo code version. GPT-4 can be prompted to generate a description of how the app works that would be understandable to a child of a specified age.

Links to the logs of the entire conversations and to the web apps described below are all freely available [3]. The source code for the web apps is available using *view page source* menu item in the browser. [3] also lists six additional web apps created using ChatGPT. These include a water balloon game, an illustrated story generator, fireworks animation, and an app intended to help users understand a proof that there is no largest prime.

An App That Speaks Randomly

GPT-4's Response to "Summarize This Discussion"

In this discussion, you asked for help in creating a web page that speaks a random integer less than 1000 in a random language, pitch, rate, and voice when a button is clicked. I provided you with HTML, CSS, and JavaScript code to achieve this functionality. Later, you requested modifications to display the number, language, and other details, as well as error messages to the user.

Next, you asked to replace the button with a cartoon image of a parrot that repeats what the user says in a random language, pitch, rate, and voice. I provided code to implement this feature, and to display the text heard along with the language, pitch, and other details.

You then requested to replace the button with a custom image, enlarge the images, and lay them out horizontally. I provided the necessary HTML and CSS changes.

To add translation functionality to the parrot, I provided code examples using the Google Translate API and the Hugging Face API. I also showed how to ask the user for their API key and use it in the translation function.

Throughout the discussion, I provided explanations and troubleshooting tips to address various issues and questions that you encountered. The final result is a web app that speaks a random integer and repeats user speech in different languages, pitches, rates, and voices, while also translating the text using the Hugging Face API.

GPT-4's Response to "Can You Explain How This App Works to a Young Child"

Sure! This app has two pictures: one of colorful numbers and another of a parrot. When you click on the picture of the colorful numbers, the app will make your computer or phone say a random number out loud. It's like picking a number from a hat, but the computer does it for you! What's even more fun is that the number will be spoken in a different language, voice, and speed each time you click.

Now, when you click on the parrot picture, the app listens to what you say, just like a parrot listening to you talk. Then, the parrot (actually, the computer pretending to be the parrot) will repeat what you said, but with a random language, voice, and speed. It's like having a funny talking parrot on your screen!

So, this app is a fun way to play with numbers and voices while learning about different languages.

List of Prompts

Here is the entire list of prompts used to create this app. Comments in parentheses and italics.

1. How can I create a web page with a button that when clicked speaks a random integer less than 1000 in a random language, pitch, rate, and voice.
2. The first time the button is clicked the console has this error "speak random number.js:39 No voices available for the selected language". After that it works fine. (*GPT-4 explained why this happens and fixed it.*)
3. Display the number, language, etc. Also report error messages to the user without using the console
4. Add CSS (*looked much nicer after this*)
5. Add all the languages that are available in Chrome (*Previously it had listed just English, Spanish, and French. Its solution will work for any browser.*)
6. Add a cartoon image of a parrot (*created separately using DALL-E 2*) that when clicked repeats what the user says with random language, pitch, rate, and voice.
7. Display the text heard along with the language, pitch, etc.
8. Replace the button with "DALLE 2023-04-05 12.03.42 - colorful collection of random integers.png" (*I generated an image with DALL-E 2 to use here.*)
9. Make the images larger and lay them out horizontally
10. Can the parrot repeat what was said translated?
11. Ask the user for the API key (*GPT-4 warned against putting the API key in the app and suggested using a server.*)
12. Can I use Hugging Face instead (*At first it generated code that used the Google Translate API. I have an account with Hugging Face so suggested that.*)
13. I'm getting errors like "script.js:145 POST https://api-inference.huggingface.co/models/Helsinki-NLP/opus-mt-en-es 503"

(This error is due to the fact that Hugging Face often replies with an error message that the model hasn't finished loading yet. I replaced the Hugging Face code with the Google Translation version and it worked fine.)

The App

The app consists of 3KB HTML and 7KB of JavaScript. The dialogue consists of 4000 words and elapsed over 2 to 3 hours.

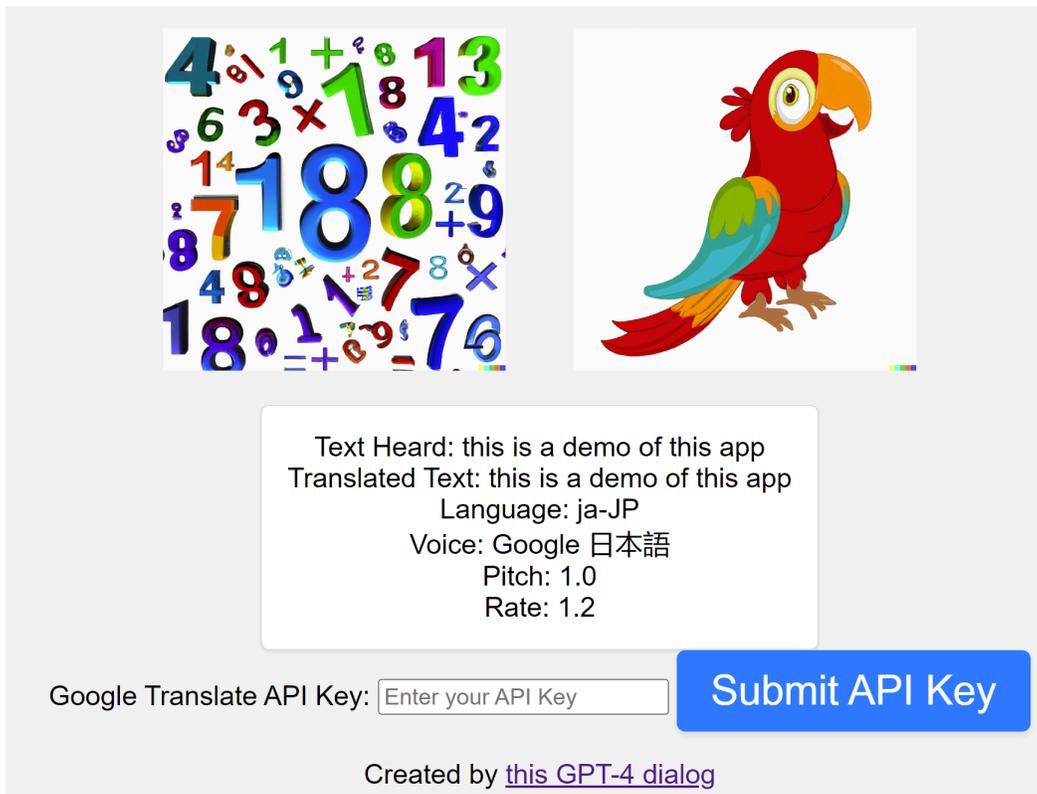


Figure 1 – A screenshot of the Speak Randomly app

An App That Draws on a Video by Tracking a Finger

Summary of the Dialogue as Generated by GPT-4

In this conversation, you asked for help in creating a web page that can detect the direction your finger is pointing and use it to draw on a canvas. The app should also change the color of the drawing based on the last color you spoke. I provided you with code and instructions for creating the app using handpose and speech recognition. We went through several iterations of troubleshooting issues with the code, such as accessing the `<video>` element, speech recognition not working, and displaying the last spoken color [Author's note: it was the last spoken utterance not color] and current color on the same line. Eventually, the app started working as intended.

GPT-4's Response to "Could You Generate a Description of How It Works That a 10-Year Old Might Understand"

This app is like a magical drawing board. It uses your computer's webcam to see your hand and can tell which way you're pointing your finger. When you move your finger around in front of the webcam, it's like using an invisible paintbrush to draw on the screen!

There's another cool trick this app can do: it can listen to what you say and change the color of the paintbrush based on the color you speak. So, if you say "red," the app will start drawing with red, and if you say "blue," it will switch to blue.

The app uses two special abilities of your computer. One is called "handpose," which helps the computer recognize your hand and know where your finger is pointing. The other is called "speech recognition," which helps the computer understand the words you say.

When you use the app, it watches your hand and listens to your voice. It then combines both of these inputs to create a fun and interactive drawing experience!

The App

The final product consists of 3KB HTML and 4KB JavaScript. The dialogue consists of about 4000 words and elapsed over 2 to 3 hours.

An App That Predicts Whether Some Text Expresses Confidence

Summary of the Dialogue as Generated by GPT-4

In this discussion, you asked for help in creating a web page that predicts the level of confidence for a given text based on a CSV file containing labeled data. I provided guidance for building a solution using TensorFlow.js and the Universal Sentence Encoder (USE) in a browser environment. We went through several iterations to improve the model, user interface, and functionality:

1. We created a simple neural network using TensorFlow.js and trained it using the provided data. We used the USE to convert text to embeddings.
2. We built an interactive web page that allows users to train the model and make predictions. The page includes a form for text input, a button to train the model, and a graph to display training loss.
3. We added CSS to style the web page.
4. We modified the model to include likelihood scores in the predictions.
5. We improved the model's architecture by adding more layers and dropout regularization.
6. We added an input field to let the user specify the number of training epochs.
7. We updated the graph in real-time during training to show the progress.
8. We added comments to the train function for better understanding.
9. We addressed an issue with case sensitivity by preprocessing the input text.

By following the provided guidance and code snippets, you should have a functional web page that trains a model to predict confidence levels in text and displays the results interactively.

GPT-4's Response to "Can You Explain How This App Works to a Young Child"

Sure! Imagine you have a magic box that can tell if someone is feeling confident, neutral, or not confident just by

listening to what they say. This magic box needs to learn what confidence sounds like before it can start making guesses. So, we give it examples of things people have said before, and whether those sentences showed confidence, were neutral, or lacked confidence.

When you press the “Train Model” button on the web page, the magic box starts learning from these examples. It practices many times (called “epochs”) to get better at understanding the differences between the three types of sentences. While the box is learning, you can see a chart that shows how well it’s doing.

Once the magic box has finished learning, you can type a new sentence into the text box, and the magic box will try to guess if it’s a confident, neutral, or not confident sentence. It will also tell you how sure it is about its guess, like “80% confident” or “60% not confident.”

And that’s how this app works! The magic box learns from examples and then uses what it learned to make predictions about new sentences.

The App

The final product consists of 2KB HTML and 6KB JavaScript. The conversation consists of about 3800 words and elapsed over 2 to 3 hours.

Confidence Predictor

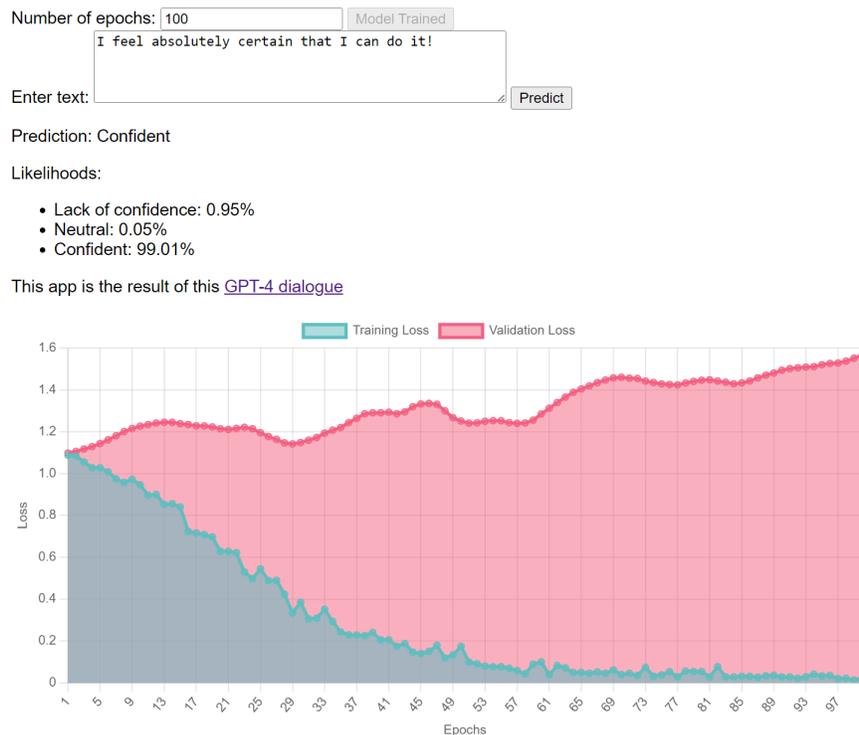


Figure 2 – A screenshot of a confidence predicting app

An App That Simulates the Conversation Between Any Two Personas

Summary of the Dialogue as Generated by GPT-4

In this discussion, you sought assistance in creating a web page where users can engage in a conversation with two virtual personas, Aristotle and Galileo powered by GPT using OpenAI's Chat API. We provided guidance on creating the chat interface, setting up the API calls, and handling different aspects of the conversation, such as alternating between personas.

Throughout the conversation, we addressed several issues related to the implementation, including repetitive messages, persona confusion, error handling, message formatting, and input field modifications. We also discussed how to make the speaker's name bold in the chat interface and suggested adjusting the temperature parameter to reduce the chances of repetitive responses from the AI.

By the end of the discussion, you had a working chat interface where users can converse with the virtual personas, and the API key input field was modified to be hidden like a password field.

GPT-4's Response to "Can You Explain How This App Works to a Young Child"

Sure! This app is like a special chatroom where you can talk to two pretend friends named Aristotle and Galileo. They are very smart and can answer lots of questions. When you type a message and press the button, the app sends your message to a big computer called GPT, which thinks of a reply for Aristotle or Galileo to say. Then the app shows their response on the screen so you can read it. You can keep chatting with them and learn fun things about science, philosophy, and much more!

The App

The final product consists of 2KB HTML, 1KB CSS, and 5KB JavaScript. The dialogue consists of about 6800 words and elapsed over 2 to 3 hours.

Virtual Persona Chat

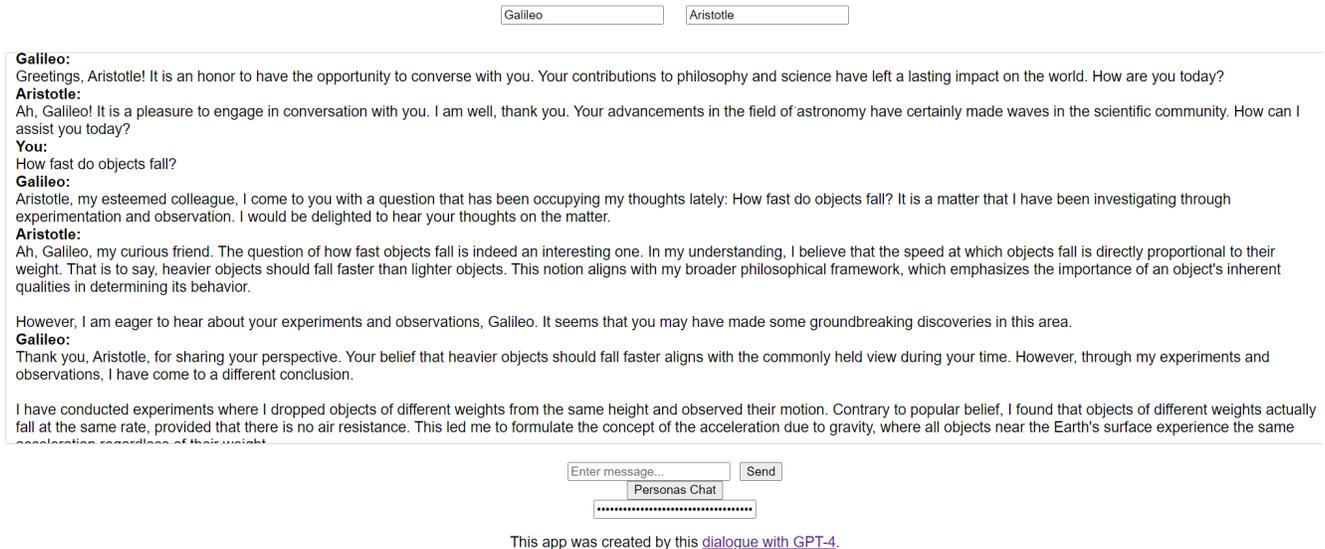


Figure 3 – Screenshot of a virtual conversation app that uses gpt-3.5-turbo

Not just Aristotle and Galileo

Later when testing the app I discovered that it didn't work properly when I entered new personas. So I continued the discussion but accidentally in a manner where ChatGPT didn't have enough context and the extended conversation isn't shareable. After several errors the app was revised to enable chats such as one where Aristotle and Galileo were replaced with the words "Lion" and "Elephant" [4].

But ChatGPT Can Do This Without a Specialized App

I then wondered if ChatGPT-4 could simulate a conversation between Aristotle and Galileo and myself. I tried the prompt "Can you simulate a conversation between Aristotle and Galileo in such a way that after every exchange I can add something to the conversation?" and not only did the conversation go well but I was able to bring Newton into the conversation at an appropriate time [4]. I tested this with four other chatbots with mixed results. And ChatGPT-4, as well as GPT-3, were able to simulate a conversation between a lion, an elephant, and myself.

Technical Details

Everything was done in a Chrome browser connected to the GPT-4 March 23 version of ChatGPT. Access to ChatGPT Plus is currently required to access GPT-4 in this manner and costs \$20/month. Alternatively, using the OpenAI API of GPT-4 costs \$0.06 for every thousand tokens (750 words) generated. So each dialogue would have cost between 25 and 50 cents. Free alternatives exist but the performance of Bard, Bing Chat, Claude, ChatGPT 3.5, and some open source models were markedly inferior to GPT-4. But there will no doubt be improvements in free alternatives.

GPT-4 can generate programs in other languages (at first it suggested Python for the confidence prediction app). An advantage of JavaScript is that running the app can be done in any modern browser without installing any software.

Discussion

There are many reasons for a child to learn to program. The question this paper raises (without answering) is how many of them still hold in an era where there is easy access to GPT-4 and the like. One answer is that the child is still programming – only they are doing so in English (or their language of choice, GPT-4 claims “Some of the languages I can converse in include English, Spanish, French, German, Italian, Portuguese, Dutch, Russian, Chinese, Japanese, Korean, Arabic, and many more.”). But they are programming at a much higher level of abstraction than what programming languages offer. They are expressing intentions not procedural instructions. It is a dialogue where the child not only tries to express what they want but also needs to provide the chatbot with useful feedback about failures and errors. The programs (nicely commented and formatted, displayed in five colors) are there for the child to copy and paste. Perhaps also to read or to ask questions of.

The focus of this paper is building AI apps but GPT-4 has been used to create a wide variety of apps including video games. Probably the majority of Scratch and Snap! projects could have been reproduced in JavaScript by chatting with GPT-4. Computer programming has empowered children to creatively express themselves in powerful ways. Chatbots like GPT-4 arguably empowers a larger number of children in a greater variety of tasks. They need fewer technical skills. (I typed the prompts but this is easy to replace with speech. They need to copy and paste the output of GPT-4 into HTML and JS files, but this was automated by ChatGPT’s WebDev plugin after this study was performed. They can construct apps that rely upon powerful AI capabilities such as pose detection, speech synthesis and recognition, vector encoding of texts, neural network training, and much more. While students may no longer be creating programs line-by-line or block-by-block, they instead will be designing apps and creatively combining AI capabilities.

References

1. Kahn, Kenneth. (1977). Three interactions between AI and education. In E. Elcock and D. Michie, editors, *Machine Intelligence 8: Machine Representations of Knowledge*. Ellis Horwood Ltd. and John Wylie & Sons.
2. Kahn, Ken and Winters, Niall. (2018). “AI Programming by Children”, Constructionism Conference, Vilnius, Lithuania.
3. Kahn, Ken. (2023). <https://tinyurl.com/apps-created-by-GPT4>
4. Kahn, Ken. (2023). <https://tinyurl.com/aristotle-galileo-plus>
5. Lane, Dale. (2023). <https://machinelearningforkids.co.uk/>
6. OpenAI. (2023). <https://platform.openai.com/docs/guides/chat>
7. Papert, Seymour. (1981) “Mindstorms: Children, Computers, and Powerful Ideas.”
8. Scratch. (2023). <https://scratch.mit.edu/studios/2924464>
9. Solomon, Cynthia Ann, Brian Harvey, Ken Kahn, Henry Lieberman, Mark L. Miller, Margaret Minsky, Artemis Papert and Brian Silverman. (2020). “History of Logo.” *Proceedings of the ACM on Programming Languages* 4: 1 – 66.
10. Wolfram, Stephen. (2017). <https://writings.stephenwolfram.com/2017/05/machine-learning-for-middle-schoolers/>

Embracing the Challenge

A Committed Constructionist's Reflections on Strategies for Fostering an Engaging Learning Community

Alberto Montresor, University of Trento, alberto.montresor@unitn.it

Francesca Fiore, University of Trento, francesca.fiore@unitn.it

Abstract

The UniTrento FabLab, located within the Department of Computer Science and Engineering at the University of Trento, serves as a vital educational hub for a broader constructionist community in the local area. By connecting university departments, local schools, cultural associations, and other stakeholders, the FabLab promotes free exploration, hands-on experimentation, and social interaction, ultimately fostering an inclusive and innovative learning environment. However, building such a community has not been without its challenges, many of which are still not completely solved. In this paper, we reflect on the history and organization of the UniTrento FabLab, examining both its successes and failures. We aim to provide both a starting point and a cautionary tale for those embarking on a similar journey from the point of view of an organization that recently started. While we acknowledge that many questions remain unanswered, we hope to initiate a debate on the most effective methods for promoting constructionist approaches, particularly within one's local community. Overall, our goal is not to evaluate the efficacy of the constructionist methodology but rather to encourage discussion and reflection on the best strategies to foster it.

Introduction

In Italy, university FabLabs are typically established within design, architecture, and art faculties. They provide students with access to digital fabrication tools that enhance their technical skills and stimulate their creativity (Blikstein, 2013). Alternatively, they can be found within civil and industrial engineering departments, giving technical students the opportunity to rapidly prototype their designs before moving them to production (Martin, 2015). These FabLabs promote the maker approach, which is based on hands-on and project-based learning methodologies, within the universities.

The FabLab at the University of Trento, on the other hand, has a unique story. The UniTrento FabLab was created within the Department of Computer Science and Engineering with a distinct aspiration: to serve as the “educational hub” for a broader constructionist community, connecting all university departments and potentially reaching all the educational stakeholders in the local area, such as schools, cultural associations, and museums.

Although some may find it surprising that an initiative like this originates from a computer science department, it is, in fact, a natural fit (Papert, 1980). Our primary aim is to promote the constructionist philosophy, which emphasizes free exploration, hands-on experimentation, and social interaction, by exploiting the protean ability of computers to embrace and facilitate learning across all the STEAM disciplines, ultimately fostering an inclusive and innovative learning environment (Resnick, 2017).

UniTrento FabLab is thus more than just a FabLab: it is a learning center, a professional development facility for teachers, and a place where university professors can meet to discuss innovative approaches to their teaching. It also serves as

a social club where students can hang out, freely explore, and connect their ideas. Instead of merely “being present” and hoping that its physical existence alone would facilitate the sharing of ideas, the UniTrento FabLab actively fosters a blending of ideas and skills. It facilitates projects, connects students, and promotes design events both within and beyond the university. In doing so, it exports the skills and enthusiasm of its students throughout the region and realizes the university’s third mission toward society.

To achieve this goal, the UniTrento FabLab has established an external “arm,” namely a cultural association called Glow. Its objective is to showcase the innovations and designs developed within the academy, by connecting with people and communities that are typically beyond the reach of an university, such as youth organizations, town squares, mountain villages, and more. Glow plays a crucial role in our design: not only does it implement projects funded by charitable and non-profit foundations, but it also brings together volunteers and enthusiasts who believe in constructionist ideas and might not otherwise be affiliated with the university.

The process of creating such an environment is ongoing. Although we only started recently (2019) and were hit by the COVID emergence like everyone else, the growth we are experiencing now is astounding. This is the time to reflect on the results achieved so far and to consider the challenges that lie ahead of us.

Building a thriving constructionist community is no easy task; it requires constant effort, adaptation, and collaboration among various stakeholders. Some of the key challenges we face include cultivating a sense of belonging and shared values among community members, while respecting and celebrating the diversity of backgrounds, disciplines, and expertise they bring to the table; establishing channels for effective communication and collaboration within the community, fostering an atmosphere of openness, trust and mutual respect; develop and maintaining partnerships with external organizations and institutions to expand the reach and impact of our initiatives; continuously assessing and refining our strategies and practices to ensure that we are effectively responding to the evolving needs and aspirations of our community members.

During the process of building our community, we found immense value in the extensive literature available on constructionism and its effect on learning in formal and informal settings (Papert, 1980; Martinez, 2013; Resnick, 2017). However, we observed a scarcity of research and reports addressing the broader objective for a university to create a constructionist community both within and outside its walls, ensuring its sustainability and growth (Taylor, 2016). While this paper may not have all the answers, we hope it offers valuable insights into the success we achieved and the challenges we encountered, and inspires other communities to embark on similar endeavors. By shedding light on the many open questions we continue to grapple with, we aim to foster a discussion not only on the most effective approaches to promote constructionist methodologies, inside and outside the university, but also on the process required to establish a thriving constructionist community.

The Context and a Brief History

The University of Trento is a medium-sized, generalist university with 16,000 students located in the alpine region of Italy. Trento is an autonomous province, enjoying a certain degree of political and administrative autonomy from the central government of Italy. This autonomy allows the province to manage its own affairs in areas such as education, healthcare, transportation, and local administration. It also enables the province to make decisions and policies that cater more effectively to the specific needs and interests of its citizens while preserving and promoting its unique cultural and linguistic heritage. As a result, a strong sense of community is present in the region. The University of Trento is the sole academic institution in the area, fostering strong ties between the university and the local community.

The University offers a variety of degrees in numerous fields, including science, engineering, humanities, law, business, social sciences, psychology, and more recently, medicine. Arts and design programs are absent, except for a blended

engineering and architecture degree with strong roots in the Department of Civil Engineering. Very recently, the university established a Teaching and Learning Center, trying to innovate its pedagogy, and started to participate into European networks where challenge-based learning is studied and encouraged.

In 2019, the Department of Computer Science and Engineering established a FabLab, which, after a period of reduced activity due to the pandemic, became fully operational in 2021. This FabLab opened its doors to students from all departments, both scientific and otherwise, as well as to students of the local schools, and, although less frequently so far, to the general public. The creation of the FabLab marks the culmination of several initiatives the department has launched over the past decade, with goals as varied as providing extracurricular activities for students and forging strong connections with the local community. Over the years, these goals have evolved into the broader ambition of innovating education across all disciplines and educational levels through the integration of constructionist theories and methodologies.

Next to the Fablab, Glow has been created, a cultural promotion association” (one of the legal forms of the third sector in Italy). Its mission is to broaden the reach of the constructionist community beyond the university walls and to disseminate the scientific achievements attained by the Fablab.

Figure 1 shows a diagram of our model. In input, there are the skills provided by the various departments that make up the university, embodied by our students, and a set of cultural associations that collaborate with us, some of which were founded by former students. At the center is the Fablab-Glow duo, operating in synergy as if it were a single entity. In output, there are our areas of intervention, not only within the university but especially in the world of education and the local community.

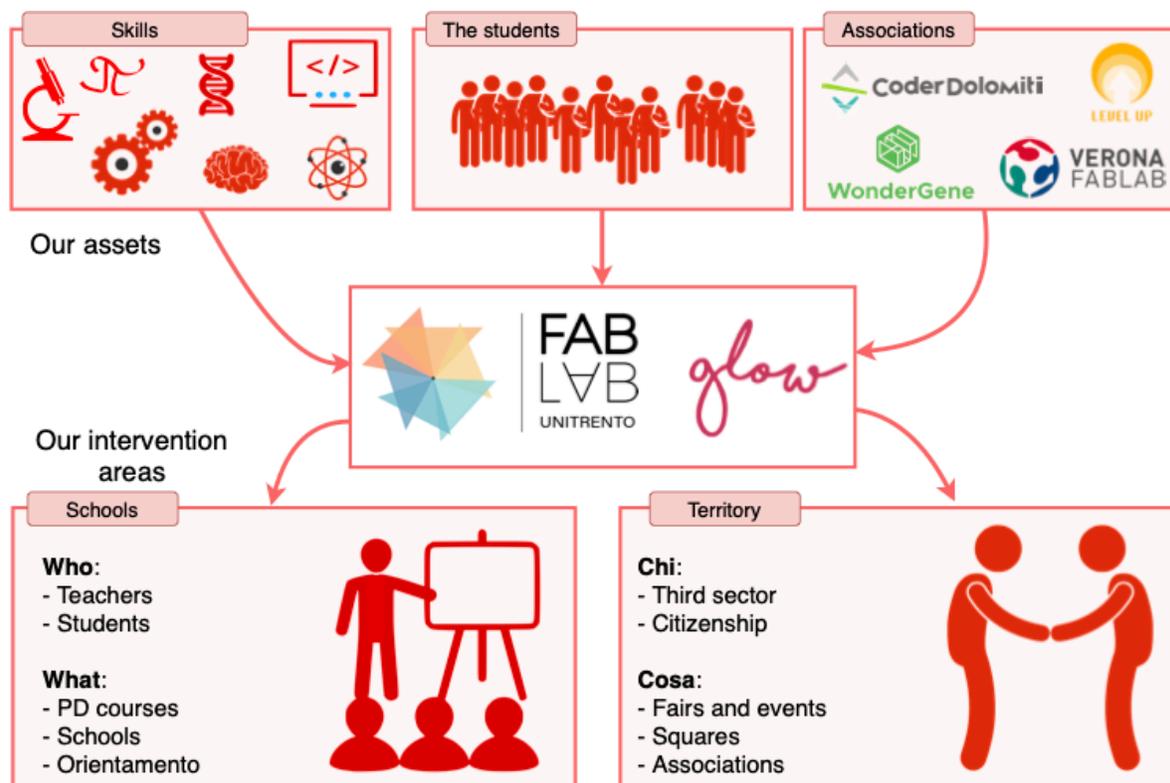


Figure 1 – Overall picture of the UniTrento Fablab ecosystem.

The FabLab UniTrento is coordinated by the two authors and is equipped with a technical staff unit to ensure the

operation of the devices; additionally, the second author is also the founder and president of Glow. The rest of the staff is hired on a project basis, according to the competitive calls won.

The Areas of Intervention

The FabLab's initiatives can be broadly categorized into three main areas: supporting university students, engaging with schools, and connecting with the local community.

Supporting University Students

Papert's constructionist vision, Resnick's creative learning approach, and the free access to new technologies provided by the maker movement are concepts that are seldom encountered in Italy's schools, particularly at higher levels. As students grow, they increasingly find themselves confined within individual disciplines, with limited opportunities for both interdisciplinarity and free experimentation. Consequently, they are forced into rigid learning patterns, becoming focused on obtaining grades and credits.

When students enter university, their experience often remains unchanged: they find themselves caught in a continuous cycle of lectures, studying, and exams, with little to no room for curiosity, serendipity, and personal exploration. This holds true even for courses employing innovative educational approaches, such as problem- and project-based methodologies (Barron, 1998). The UniTrento FabLab's primary objective is to break this cycle by providing students with a unique space in which they can develop their ideas, passions, and skills within a highly interdisciplinary context. Interdisciplinarity here means the collaboration between different academic disciplines and fields, fostering an environment where students from various backgrounds can merge their unique perspectives, knowledge, and skills to explore complex problems and create innovative solutions. It encourages creative thinking, enriches the learning experience, and allows students to see beyond the confines of their particular study area.

The UniTrento FabLab grants free access to students from all departments and offers basic skills training for those without technical backgrounds. To guarantee a truly authentic learning experience, the authors strongly believe that all activities offered by the FabLab should be extracurricular, not carry any credits, and be completely disconnected from any form of summative assessment (Hattie, 2007).

Faced with this newfound freedom, students often struggle to adapt – after years of indoctrination by schools, they seem to be always waiting for someone to tell them what to do (Kirschner, 2006). It is essential to provide them with the right prompts and create a community that can offer examples, fostering an exchange of ideas that enables a creative spark in students (Schunk, 2011). We offer a variety of initiatives to foster learning and growth among students:

- *Introductory workshops*: We regularly organize introductory workshops to help students acquire knowledge and skills related to machine usage; examples of topics include 3D printing, parametric 3D design, laser and vinyl cutting, CNC milling and engraving. The laboratory is more than just a Fablab, however; it can take the form of a hackerspace, and meetings related to software tools have been organized as well; Flutter, OpenStreetMap, and LaTeX are just a few examples.
- *Resident students*: We encourage university students to live in our spaces and enhance their functionality. They often take an active role, such as welcoming newcomers and providing explanations on how the laboratory works, driven by the enthusiasm of being part of a community. When they are particularly proactive and enthusiastic, they are promoted to the role of resident students; they can access the laboratory even in the absence of staff and

provide an essential contribution to the functioning of the laboratory.

- *Events and conferences*: We empower students to share their knowledge and transition from being learners to educators by allowing them to take on active roles in organizing workshops, seminars, and meet-ups on various topics. Some of the workshops listed above have been conducted by students.
- *Hackathons and competitions*: We often organize challenge-based events that enable students to test their skills and collaborate with companies and associations. We participated in several international hackathons and programming competitions, such as DigiEduHack (two of our teams won the last two editions) and Google Hashcode (our hub was ranked second in the world in the last three editions). But more importantly, we support local companies in the organization of small hackathons that are used to get to know our students.

The key to engaging students is helping them understand the significant contrast between the conventional learning methods they are accustomed to and the entirely distinct approach we adopt in the laboratory (Hyun, 2017). Once they grasp this difference, the next step is to engage them in spreading the initiative. They all become ambassadors of the FabLab, sharing their experience and recruiting new members. Moreover, they often become collaborators in activities outside of the lab, such as those described in the Sections titled “Towards Schools” and “Towards the Local Community”. Examples are to support younger students in carrying out projects and to assist teachers as they participate in activities promoted by the FabLab.

Towards Schools

An important aspect of the FabLab’s mission is its connection with the world of primary and secondary education. The challenges faced in this context are similar to those mentioned previously – constructionist approaches are rarely applied, and teachers often resist change (Le Fevre, 2014). The strategy we are adopting involves gently guiding teachers towards a more constructionist model, without forcing them, and allowing them the necessary time to adapt. We adopt a scaffolding approach, where teachers are first introduced to a well-defined initial environment and provided with teaching materials to start. Then, they are supported by our students in the initial implementation of the activities; finally, this support is gradually withdrawn as the teachers become more independent.

- *Teacher training workshops*: We organize professional development workshops for educators to learn about computational thinking, educational robotics, creative learning, and the maker approach. Our workshops provide teachers with both technical instruction and a space to discuss novel approaches to teaching, enabling them to incorporate hands-on learning and interdisciplinary problem-solving in their classrooms. More than 170 educators participated in the last edition of our main event, called Teacherdojo, which can be more aptly defined as a community of practice (Wenger, 1998), as our trainers are experienced educators themselves who substantiate constructionist theory with real examples of activities that have been successfully implemented in the classroom.
- *Curriculum development*: We partner with schools to create interdisciplinary, project-based curricula that prioritize experiential learning, teamwork, and critical thinking. This is achieved by incorporating FabLab resources and technologies into the educational programs, enabling engaging, hands-on experiences. These collaborations often arise from the workshops previously mentioned. Teachers recognize the potential advantages of these collaborations and seek support to more widely implement the constructionist approach in their teaching practices. For example, we recently developed a curriculum and materials for performing physics experiments that are instrumented with Arduino. By following a constructionist approach, the experimental materials must be assembled by the students. This provides a full and realistic experience that reflects the work of a physicist.
- *After-school programs*: We offer after-school programs for students, where they can engage in constructionist learning activities, learn new skills, and explore their interests. A particularly captivating example is “Matematica in Gioco” (Mathematics in Play), an after-school program in which high-school students from various

backgrounds—including both scientific and artistic specializations—designed and implemented board games inspired by mathematics, with the assistance of university students.

When possible, these programs are co-designed with schools and teachers: the idea is to develop activities that can fit their current curriculum, but providing students time and space for free exploration. For example, we co-designed a bio-informatics activity whose goal was to identify genetic diseases in datasets provided by the Biotechnology department. In the first two years, the activity was promoted by the university and the school. Starting next year, the activity will be guided solely by school's teachers, without our intervention.

Towards The Local Community

An important aspect of the FabLab's mission is its engagement with the local community. By fostering collaborations and organizing public events, the FabLab aims to create a network of individuals and organizations that promote informal learning events in the region. In all the activities listed above, cooperation with Glow is crucial; University bureaucracy would have hindered the completion of most of them.

- *Mobile Lab*: We created a mobile FabLab that brings science and technology to local communities, fostering formal and informal learning processes, creative co-planning, and community empowerment.
- *Mountain Cabin*: We operate a mountain cabin that hosts a variety of events, including science-focused summer camps, which immerse participants in the beauty of nature.
- *Partnerships*: The FabLab-Glow collaboration serves as the hub for a network of partnerships with organizations that foster informal learning and innovative teaching in the local area. For instance, Coderdojo Trento is a youth club that encourages computational thinking via coding; Level-up is an academic startup that creates kits for learning science and physics; Wondergene is an initiative focused on making genetic analysis, typically conducted in specialized laboratories, portable and accessible to non-experts, including schools. We also cooperate with Verona Fablab, which operates in a neighboring province, and we plan to expand our reach to other local areas.
- *Public events*: The FabLab organizes and participates in scientific fairs and public activities to engage with a broader audience and promote science and technology education. By showcasing the latest developments in the field and demonstrating the potential of constructionist learning, the FabLab aims to inspire community members to embrace innovative teaching methods and foster a culture of lifelong learning.

Open Questions

In building a thriving constructionist community, several open questions and challenges arise that need to be addressed in order to ensure the continued success of the UniTrento FabLab and similar initiatives. We will discuss some of these challenges here.

Q1: *Sustainability*. How can the UniTrento FabLab ensure long-term sustainability in its operations and community engagement? What measures can be taken to balance growth and resource management?

This is the fundamental question from which this article emerged. The first author's personal journey began with an encounter with constructionist literature more than a decade ago. Since then, he has spearheaded numerous initiatives within his department and university. After meeting with the second author, these experiences ultimately converged in the establishment of the FabLab as an educational hub, leading to the definition of the model described in this article. At the beginning, most of the activities rested on the shoulders of the two founders; fortunately, as the community

grows, an increasing number of people are becoming involved. Yet, the vision of the FabLab is still promoted and carried forward by the two of us, and the core group of people leading the Fablab has not expanded. The founders' syndrome is a common problem among many organizations (Schein, 2010). Given that the FabLab aspires to become a permanent center within the university, we must find new management models to ensure its sustainability over the years.

Q2: *Replicability*. How can the UniTrento FabLab's model be replicated in different settings? What are the key factors that contribute to its success, and how can they be adapted to other contexts?

We believe that addressing this question is fundamentally important for promoting the growth of the constructionist community. We are definitely not the first constructionist lab to be founded in a university, so we are likely grappling with the same issues that many other venues have encountered (Valentine, 2004). We believe that a literary debate on such issues is needed (Holbert, 2020), with this paper going in this direction.

Q3: *Integration with Formal Education*: How can the FabLab's constructionist approach be integrated into formal education systems at all levels (primary, secondary, tertiary) without compromising its core principles of free exploration, hands-on learning, and interdisciplinary collaboration? What might be the potential barriers and opportunities when aligning the constructionist approach with the existing pedagogical models in schools and universities?

Determining the ideal balance between the requirements of formal education – in particularly as declined in countries with more traditional educational systems (Kynigos, 2022) – and the freedom fostered by constructionism remains an unresolved issue, initially acknowledged by Papert himself (Papert, 1991). We believe that anyone captivated by the constructionist approach and striving to advocate for it within their community encounters this challenge. Along the way, the same mistakes may be repeated, such as the simplistic assumption that merely lecturing teachers about constructionism will pave the way for a bright constructionist future. Our current success stems from the understanding that the only feasible method for disseminating these ideas and cultivating a constructionist community is to embody the constructionist approach itself: creating an environment in which everyone involved—from students and teachers to volunteers and association staff—can appreciate the value of constructionism by experiencing it firsthand and rediscovering it anew.

A significant part of the constructionist approach is the embrace of “tinkering” – a playful and experimental exploration of materials, tools, and ideas. It is a method that welcomes trial and error, recognizing that mistakes are not failures but vital learning opportunities. This culture of accepting errors as part of the learning process is in stark contrast to many traditional educational systems, where errors are often penalized. Implementing a mindset that values mistakes as a source of insight and growth can be a transformative aspect of integrating constructionism into formal education. It encourages resilience, creativity, and the development of a deep, personal understanding of the subject matter.

Q4. *Collaboration and Networking*: How can the FabLab foster a culture of collaboration and networking among its community members, both within and beyond the university setting?

An indispensable component, often difficult to duplicate, involves nurturing a sense of unity and shared principles among community members, while valuing and honoring the variety of backgrounds, disciplines, and skills they provide (Schein, 2010). In our context, the community includes the FabLab staff, students engaged with the lab, former students who are now teachers, collaborators employed at Glow, and individuals involved in satellite associations.

To accomplish this, creating avenues for efficient communication and cooperation within the community is vital, promoting an environment of transparency, trust, and reciprocal respect (Katzenbach & Smith, 1993). We aim to organize regular community events and workshops to facilitate interaction, knowledge sharing, and skill development among members (Wenger, 1998); implement mentorship programs that pair experienced members with newcomers, fostering relationships and promoting the exchange of ideas (Kram, 1985); and recognize and celebrate the

accomplishments of community members, reinforcing their sense of belonging and motivation to contribute further (Amabile, 1997).

Q5. *Cooperation with external associations.* What are the most effective strategies to build and maintain partnerships with external organizations and institutions?

To ensure scalability, collaboration with external non-profit organizations is crucial. They can provide the workforce that a single lab could not furnish, and they are vital for sustaining the FabLab's growth and impact. We have adopted a dual model here, with Glow being directly founded by us. Meanwhile, other associations and companies form a constellation, each specializing in a different sector or regional area.

Adopting a boundary-spanning approach can help facilitate these collaborations, as it involves actively seeking opportunities to engage with diverse stakeholders and share resources, knowledge, and expertise (Aldrich & Herker, 1977; Tushman & Scanlan, 1981).

Additionally, the economic sustainability of these external associations is of significant importance. A clear understanding of the financial models, shared responsibilities, and revenue streams that support the collaboration is crucial for long-term success. By aligning the economic interests of the FabLab with those of the external associations, and ensuring transparency and fairness in financial agreements, the partnerships can be maintained on a stable and sustainable footing. This alignment contributes not only to the resilience and growth of the FabLab but also fosters a thriving ecosystem where each entity, including the university, benefits from mutual cooperation and shared goals.

Q6: *Measuring Impact:* What are the most effective methods to assess the impact of the FabLab's initiatives on students, educators, and the broader community? How can the FabLab continuously evaluate and improve its practices based on this assessment?

We have yet to find a definitive answer to this. To gather feedback on the experiences and perceived value of the FabLab's initiatives, we conduct regular surveys and interviews with students, educators, and community members. We monitor quantitative metrics such as attendance, participation rates, and the number of completed projects or collaborations. Additionally, we implement pre- and post-assessments to measure growth in skills, knowledge, and attitudes among participants.

Nevertheless, we remain unsatisfied. Given our relatively short history, longitudinal studies are still beyond our reach, and we may only perceive the indirect effects of our efforts, as evidenced by anecdotal stories of students that we have been able to follow from young age up to our classrooms, and reports from satisfied teachers. This lack of measurable impact may discourage many universities from pursuing such an approach.

Conclusions

Promoting a constructionist approach to teaching can be pursued in two ways: initiating major revolutions, such as the development of Logo in the 1980s and the development of Scratch more recently, which reach millions of students, teachers, and educators; or by helping one's local community realize and implement the promises of these major revolutions. This can be done more effectively when the relationship between the entity driving the change and the territory connected to it is particularly close, as in the situation described in this article. Despite the narrower scope, however, challenges are not lacking. The contribution of this article is to initiate a debate on the type of support that needs to be provided to these communities, in terms of sharing experiences and the difficulties encountered in the process of creation.

References

- Aldrich, H., & Herker, D. (1977). Boundary spanning roles and organization structure. *Academy of Management Review*, 2(2), 217-230.
- Amabile, T. M. (1997). Motivating creativity in organizations: On doing what you love and loving what you do. *California Management Review*, 40(1), 39-58.
- Barron, B. J., Schwartz, D. L., Vye, N. J., Moore, A., Petrosino, A., Zech, L., & Bransford, J. D. (1998). Doing with understanding: Lessons from research on problem- and project-based learning. *Journal of the Learning Sciences*, 7(3-4), 271-311.
- Blikstein, P. (2013). Digital fabrication and 'making' in education: The democratization of invention. In J. Walter-Herrmann & C. Büching (Eds.), *FabLabs: Of machines, makers and inventors* (pp. 203-222). Bielefeld: Transcript Publishers.
- Hattie, J., & Timperley, H. (2007). The Power of Feedback. *Review of Educational Research*, 77(1), 81-112.
- Holbert, N., Berland, M., & Kafai, Y. (Eds). (2020). *Designing Constructionist Futures: The Art, Theory, and Practice of Learning Designs*. MIT Press. Boston, MA.
- Hyun, J., Ediger, R., Lee, D. (2017). Students' Satisfaction on Their Learning Process in Active Learning and Traditional Classrooms. *International Journal of Teaching and Learning in Higher Education*, 29(1): 108-118.
- Katzenbach, J. R., & Smith, D. K. (1993). *The wisdom of teams: Creating the high-performance organization*. Harvard Business Review Press.
- Kynigos C. (2020). Half-Baked Constructionism: A Strategy to Address the Challenge of Infusing Constructionism in Education in Greece. In Holbert, N., Berland, M., & Kafai, Y. (Eds). (2020). *Designing Constructionist Futures: The Art, Theory, and Practice of Learning Designs*. MIT Press. Boston, MA
- Kirschner, P. A., Sweller, J., & Clark, R. E. (2006). Why minimal guidance during instruction does not work: An analysis of the failure of constructivist, discovery, problem-based, experiential, and inquiry-based teaching. *Educational Psychologist*, 41(2), 75-86.
- Kram, K. E. (1985). *Mentoring at work: Developmental relationships in organizational life*. University Press of America.
- Le Fevre, D.M. (2014) Barriers to implementing pedagogical change: The role of teachers' perceptions of risk. *Teaching and Teacher Education*, 38:57-64.
- Nahapiet, J., & Ghoshal, S. (1998). Social capital, intellectual capital, and the organizational advantage. *Academy of Management Review*, 23(2), 242-266.
- Martin, L. (2015). The promise of the maker movement for education. *Journal of Pre-College Engineering Education Research (J-PEER)*, 5(1), 30-39.
- Papert, S. (1980). *Mindstorms: Children, computers, and powerful ideas*. New York, NY: Basic Books.
- Papert, S. (1991). Situating constructionism. *Constructionism*, 36(2), 1-11.
- Resnick, M. (2017). *Lifelong Kindergarten: Cultivating Creativity through Projects, Passions, Peers, and Play*. MIT Press.
- Schein, E. H. (2010). *Organizational culture and leadership* (4th ed.). Jossey-Bass.

Schunk, D.H., & Zimmerman, B. (Eds.). (2011). *Handbook of Self-Regulation of Learning and Performance* (1st ed.). Routledge.

Taylor, N., Hurley, M. and Connolly, P. (2016). Making Community: The Wider Role of Makerspaces in Public Life. In Proceedings of the 2016 CHI Conference on Human Factors in Computing Systems (CHI '16). Association for Computing Machinery, New York, NY, USA, 1415–1425.

Tushman, M. L., & Scanlan, T. J. (1981). Boundary spanning individuals: Their role in information transfer and their antecedents. *Academy of Management Journal*, 24(2), 289-305.

Valentine, D.W. (2004) CS educational research: a meta-analysis of SIGCSE technical symposium proceedings. In Proceedings of the 35th ACM SIGCSE technical symposium on Computer science education, SIGCSE '04, pages 255–259.

Wenger, E. (1998). *Communities of practice: Learning, meaning, and identity*. Cambridge University Press.

Algorithms for Designing Learning

A Constructionist Perspective on Teacher Professional Development

Jake Rowan Byrne, Trinity College Dublin, The University of Dublin, jake.byrne@tcd.ie

Carina Girvan, Trinity College Dublin, The University of Dublin, girvanc@tcd.ie

Abstract

With the focus on 21st century skills, also known as transversal competencies, ever growing in the educational policy landscape, constructionism has a new opportunity to make a meaningful impact on both educational policy and practice. However, addressing the challenge of scaling constructionist approaches is one of the biggest obstacles facing the constructionist community. In this paper, the authors propose an algorithmic analogy to designing learning activities that can help educators implement constructionism in a more systematic and scalable way. Algorithms for Designing Learning engage teachers as constructionist learners in the process of designing constructionist learning experiences for others. They become a professional development tool, making tangible the abstract ideas of theory, without pre-prescribing the learning activities, domains or profiles of learners that teachers are designing for. The Bridge21 Activity Model is one such algorithm for designing learning activities that draws on Design Thinking principles with strong constructionist foundations. It has been used across a wide range of different subject areas from the Arts and Humanities through to STEM. It has also been used in a wide variety of learning contexts from designated disadvantaged schools, through to private schools, mixed and single gender schools, urban and rural schools, in educational outreach and beyond. We explore how the activity model can be seen as an algorithm, with procedures that can call other procedures and loop back as needed. In the context of professional development, whether in a formal course or informal mentoring, the algorithm acts as a boundary object for different actors within a community of practice. As a tangible tool, it mediates teachers' engagement with abstract theory and enables them to engage in the process of creation, testing, reflection and refinement as they develop and redevelop learning activities for their students, whilst simultaneously developing and redeveloping their own understanding of constructionism.

Introduction

There is no doubt that constructionism has influenced formal and informal education around the world. In recent years we have witnessed the international second wave of programming in schools, in which learning to code is contextualized through the creation of an artefact largely influenced by the substantial work of the constructionist community in the 1980s and 1990s [1]. Makerspaces have also become increasingly popular at an international level, providing informal and nonformal environments for constructionist learning.

At the same time, there are relatively untapped opportunities for constructionism to influence policy and practice within formal education. Internationally, there are increasing expectations at a policy level that children and young people should be developing 21st century (transversal) skills and competencies in school [2, 3] but the same policies typically lack clear direction on how this should be achieved. In some countries there are new opportunities for teachers to develop their own curricula (e.g. the New Curriculum for Wales), yet teachers typically lack professional experience or training to do so.

In these cases, there are significant opportunities for constructionism to lead pedagogy. Indeed, there is an increasing body of research [4, 5] and examples from teachers' own practice [6] to show constructionist activities develop 21st century skills alongside domain knowledge and in an environment where teachers and schools can develop their own curricula not only to meet the academic needs of students but also make learning relevant to their everyday lived experience. Constructionism provides a theoretical foundation upon which teachers can design such a curriculum which could enable meaningful interdisciplinary teaching and support new ways of thinking about assessment.

Yet, scope and scaling have long been problems with mainstreaming constructionism in schools. With much of the past and current research focused on computer science and math education, particularly when it comes to scaling (see for example ScratchMaths, Globaloria), it can be difficult for outsiders (as for many insiders) to imagine what a constructionist learning experience could look like outside STEM subjects. Many integrated STEAM projects can also be critiqued for being tokenistic when it comes to Arts and even Science. This is not to say that there are no excellent examples of constructionist STEAM, Arts or even Social Science learning activities. Indeed, in recent years Turtle Stitch and tangible programming have been rapidly growing and brought a new and much needed emphasis on the Arts and field of Design. However, they remain in the minority, are not in the mainstream and are rarely at the forefront of the mind when "constructionism" is mentioned. This leads to questions such as: How can we improve the visible scope of constructionism? How can we achieve scaling?

We argue that teacher professional development is the key to unlocking the potential of constructionism in the classroom and wider transformation of schools. While research and policy are obvious targets for action, without teachers, the change-makers in classrooms, constructionism cannot proliferate. However, teachers are often reticent to use constructionism in the classroom without a pre-defined activity. We often hear that constructionism is "a nice idea but it wouldn't work in my subject" or "it wouldn't work in my school/classroom". This aligns with others' experiences, e.g. Holbert who describes teachers assuming that constructionism "only works in the best schools with the most successful kids" [7, p. 141]. Essentially, teachers are conceptualizing constructionism as an 'elite' pedagogy. In addition, we (as a community of researchers) are often guilty of bringing innovations to classrooms and when the researcher leaves, so too does the innovation. This inhibits sustainability of interventions and at worst fuels teachers' existing views that they could never achieve this on their own in their classroom. So, if we want constructionist learning to be a regular experience for all students in all subjects and at all stages of their education, we contend that as a community we must prioritize, problematize and reconceptualize our engagement with teachers.

Despite their importance, teachers are often sidelined in constructionist theory and research. Indeed, they do not even make it into the index of the recent *Designing Constructionist Futures* book [1]. There has been limited engagement by the constructionist community in problematizing and developing solutions for teacher education. Notable exceptions include the work of Butler and Leahy [8] in pre-service teacher education, Brennan [9] in professional development. Significantly, both are in the context of computational thinking. This is not to say that constructionism does not feature in teacher education and professional development courses world-wide, but that where it does occur the design and outcomes are under-researched. Thus, we lack evidence and 'best' practice to share within and outside the community.

To begin to address these problems, this paper engages in a playful exploration of constructionist concepts with the aim of providing new ways of thinking about how we can achieve broader adoption of constructionism through synergies with emerging 21st century pedagogic praxis which align with constructionist theory, the development of professional practice and new policy directions. We draw on our own experiences from a university outreach program in schools (blinded), post-graduate certificate program for teachers (blinded) and an educational robotics project in schools (blinded), all underpinned by constructionist theory. Our exploration begins with a brief exploration of the potential and pitfalls of professional development, before focusing on the teacher who is unfamiliar with constructionism and unpacks some of the reasons for their reticence. We then present *Algorithms for Designing Learning* as a way to engage teachers as constructionist learners, in the process of designing constructionist learning experiences for others. A practical

example is offered, before considering the implications of this way of thinking about the classroom, learning design and professional development.

Professional Development

The importance of professional development (PD) which involves active learning and reflection is well established [10, 11] yet the initial introduction of new ideas and practices are still typically presented to teachers using traditional approaches such as transmission of information and observation of ‘expert teachers’ with experienced classes, which does not attend to the personal nature of PD. While Day and Sachs [12] highlight the value of engaging teachers in PD experiences which are meaningful and in alignment with teachers’ personal beliefs and values, there is a significant challenge when we want to design PD which will directly challenge teachers’ existing practices. Additionally, there is often an assumption that having engaged in PD activities, teachers will be able to simply replicate the practices that they have been exposed to [13].

Traditional PD, characterized by teacher-centered, transmission of information to teachers (in the role of learners) and assumptions about the individual processes that lead to an immediate change in practice and the ability to apply a new approach in a variety of contexts, clearly fails to align with constructionist values. Critically, it has also been found to be “insufficient to foster learning which fundamentally alters what teachers teach or how they teach” [14, p. 47].

These well-established and ongoing issues, raised in the international literature on PD in general, are acutely important when we consider both the reasons why teachers are reticent to use constructionism in their own classrooms and how we, as constructionists, should position the teacher as a learner.

Valuing the Teacher

As Holbert notes, “Constructionism respects the learner above and beyond...and valuing the learner – their experiences, perspectives, and needs – also means valuing their frustration, their anxiety and anger”. [7, p. 142]. If this is the case, and we consider teacher PD to universally position the teacher as a learner, then those of us who are passionate about empowering teachers to be designers and facilitators of constructionist learning experiences in their own classrooms, need to acknowledge and work with teachers to address these barriers to learning.

Some of the barriers we have encountered over the years that are also apparent in the literature include a sense that constructionism is an abstract, intangible theory with no clarity on how to operationalize it; as previously described, constructionism can be viewed as a ‘pedagogy of the elite’; examples are domain specific, lack identifiable generalizable features and considered either “impossible” or “too childish” for the teachers’ own students. Many teachers express having no recognizable personal experience of engaging in a constructionist activity as a student themselves, meaning they struggle to conceptualize the activity from the learners’ point of view – including the challenges and opportunities it might present their learners. Assumptions that teachers need to have expertise in coding can also discourage non-specialist teachers. Time is often seen as another barrier. From inflexible timetables and an over-crowded curricula to perceptions of students not having sufficient time to fully engage and challenges about when to stop. Along with being time-consuming, teachers also fear student-directed activities will become directionless and students will fail to engage with the curriculum knowledge the teacher could have imparted in significantly less time; whilst also being concerned that each project will take students within the same class in different directions and beyond the expertise of the teacher who will no-longer be able to support the student. For many this last point is a significant threat to their identity as a teacher.

Changing Teacher's Values and Beliefs Through Professional Development

It is essential that in any PD program, we address the underpinning ideas, beliefs and values of teachers, which inform, justify and sustain existing practices [15]. Pre-existing teacher-role identity [16] influences these ideas, beliefs and values, which are reinforced by pressures from national assessments and cultures of compliance within schools. While a significant motivating factor for teachers is observing positive changes in student outcomes [17], the potential of confirmation bias on negative outcomes should also be considered.

Extended experiential learning [18, 19] provides opportunities to not only take a learner-centered approach to teacher PD, but an opportunity for the teacher to experience the pedagogy for themselves as a learner, prior to designing learning activities for their own students. It is highly effective in changing teachers' attitudes and beliefs. As Papert noted, the teacher first needs to become a constructionist before they can design constructionist learning experiences. It also tackles head-on the notion of constructionist pedagogy being 'elite' by providing opportunities for teachers to take a step back and observe their own students engaging in the same types of learning activities. Yet significant issues remain – how can we continue to support teachers and foster their independence when they are no longer engaged with the so-called 'experts'? How can we scale the experience with limited human resources? How can we distill the abstract theory into a tangible yet sufficiently generalized form so that it can cross subject domains, educational phases and enable teachers to engage in constructionist PD?

We argue that teachers require an object-to-think-with. A tool with which they can tinker, play with ideas, share with others and move from the abstract to the tangible and back again. We call these tools 'Algorithms for Designing Learning'.

Why Algorithms for Designing Learning?

Algorithms provide step-by-step processes to follow which are consistent and scalable. There is a clear end and depending on their initialization the outcome is relatively predictable. Essentially what this describes are the supports that many of the teachers we work with are looking for as they begin to design their own constructionist learning experiences. Thus, algorithms become a metaphor for a specific sub-set of learning design tools. In this section we expand on this metaphor, providing specific examples and discussing how algorithmic design tools work as objects for teachers to think with, becoming boundary objects and mediating artefacts in both formal and informal professional development activities.

Design Thinking and Other Process As Algorithms

At first algorithms might seem to be too inflexible to support creative, constructionist teachers in the classroom. We hope to demonstrate that there are a number of possible real-world algorithms that might be considered for this purpose, understanding that the metaphor of the algorithm would align more closely with Meta-Heuristic Algorithms [20]. These approaches are not problem specific and do not assume optimal solutions as they are approximate and non-deterministic in nature. It is with this approach in mind that we explore Design Thinking and the Bridge21 Activity Model as two possible processes that could be used for such an approach in the context of designing learning experiences, noting that there are other possible processes (Figure 1) that are currently used in other domains that might be similarly applicable.

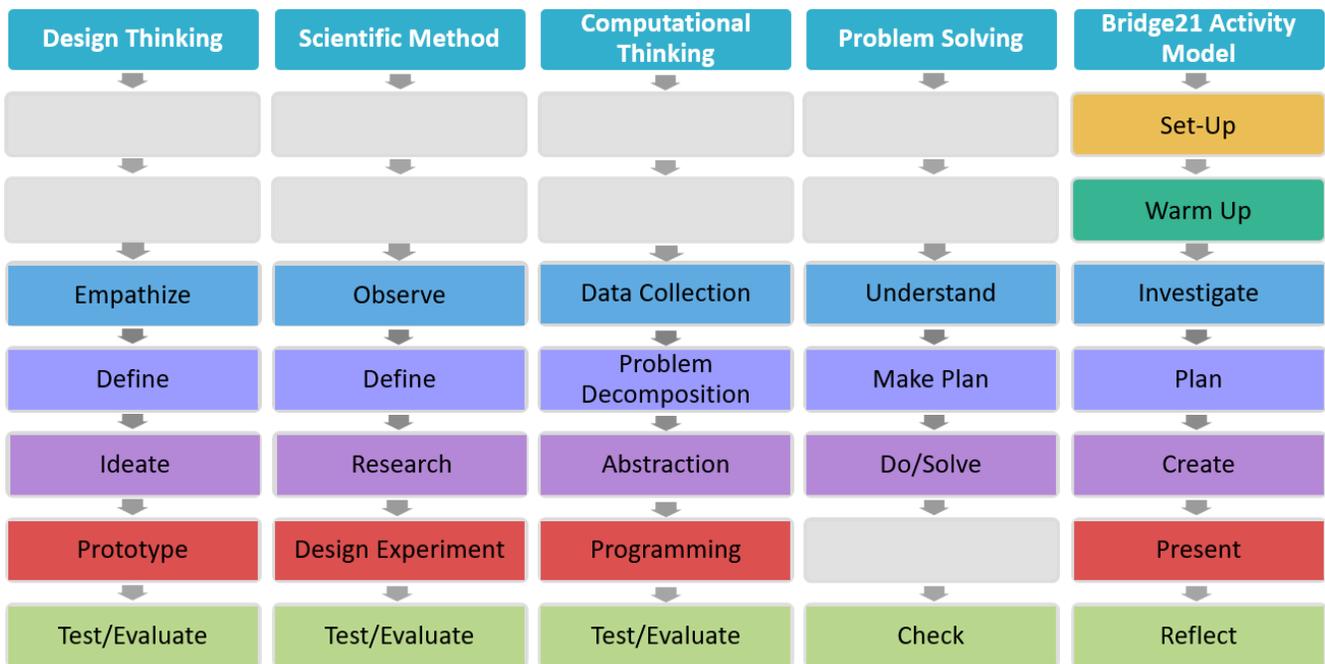


Figure 1: Algorithms for Designing Learning

Design thinking is a common example of such a process. At its core, design thinking involves empathizing with users, defining the problem, ideating potential solutions, prototyping and testing, and iterating based on feedback [21]. This process is characterized by an emphasis on creativity, collaboration, and experimentation, making it a good example of an algorithm for learning. The iterative nature of design thinking also aligns with constructionist approaches to learning, which emphasize the importance of learners actively constructing their understanding through a process of exploration and inquiry. Design thinking shares features of algorithms such as procedures, call-backs, iterations/loops and testing (Figure 2). It is for this reason we consider the algorithmic analogy useful, where it provides a more flexible and non-linear perspective on what might be more traditional approaches such as lesson or activity plans, while still “bounding” the learning.

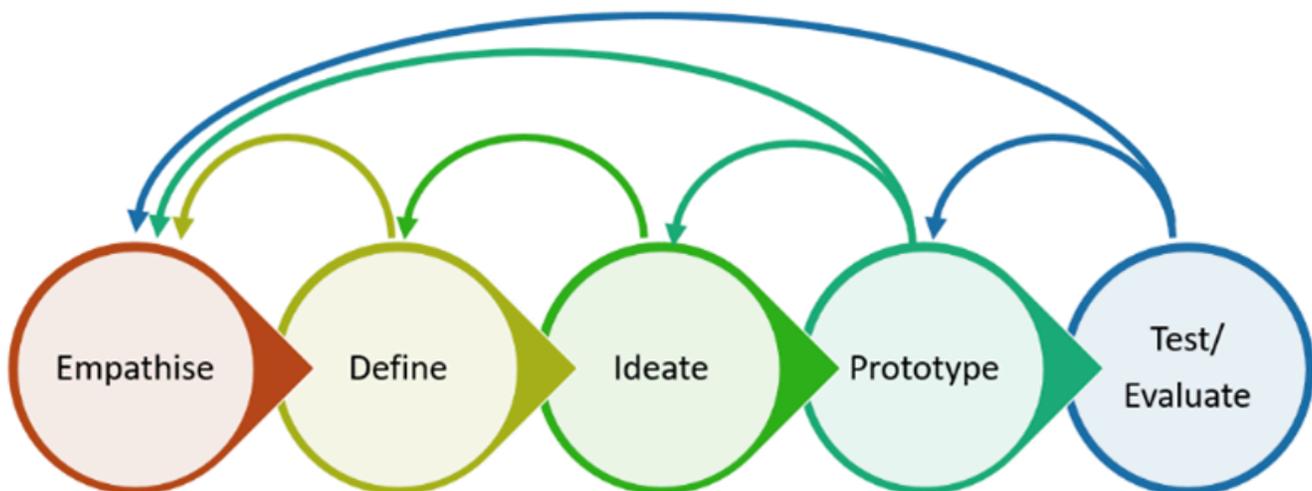


Figure 2: Design Thinking with call-backs, loops and iterations
The Bridge21 Activity Model – an Algorithm for Designing Learning

Design thinking is a relatively new and under-theorized pedagogical approach, emerging in classrooms today. By contrast, the Bridge21 Pedagogical Model (Figure 3a) is an established pragmatic approach to constructionism and 21st Century education that has been adopted by teachers in schools across Ireland and in smaller numbers across Europe and India. It has been implemented in diverse subject areas, spanning the Humanities and STEM. While the Bridge21 pedagogical model outlines the fundamental components and context that are essential for creating a successful constructionist, 21st-century learning environment, it does not offer a comprehensive framework for the design of activities. This is where we argue that teachers need an algorithm for designing learning, which abstracts a generalizable process, bounds it and makes it tangible for teachers to work with as an object-to-think-with. The Bridge21 Activity model was designed to achieve just that [22].

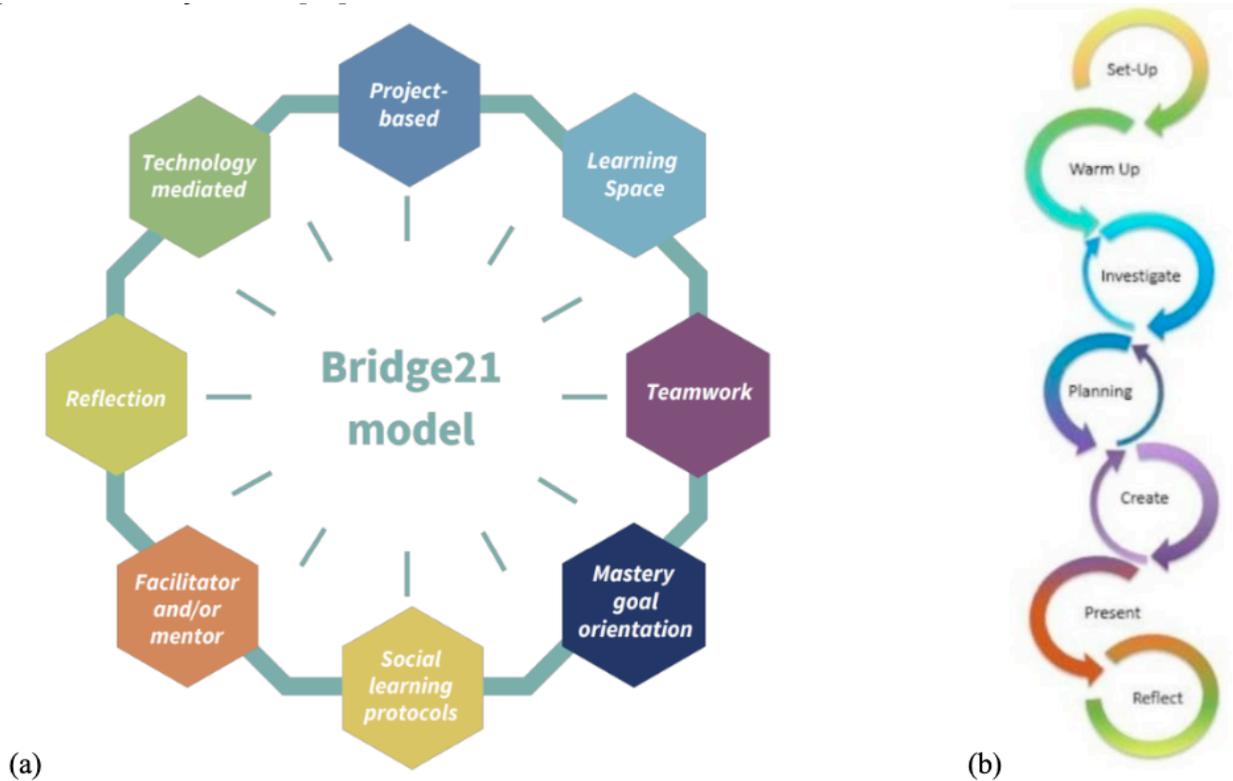


Figure 3: (a) Bridge21 Pedagogical Model (b) Bridge21 Activity Model

The Bridge21 Activity Model, consisting of seven stages (Figure 3b), can be used as a guide for designing a learning activity. Similar to design thinking, the algorithm permits a non-linear approach, allowing teams to revisit and modify previous stages as necessary. It is generic and generalizable enough that it has been used across the curriculum in subjects such as History [23], English [24], Physics [25] and Mathematics [26] with many more subject areas covered in practice by graduates of the Postgraduate Certificate in 21st Century Teaching and Learning in Trinity College Dublin [27]. Significantly, it has supported teachers to integrate 21st century skills/competencies into their subject-specific teaching and removed barriers to the incorporation of constructionist learning in the classroom [28], by providing a tangible process to follow, which is sufficiently open to be flexible to any domain or contextual needs.

With an algorithm for designing learning, teachers can use and adapt the steps of the Bridge21 Activity Model as they would alter procedures in an algorithm, noting that procedures can call other procedures and loop back as might be needed, analogous to how a coder might adapt or design an algorithm. These calls to other procedures might be implicit or explicit teaching strategies, such as providing additional scaffolding or to take a Socratic questioning

approach to student guidance. But ultimately, as the teacher fleshes out the activity plan with specific ideas, it makes the abstract thought process behind the final lesson tangible. In doing so, the ideas behind the lesson which plays out in the classroom is sharable, much like the code under the Scratch game. Both can be shared, discussed, returned to, interacted with and modified with and by others. In addition, the activity plan can be tested through the delivery of the activity, providing another analogous link to running an algorithm as a program.

Algorithms As Mediating Artefacts And Boundary Objects To Support Professional Development And Beyond.

We have found the Bridge21 Activity Model to be invaluable in professional development. It has provided teachers with a mediating artifact [29] as they try to give form to their initial ideas, whilst simultaneously developing their nascent abstract understanding of what constructionist activities might 'look like' in their own classrooms. At the other end – when a lesson or series of lessons have concluded – the algorithm provides a tool to scaffold the teacher's reflection on action. Reflection on action is essential part of professional development [30] but teachers often lack tangible tools to mediate their personal reflection process.

Algorithms are usually initialized using a set of starting variables or factors, in this context these factors might be how the classroom environment is organized, what resources are available, time, the curriculum content to be covered, the students' abilities or any other factors that might influence the learning environment. In creating their own activity plans for their own classes using the model, teachers generate their own objects-to-think-with, which enable “an intersection of cultural presence, embedded knowledge, and the possibility for personal identification” [31, p. 11].

The algorithm metaphor also makes what can seem complex and abstract processes and theory tangible and thus sharable. They become boundary objects that facilitate discussion of pedagogy and intervention [32], essential in the professional development process whether supported externally through formal courses or informally through mentoring relationships. As a boundary object, the algorithm is not the lesson plan, the classroom activity, nor the reflection itself, but a tool to support those activities. We have also found that our algorithm for Bridge21 Pedagogy is not only valuable in professional development settings but also as a boundary object when engaging senior management in schools, policy makers and even parents with constructionist ideas as part of an agenda of whole school transformation and curricula reform.

Conclusion

Purist notions of what constructionism is (often held in the minds of others), the abstract presentation of theory, and a lack of concrete examples beyond programming or mathematical problem-solving, have held back the mainstream adoption of constructionism in classrooms. With global educational policy interest in the cross-curricula development of 21st century skills (also known as transversal competencies) in the classroom, a new opportunity has arisen for constructionist pedagogy to shape the future educational landscape. However, teachers often lack experience of constructionist pedagogy and believe it to be at odds with their everyday professional experience.

To address this, our paper has presented Algorithms for Designing Learning as one piece of a wider professional development puzzle, which values the teacher, their experiences and beliefs. Algorithms such as the Bridge21 Activity Model engage teachers as constructionist learners in the process of designing constructionist learning experiences for others. They have been used in both formal and informal professional development activities across Arts, Humanities and STEM disciplines. They empower teachers to have conversations and build on what already works well, while

creating the space for innovative ideas and alternative approaches. They also enable a shift in focus from the teaching of domain specific knowledge to the teaching of transversal competencies and 21st century skills, whilst still meeting curriculum requirements. Not limited to the classroom, Algorithms for Designing Learning can also be seen to influence the development of national curricula, such as the Leaving Certificate Computer Science curriculum in Ireland, through the spiral curriculum adopted and the focus on applied learning tasks [33].

References

1. Holbert, M. Berland, and Y. B. Kafai, *Designing constructionist futures: The art, theory, and practice of learning designs*: MIT Press, 2020.
2. E. Care, K. Anderson, and H. Kim, "Visualizing the breadth of skills movement across education systems," *Brookings Institution*, 2016.
3. OECD. "The Future We Want: The Future of Education and Skills, Education 2030," [https://www.oecd.org/education/2030/E2030%20Position%20Paper%20\(05.04.2018\).pdf](https://www.oecd.org/education/2030/E2030%20Position%20Paper%20(05.04.2018).pdf).
4. C. M. Wickham, C. Girvan, B. Tangney, A. Sipitakiat, and N. Tutiyaiphuengprasert, "Constructionism and microworlds as part of a 21st century learning activity to impact student engagement and confidence in physics," *Constructionism*, pp. 34-43, 2016.
5. M. Qian, and K. R. Clark, "Game-based Learning and 21st century skills: A review of recent research," *Computers in human behavior*, vol. 63, pp. 50-58, 2016.
6. J. Jenner, A. Jeethan, and M. Zupan. "Teaching 21st Century Competencies Through Makerspaces : An Introduction," <https://openlibrary-repo.ecampusontario.ca/jspui/handle/123456789/1192>.
7. N. Holbert, "Constructionism as a Pedagogy of Disrespect," *Designing Constructionist Futures: The Art, Theory, and Practice of Learning Designs*, pp. 141-150, Boston: MIT Press, 2020.
8. D. Butler, and M. Leahy, "Developing preservice teachers' understanding of computational thinking: A constructionist approach," *British Journal of Educational Technology*, vol. 52, no. 3, pp. 1060-1077, 2021.
9. K. Brennan, "Beyond technocentrism: Supporting constructionism in the classroom. *Constructivist Foundations* 10 (3): 289-296," 2015.
10. D. Clarke, and H. Hollingsworth, "Elaborating a model of teacher professional growth," *Teaching and teacher education*, vol. 18, no. 8, pp. 947-967, 2002.
11. L. M. Desimone, "A primer on effective professional development," *Phi delta kappan*, vol. 92, no. 6, pp. 68-71, 2011.
12. C. Day, and J. Sachs, "Professionalism, performativity and empowerment: Discourses in the politics, policies and purposes of continuing professional development," *International handbook on the continuing professional development of teachers*, pp. 3-32: Open University Press, 2004.
13. A. Datnow, L. Hubbard, and H. Mehan, *Extending educational reform*: Taylor & Francis, 2002.
14. B. Boyle, D. While, and T. Boyle, "A longitudinal study of teacher change: What makes professional development effective?," *Curriculum Journal*, vol. 15, no. 1, pp. 45-68, 2004.
15. P. A. Alexander, "Charting the course for the teaching profession: The energizing and sustaining role of motivational forces," *Learning and Instruction*, vol. 18, no. 5, pp. 483-491, 2008.
16. J. G. Knowles, "models for understanding pre-service and beginning teachers' biographies: illustrations from case studies," *Studying teachers' lives*, pp. 111-164: Routledge, 2013.
17. T. R. Guskey, "Professional development and teacher change," *Teachers and teaching*, vol. 8, no. 3, pp. 381-391, 2002.
18. L. Fisher, J. R. Byrne, and B. Tangney, "Teacher Experiences of Learning Computing using a 21st Century Model of Computer Science Continuing Professional Development." pp. 273-280.
19. C. Girvan, C. Conneely, and B. Tangney, "Extending experiential learning in teacher professional development," *Teaching and teacher education*, vol. 58, pp. 129-139, 2016.
20. S. Desale, A. Rasool, S. Andhale, and P. Rane, "Heuristic and meta-heuristic algorithms and their relevance to the

- real world: a survey,” *Int. J. Comput. Eng. Res. Trends*, vol. 351, no. 5, pp. 2349-7084, 2015.
21. T. Brown, and J. Wyatt, “Design thinking for social innovation,” *Development Outreach*, vol. 12, no. 1, pp. 29-43, 2010.
 22. J. R. Byrne, S. Kearney, and K. Sullivan, “Technology-mediated collaborative learning: The Bridge21 activity model in theory and practice,” *Didactics of smart pedagogy: Smart pedagogy for technology enhanced learning*, pp. 309-330, 2019.
 23. D. O'Donovan. “Enquiry Based Learning at Bridge21,” <https://sites.google.com/site/enquirybasedlearningatbridge21/home>
 24. S. Kearney, “Using the Bridge21 pedagogical model of 21st century teaching and learning to teach new literacies in second-level English education, and the impact on students’ attitudes,” Trinity College Dublin. School of Computer Science & Statistics. Discipline ..., 2018.
 25. C. Wickham, “Investigation into the use of microworlds as part of a 21st century learning activity and the impact on student engagement and confidence in physics,” 2015.
 26. I. Boran, “As Part of a 21st Century Learning Activity, an Investigation into the Effect of Utilising a Synthesized Problem Solving Model in a Microworld Simulation to Develop Problem Solving Skills in Maths Education,” 2017.
 27. A. Bray, J. Byrne, and B. Tangney, “STEM continuing professional development for 21st Century teaching and learning: The Bridge21 approach,” *Science and mathematics education for 21st Century citizens: Challenges and ways forward*, pp. 3-23, 2020.
 28. A. Bray, J. Byrne, B. Tangney, and E. Oldham, “The Bridge21 Framework: Impact on Teachers and Implications for Equitable, Inclusive Classrooms,” *ATEE*, pp. 151, 2023.
 29. G. Conole, “The role of mediating artefacts in learning design,” *Handbook of research on learning design and learning objects: issues, applications, and technologies*, pp. 188-208: IGI global, 2009.
 30. D. A. Schon, “The reflective practitioner,” *New York*, 1968.
 31. S. Papert, *Children, computers, and powerful ideas*: Harvester, 1980.
 32. C. Kynigos, “Constructionism: Theory of learning or theory of design?” pp. 417-438.
 33. C. Connolly, J. R. Byrne, and E. Oldham, “The trajectory of computer science education policy in Ireland: A document analysis narrative,” *European Journal of Education*, vol. 57, no. 3, pp. 512-529, 2022.

Brazilian Creative Learning Network

A social movement approach to constructionist educational reform

Ann Berger Valente, MIT Media Lab, annbv@media.mit.edu

Leo Burd, MIT Media Lab, leoburd@media.mit.edu

Abstract

Brazil has a long tradition of innovative educators, artists, researchers, inventors who have been working to develop a meaningful, student-centric education aligned with the ideas of constructionism in a variety of formal and informal educational settings. Often these individuals and organizations have supported these efforts from the margins – feeling isolated and lacking the power and positionality to make large systems change. The Lifelong Kindergarten group at the MIT Media Lab, through the Brazilian Creative Learning Network, has advanced the initiatives of these pathfinders to address the question of how to foster learning experiences that are more creative, meaningful, and hands-on for young people across Brazil. Utilizing the activism techniques of social movements, inspired educators from all levels of the educational ecosystem, from classroom teachers to decision makers in the secretaries of education, are joining together in this grassroots movement. The paper discusses some of the strategies adopted in this process, including support of inspirational pathfinders, creation of distributed local hubs of innovation, and online activities and resources.

Mayors, Secretaries of Education and Brazilian educational administrators visit the Lifelong Kindergarten group at the MIT Media Lab to explore possibilities to transform their school systems. Using digital technologies and craft materials they imagine the dimensions of their creative school in terms of space, time, equity, pedagogy, teacher development, curriculum, youth agency, community engagement, technology investments and evaluation.



Figure 1: Education policy makers engaged in imagining school transformation.

They share their aspirations with engaged colleagues, receive feedback and refine their ideas. They are experiencing first-hand the power of constructionism to collaboratively create personally meaningful representations of the school systems they would like to implement based upon their lived experiences. Then they bring this lived experience to organize their ideas into strategies and specific work plans to guide future decision making.

The most important thing I learned from this experience was how to promote student agency; understanding how a more flexible curriculum, the organization of spaces, the pedagogic guidelines, and the relationship with the

community can be organized with this objective in mind. [Participant reflection from post symposium evaluation form]

Introduction

This professional development experience with education leadership is part of the many initiatives in Brazil promoted by the Lifelong Kindergarten research group at the MIT Media Lab. In kindergarten, children playfully create and explore materials – from blocks to paint. They might use blocks to build towers, or fingerpaints to investigate how colors mix together, all the while trying out ideas and gaining new ones from engaging with their peers. We think all learning should look like this – not just kindergarten. In this sense, it is not unusual to see Secretaries of Education seated on the floor building their model schools. As they play, experiment, build, and share their creations, children and adults engage in a creative learning process that embodies what Resnick (2017) has described as the 4P's of Creative Learning – working on Projects that are aligned with the child's Passions, in collaboration with Peers, in a Playful spirit. Creative Learning embodies the essential elements of the constructionist tradition as defined by Papert (1980) which envisions learning as a process of building knowledge through the construction of personally meaningful and shareable objects such as wooden cars, poems, theatrical presentations, sandcastles, and even computer programs. Unfortunately, as children go on to traditional schooling, increasingly they are told how things work with fewer and fewer opportunities to create and test out their own ideas. This tendency is a phenomenon that affects educational systems globally.

In 2015, a Brazilian organization, the Lemann Foundation, reached out to the Lifelong Kindergarten (LLK) with the intention of making the Scratch programming language, developed at LLK, widely available in Brazilian schools. Yet, based upon previous national and international initiatives, the MIT researchers wanted to avoid some of the pitfalls of an approach that is overly focused on the technology without developing the social and educational objectives that situate the technology in the cultural context (Papert, 1987). The LLK researchers set out to discover how to build a sustainable network of innovators who were already using technology, and other resources, to foster learning experiences that are more creative, meaningful, and hands-on for children and youth across Brazil. With this focus, the Brazilian Creative Learning Network (BCLN) began as an idea connecting a handful of inspired educators including teachers, parents, students, educators, artists, entrepreneurs, activists, and researchers and has grown into a movement of over 10,000 individuals collectively committed to re-envisioning Brazilian education.

In the following article we describe the theoretical basis behind the design decisions and exemplify several strategies that were utilized to build the Brazilian Creative Learning Network. We show how they worked in tandem to build an organic educational movement throughout the country.

A Movement Designed to Reimagine Education

Brazil has a strong tradition of progressive thought leaders including the critical, participatory, and dialogic pedagogy of Paulo Freire (Freire, 1970) that has influenced educational policies, academic research, and pedagogic practice in schools across the country. From as early as the mid 1980's the Brazilian Ministry of Education and other agencies of Federal Government invested in training, curriculum, research, and evaluation through the creation of a series of programs and public policies designed around the progressive uses of technology. Notwithstanding implementation challenges, these programs contributed to a critical mass of educators committed to the transformation of public education through innovation and technology. (Valente & Almeida, 2020). More recently, the educational community is engaging in a discussion of national curriculum standards that are learner-centered and competency-based (Brasil, 2018). At the same time, maker spaces and fabrication laboratories are appearing across the informal and formal education landscape.

Each of these factors are seen as opportunities for educational reform in the local context of Brazilian teachers and educational thought leaders, despite the prevalent structural difficulties.

Papert (1993) describes the transformation of human activity through the scientific and technological growth of the past century and the stark absence of commensurate change in the school environment. As he explores the roots of this situation, he describes a dichotomy between what he calls Schoolers and Yearners. While Schoolers dismiss transformational change due to the immediate pressing needs of a system in crisis, well-intentioned Yearners operate on the margins of the school apparatus to create oases of meaningful learning. The workshop Lifelong Kindergarten facilitated with policy makers, involves Yearners who are in positions of authority and are being supported to institute incremental yet significant changes in the culture and operations of their school systems. Incremental changes are often placed on the evolutionary end of the “evolution versus revolution” spectrum debated within the Constructionist community in which Papert (1998) calls for the extinction of entrenched features of schools such as segregation by age and linear curriculum. Nevertheless, the work of BCLN in Brazil is disruptive of existing practices based upon the cumulative forces of a grassroots movement.

The mobilization of individuals and civic associations provides an interesting solution to bring these Yearners together in a way that is respectful of the different realities across the country and can develop organically into a sustainable and scalable social movement (Andrews, et. el., 2010). Social movements are built upon meaningful relationships between people committed to a particular cause. These voluntary commitments constitute the fabric from which the formal structures of a network can be woven. (Ganz, 2010). For LLK, what was needed was to invest in building relationships between educators who share a common mission to transform the educational opportunities for children and youth but have no idea they could be part of a larger movement. Ganz explains the basis for these relationships. “Commitment to a shared future and the consequences of a shared past transform an exchange into a relationship” (Ibid, pg 532). These were people who experienced first-hand the inadequacies of traditional education and are already coming up with viable alternatives for the future. But what kinds of opportunities could be afforded to promote meaningful relationships? It is not enough to just showcase people’s projects. If a social movement is to be created by a network of action-oriented, like-minded individuals, there need to be opportunities to share personal narratives, experiences, successes, and failures, as well as dreams for the future. As with the secretaries of education in the seminar described above, or in similar events organized by BCLN with teachers, students and families, the leaders had the opportunity to share their personal narratives through creating projects that communicate personally meaningful ideas and to participate in shared reflection sessions. Different from traditional networks or communities, a social movement provides a broader sense of purpose that meaningfully attracts and engages its members. This can only be achieved in an environment of caring and mutual respect.

According to Ganz, the capacity to cultivate local leadership is a core competency of social movements. Scale can only be achieved through a network of skilled leaders committed to a common cause, but who have the autonomy to mold the work in response to the needs and interests of their local context. Scale could never have been achieved if leadership were limited to the manpower and experiences of the core BCLN team. The challenge is to cast a wide enough net to recruit individuals who can carry out the work, while supporting them and coaching their development (Ganz, 2010. p. 533). The narratives of these leaders provide the glue behind the relational efforts that are fundamental to fostering the connection and collaboration between interested individuals.

As LLK was considering its strategies to initiate a social movement in Brazil, it began with the hypothesis that there were already many existing initiatives in the country that were aligned with the notions of constructionism and creative learning. The problem was that these initiatives existed in isolation from one another. With this in mind, instead of introducing an external program to be adopted locally, it would be better to invest in identifying the pioneers of these initiatives and connecting them in order to promote the exchange of ideas. By mutually supporting their respective growth, people could develop a sense of belonging to this newly emerging movement. By designing for belonging, the

movement could benefit from already existing experiences and expand in ways that would be respectful of the different regional identities as it emboldened peoples' creativity and exploration (Wise, 2022).

In this way, the Brazilian Creative Learning Network adopted a model of grassroots mobilization based upon leveraging the initiatives of like-minded people throughout the country. To get started, it was necessary to **identify** creative and dedicated individuals already pursuing work in the spirit of creative learning. These individuals included not just teachers but educators more broadly, including artists, researchers, decision makers, inventors, activists, students, and families. BCLN **connects** these people through a variety of **collaborative** initiatives that enable the refinement of their practices and the development of new ideas. In turn, BCLN **promotes** the fruits of these relationships to amplify the ideas throughout the educational ecosystem in order to inspire new populations to join the movement in a continuous cycle of engagement, growth, and expansion as shown in Figure 2.

Leveraging creative learning in Brazil

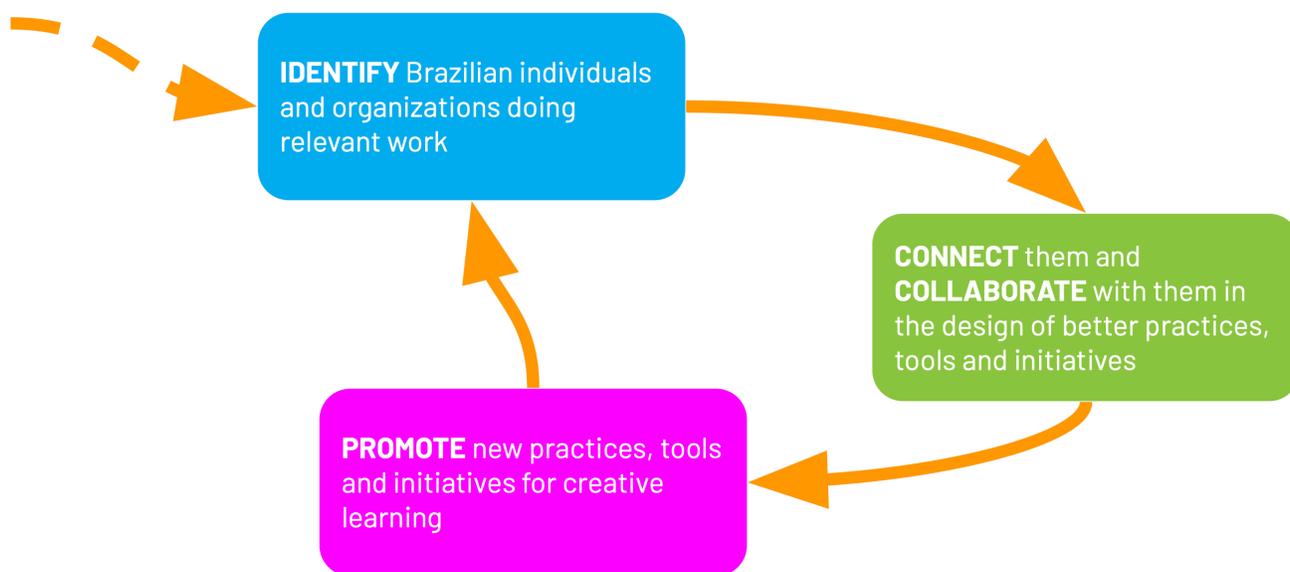


Figure 2: The Brazilian Creative Learning Network mobilization approach.

Strategies to Support Local Pathfinders

Several different social movement strategies have been adopted to leverage the ideas of constructionism and creative learning in Brazil. Here we describe in detail those that focus on the local pathfinders that are central to this movement. We then outline the events and online resources that come into play to support their initiatives.

The Lifelong Kindergarten developed a fellowship program for a select group of Brazilian educators working in socio-economically vulnerable communities. The objectives were to give visibility to their creative projects, to advance their experiences in Creative Learning, and to share this knowledge as inspiration for new creative learning initiatives across the country. There were five annual editions of the program between 2015 and 2020 of what came to be called the Creative Learning Challenge Brazil (Valente & Burd, 2019). Each call for proposal received hundreds of submissions from educators, artists, researchers, and inventors, providing an incredible opportunity to identify individuals and organizations doing relevant work in Brazil. Over the course of a year, fellows had the opportunity to develop their

projects, benefiting from the collective knowledge and experience of their colleagues, as well as from a variety of inspirational thought leaders. Fellows were located across the country but would have three opportunities to come together for in-person events. One of these was the international trip to Boston where they visited several formal and informal educational spaces dedicated to innovative approaches to education. Their notion of educational practice was further expanded by visiting the MIT Media Lab, a hub of innovation and learning, and in conversation with members of the Lifelong Kindergarten. Fellows had the opportunity to present and discuss their projects with an interested and experienced audience, allowing them to shape and sharpen their ideas about their own work.

Many of the fellows grew to become leaders in the BCLN community, establishing satellite communities of practice, mobilizing like-minded educators, and taking Creative Learning in new directions. BCLN instituted a structure of Regional Hubs to help promote these distributed volunteer initiatives by fellows, or by other early adopters, to form communities of practice (Lave & Wenger, 1991). Support from BCLN includes a set of readily accessible materials so that volunteers do not have to reinvent the wheel in each of their initiatives. Support also takes the form of regular touch points and a responsive ear from BCLN staff. Hub members organize monthly informal meetings to create a space for trust and camaraderie that encourages sharing, learning, and collaboration. These meetings provide a form of horizontal professional development that values educators' agency (Brennan and Jimenez, 2020). As teaching is often a solitary profession, people welcome the opportunity to join and exchange ideas with like-minded individuals. Currently there are 23 regional hubs in the BCLN network representing all five of Brazil's geographic territories.

In this way, the Regional Hubs have proven to be a strategy for promoting the expression of regional cultures and the existing connections and affinities. They also provide a space for dedicated volunteers to develop their organizing and leadership skills. In addition, association with BCLN provides the Hub members with access to innovations and a multiplicity of possible solutions that drive the evolution of new practices in the network. This investment in supporting individuals organized in volunteer communities has proven highly effective in the face of school system policy shifts or changes in political party leadership. There are examples of how local communities have survived an unfavorable administration, continuing to cultivate their learning under the radar, only to return stronger with cutting edge innovations when the political tides become more receptive.

Throughout the year, the movement around BCLN and the local hubs is sustained through the organization of thematic campaigns and events. Campaigns and events are targeted to obtain specific objectives within a specific time frame. These objectives usually include recognizing existing efforts from throughout the network, and inspiring newcomers to try out new practices or ideas associated with the campaign's theme. Conception, planning, preparation, kick-off, sustainment, culmination, and resolution is like the unfolding of a story. Hub members become engaged as organizers around a common goal. "The 'adventurous' quality of a campaign facilitates the development of relationships more quickly—and with greater intensity—than would ordinarily be the case. We more easily come to share a common story that we all take part in authoring." (Ganz, 2010 p. 558). The official calendar of BCLN campaigns begins the academic year with "Back to School with Creative Learning" in February / March, "Scratch Day and Creative Computing" in May, and "Hands-on Day" in September. To have an idea of the scale of this adventure, 360 Scratch Days and Creative Computing were authored by BCLN members in 2023. In addition to the BCLN calendar, local hubs, school systems and organizations are also free to integrate constructionist and creative learning activities in their own events, for example, in literary fairs or environmental awareness campaigns.

One of the cornerstone events for BCLN are the Festivals of Invention and Creativity (FIC) – FIC Portal. FIC events are open to the public. They bring together teachers, school leaders, students, families, and local artists to foster the formation of supportive communities within a given region or school system. A total of 28 FICs were organized in 2022, engaging more than 27,000 participants. These festivals are in-person celebrations that recognize local creative learning initiatives and inspire K-12 educators to integrate creative learning ideas into their classroom practice. FIC events take on many different formats depending on the local context. The signature elements are the interactive demo sessions that highlight examples of hands-on, project-based, collaborative activities to support creative learning. The activities

are carefully curated prior to the event. In fact, the very process of curation serves as a mentoring opportunity to help the activity authors to reflect on different ways to make their proposals more aligned with the core ideas of creative learning.

While BCLN prioritizes face to face relationships between its members, the online resources are key to supporting this vibrant and distributed community across the entire country. Instant messaging (WhatsApp) is the life source that sustains communication. Techniques for organizing hands-on, creative webinars and online meetings were refined throughout the period of isolation during the COVID pandemic and they continue to be an important resource. The BCLN portal is the central locus of this community of practice. It is a source of information around constructionism and creative learning, and it offers an abundance of resources and best practices. The portal also provides a space for members to share their experiences and collaboratively build their knowledge around creative learning in practice. One of these spaces is the Pedagogic Studio where members can share their educational activities, comment on, and remix the activities of fellow members, similar in spirit to the Scratch online community (Resnick & Rusk, 2020). It also includes an online Mural with thousands of images, short videos and testimonies posted by members, particularly during the various BCLN campaigns. Both Studio and Mural provide space for community members to add their questions and comments. Some activities and experiences are tagged as “Recommended” by content managers and mediators of the portal. As any BCLN member can contribute content to the portal, these tags aim to highlight content that is more aligned with a positive, constructionist culture. In this way, the portal tries to create an environment and community that, in the spirit of creative learning, encourages educators to share their activity ideas, get inspired, ask questions, and gain recognition for their efforts within the community of practice.

Final Considerations

The experience in Brazil has provided important insights as the Lifelong Kindergarten works to develop and support sustainable, large-scale initiatives aligned with constructionism and creative learning nationally and internationally. With the increasing demand for innovative, engaging, and effective educational approaches, constructionism has the potential to become a more widely recognized and adopted approach to learning. Yet, as with any educational approach, the success of constructionism depends on the willingness of educators to embrace its principles, develop the necessary skills and knowledge, and design and implement effective learning experiences for children and young people. Instead of trying to persuade educators of the benefits of constructionism, the efforts in Brazil have given voice to individuals who already identify with these ideas and are including them into their pedagogic practice. However, individual efforts can only go so far. For promising practices to mature and spread, they need support. With that in mind, for the past three years BCLN has been investing in partnerships with Brazilian public-school systems. Through the Creative Schools program, a collaboration with the LEGO Foundation, it has explored meaningful approaches to engage classroom pathfinders with school system decision-makers. This effort combines top-down policy initiatives in the secretaries of education with the bottom-up forces of innovative classroom teachers. The policy-making workshop at the beginning of the article is an example of such an approach.

When reflecting on the evolution of BCLN, we often think in terms of three axes: reach, depth, and autonomy. Through BCLN, members have found their community of like-minded innovators, organically reaching a growing number of teachers, policy makers, researchers, artists, families, and students. Gradually they are gaining increasing autonomy, as pathfinders are supported in their efforts to mobilize their local communities through campaigns, festivals, and regional hubs. Guaranteeing the depth of the ideas continues to present a challenge. BCLN support materials, discussions, and workshops are a good step in that direction, but more is needed. What additional experiences and resources are required to encourage the construction of this knowledge beyond the circle of members closest to the BCLN staff? How to create a self-supportive and ever-expanding ecosystem that helps teachers to design environments that encourage the curiosity of children and youth through hands-on, meaningful learning experiences?

In thinking about a constructionist social movement to educational reform, we often consider an array of stakeholders within a Creative Learning ecosystem, as shown in Figure 3.

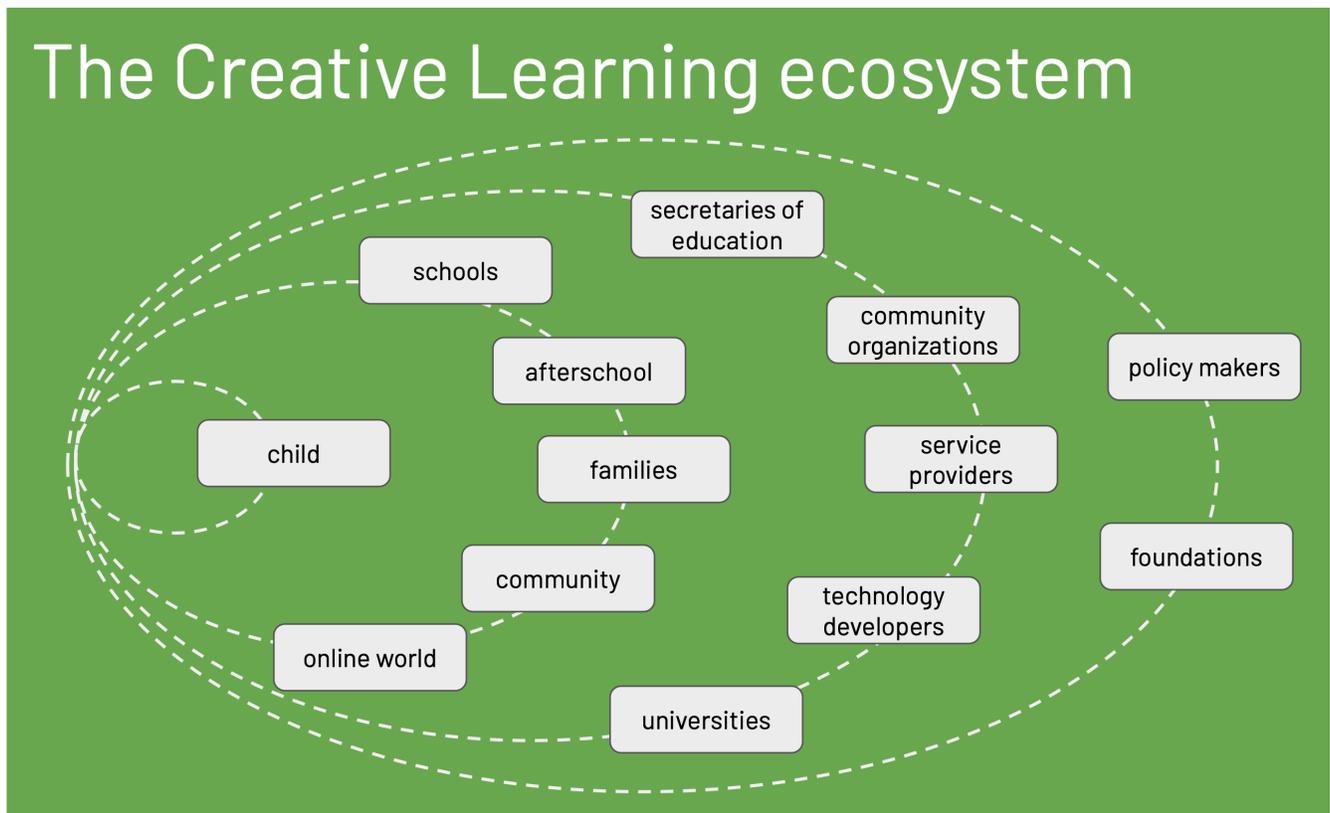


Figure 3: The education ecosystem as perceived by the Brazilian Creative Learning Network

The development of such an ecosystem may involve collaborating with colleagues and administrators to develop policies and practices that support constructionist approaches, as well as engaging with parents, students, community leaders, researchers, entrepreneurs, and other stakeholders to raise awareness of the benefits of constructionism and its potential to transform education. Looking ahead, true reform is a considerable enterprise that will require the concerted involvement of people from all sorts of trades and levels of expertise. BCLN has demonstrated some promising approaches in this direction, but there is much more to be explored.

Acknowledgements

Many people have contributed to the development of this work. Our thanks to members of the Lifelong Kindergarten Group at the MIT Media Lab, members of the Brazilian Creative Learning Network and the Creative Schools program. Special thanks to Rupal Jain for her insightful contributions and edits to this manuscript. We are grateful to the LEGO Foundation and Lemann Foundation for enabling and supporting this research. Above all, we are thankful for the thousands of Brazilian educators that continue to inspire our work and demonstrate, on a daily basis, that change is possible.

References

- Andrews, K.T., Baggetta, M., Lim, C., Ganz, M. and Han, H. (2010) Leadership, Membership, and Voice: Civic Associations That Work. *American Journal of Sociology*, 115(4), 1191-1242.
- Brasil. (2018) Base Nacional Comum Curricular. Ministério da Educação, Brasília.
- Brennan, K. and Jimenez, R. (2020) *The Scratch Educator Meetup: Useful Learning in a Playful Space*. In Holbert, N., Berland, M., and Kafia, Y.B. (Eds.), "Designing Constructionist Futures: the art, theory and practice of learning designs". MIT Press, Cambridge. pp. 85-95.
- Freire, P. (1970). *Pedagogy of the Oppressed*. Seabury Press, New York.
- Ganz, M. (2010) *Leading Change: Leadership, Organization, and Social Movements*. In Nohria, N., and Khurana, R. (Eds.). *Handbook of leadership theory and practice*. Harvard Business Review Press, Boston. pp. 527 – 568.
- Lave, J., & Wenger, E. (1991). *Situated learning: Legitimate peripheral participation*. Cambridge University Press.
- Papert, S (1980) *Mindstorms: Children Computers, and Powerful Ideas*. Basic Books, New York.
- [8] Papert, S. (1987) *Computer Criticism vs. Technocentric Thinking*. *Educational Researcher*, 16(1), 22-30 <https://doi.org/10.3102/0013189X016001022>
- Papert, S. (1993) *The Children's Machine: Rethinking school in the age of the computer*. Basic Books, New York.
- Papert, S. (1998) *Child Power: Keys to the New Learning of the Digital Century*. Speech delivered at the eleventh Colin Cherry Memorial Lecture on Communication. Imperial College, London. <http://dailypapert.com/child-power-keys-to-the-new-learning-of-the-digital-century/>
- Resnick, M. (2017) *Lifelong Kindergarten: Cultivating Creativity through Projects, Passion, Peers and Play*. MIT Press, Cambridge.
- Resnick, M. and Rusk, N. (2020). *Coding at a Crossroads*. *Communications of the ACM*, 63(11), 120-127.
- Valente, A. B. (2020) *The Creative Learning Challenge Brazil from the Perspective of Constructionism*. In *Proceedings of Constructionism 2020*. Edited by B. Tangney, J. Rowan Byrne and C. Girvan. Dublin, May. pp. 536 – 545.
- Valente, A. B. and Burd, L. (2019) *Creative Learning Challenge Brazil: A Constructionism approach to educational leadership development*. *Tecnologias, Sociedade e Conhecimento*, 6(2), 9-29.
- Valente, J. A. and Almeida, M. E. B. (2020). *Brazilian technology policies in education: History and lessons learned*. *Arquivos Analíticos de Políticas Educativas*, 28(94) <https://doi.org/10.14507/epaa.28.4295>
- Wise, S. (2022). *Design for Belonging*. Ten Speed Press, New York.

Programming Microworlds for Elementary School Mathematics

What we've been learning

E Paul Goldenberg, Education Development Center (EDC), epgoldenberg@edc.org

June Mark, Education Development Center (EDC), dspencer@edc.org

Deborah Spencer, Education Development Center (EDC), dspencer@edc.org

Kate Coleman, Education Development Center (EDC), kcoleman@edc.org

Kathryn Chiappinelli, Education Development Center (EDC), kchiappinelli@edc.org

Kristen Reed, Education Development Center (EDC), kreed@edc.org

Zak Kolar, Education Development Center (EDC), zkolar@edc.org

Abstract

This paper shares what we've learned from 6+ years of work in 7 schools (3 districts) with ~700 children using programming microworlds (MWs) for mathematics learning in regular elementary school math classes. We introduced one cohort (~100 children) to our first MWs in grade 2 (age 7) and followed them through grade 5, each year introducing new MWs designed around the mathematics of that grade. At every grade, we also introduced grade-level MWs to classes that had *not* used any MWs in earlier grades, thus testing each MW with both our long-term group and with novices to learn what adjustments might improve accessibility. Our research methodology was direct observation by at least two of our staff along with the teacher(s) in every class, cognitive interviews with selected students at the top, middle, and bottom of typical class performance, and teacher interviews. Our prior MW papers describe our underlying idea as using computer programming as a *language* to help young children express and explore their mathematical ideas, a supplement to natural language and conventional mathematical notation. Here, we focus less on the language aspect and more on the *construction*: *showing* what you mean, building small programs, and seeing the resulting *actions*. We also share our *unanswered* questions and how our thinking and MW design—*our construction*—evolved based on observations.

Introduction

This paper shares what we've learned in 6+ years of work in 7 schools (3 districts) with ~700 children using programming microworlds (MWs) for learning in regular elementary school math classes. We introduced one cohort (~100 children) to our first MWs in grade 2 (age 7) and followed them through grade 5, each year introducing new MWs designed around the math of that grade. At each grade, we also introduced our MWs to classes that had not used our MWs, testing with both novices and our long-term to adjust as needed for accessibility. Our methodology was direct observation by two staff in every class, cognitive interviews with selected students at the top, middle, and bottom of typical class performance, and teacher interviews. Prior papers describe our idea as using programming as a language for young children to express and explore mathematical ideas, supplementing natural language (imprecise and ambiguous) and conventional mathematical notation (precise but so concise as to be unforgiving) [3, 4]. Here, we focus not on language but on *construction*.

Our MWs are not special coding pullouts or enrichment, not virtual manipulatives, and not tutoring apps where initiative and evaluation rests in the computer and children merely respond. Using subsets of a powerful language (Snap!) children *program* to explore math *in their class*. The subsets vary, exposing both imperative (sequencing commands, kids' common "coding" experience) and functional programming (constructing expressions by composing functions), list manipulation, filtering a set of numbers, and even using predicates (expressions that evaluate inputs as True or False). Limiting the tools affords access; variety of tools gives rich exposure to both mathematics and programming.

Constructivism and Constructionism as a Foundation

Constructionism is more than academic dressing for the oft-quoted "I hear and I forget; I see and I know; I do and I understand" (incorrectly attributed to Confucius and likely a version of a deeper saying of Xunzi). It's also neither Piaget ("knowledge is derived from action" [6], often taken more extremely as if to say only from action) nor Bruner (learning's trajectory is "Enactive, Iconic, Symbolic" in that order), but it accords with them. Doing does not have to be "tactile" or "concrete." Colors are neither, yet children learn color names (abstractions about abstractions!) early. What makes doing powerful is that what you do, you also see and often describe to others [1]. Doing helps learning by offering children more channels to incorporate information: enactive, iconic and symbolic all at once. More access routes afford more access.

Constructionism is a constructivist pedagogy, not an epistemology. Artifacts we've constructed can support our other efforts at communication. Communicating ideas helps us more fully develop them as well as share them with others. And a construction leaves traces that an action alone doesn't—it is less ephemeral—and so it is reviewable and rediscussable.

Communication is fragile even when people share common language and experiences. Learners experience teachers' words in personal ways: learners do the interpretation and incorporation; only they build their ideas. As an epistemology, constructivism seems the only choice. It can influence pedagogy: teachers who believe they can't "impart" ideas are more likely (if given a chance) to set up classrooms with a richer soup of experience than verbal explanation and colorful posters.

On Being Usable and Useful in Regular Mathematics Classes

Because our idea was to support mathematics learning, we designed our MWs to be usable and useful *in* regular math classes, not as a supplement, pullout, enrichment, or "fun" day. That imposes constraints. Not only must MWs support the mathematics the teacher expects to teach, but teachers must recognize that at first sight or they will skip it. And it must take no more than a page of introductory reading or a video of no more than three minutes to convince a teacher with no computer background that she can easily introduce and manage it in a classroom of 20 children or so. Finally, it must be plausible that using these MWs doesn't steal time from an already overcrowded curriculum; whatever time this departure from the textbook takes, it is fully repaid in results—perhaps an easier pace through the textbook or even pages that can be skipped. More simply, to be adopted, using the MWs must entail essentially zero extra effort or time.

Our Microworlds and Introducing Them to Children (Ages 7 to 11)

Our MWs all contain three basic elements (Fig 1b): a palette containing blocks children need for their programs and buttons for choosing among explorations; space for the children's programs, a stage on which some visual

representation of their mathematical actions can appear; and buttons for specialized actions like **undo** or **reset** or choosing among sets of puzzles.

Introduction and explanation time is overhead. Our research shows that most 7-year-olds who have had no prior experience programming can, in their regular mathematics class and with no more than a ten-minute introduction, mostly active, work independently and successfully using programming blocks in Snap! to express and explore and do the essential elements of the mathematics they would otherwise be doing on paper after teacher explanation with examples.

We've learned a lot about how to keep this introduction short and exploratory, not just another teacher-talk explanation. With 7-year-olds sitting on the rug, the teacher asks what the children see (Fig. 1a) and what they think should be done.

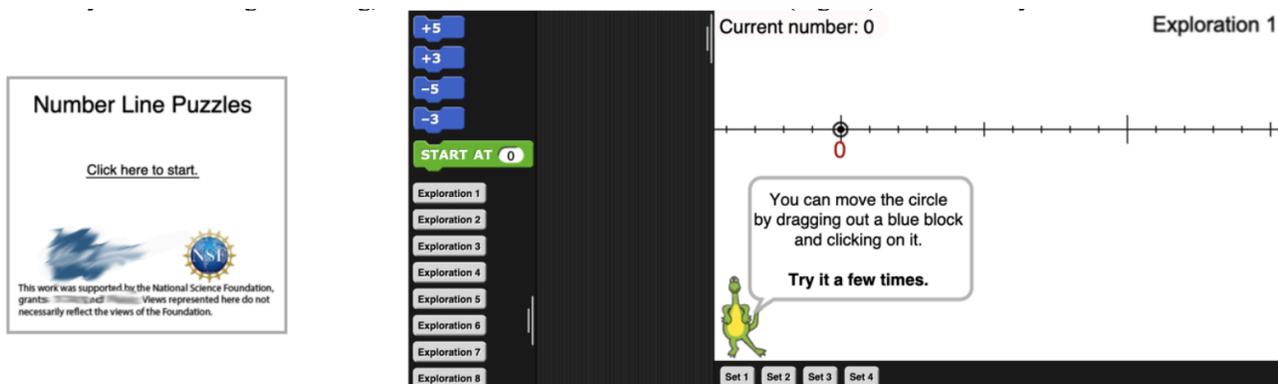


Figure 1: The integer number line MW [described in 7]. (a) Landing screen for integer number line puzzles. (b) The first exploration.

Teacher: What does it say I should do?

Child: Click here to start.

Teacher: Who would like to show how?

In 2017, few kids knew what “click here” meant. Now, no demonstration is needed. In this MW they next see (Fig. 1b).

Teacher: What is Dino telling us?

A child might read it out loud. For those who might need help with reading, clicking on Dino or Dino’s words will read them out loud. Few 7-year-olds, even now, know what “drag out a blue block and click on it” means, so the teacher shows.

Teacher: OK, I’ll drag out a blue block. (Drags out +5.) Hmm... nothing happened!

If no child tells the teacher, the teacher says “Oh, I didn’t click on it!” and invites a child to show how. Clicking ‘+5’ draws an arc that “adds 5,” moves the circle to the sum, and labels the new number (Fig. 2). Children can’t yet be expected to conclude that it *adds* 5. Perhaps it just *goes* to 5. Children infer meanings from context—in this case, more experiments.

Teacher: Who’d like to drag out a different blue block and try it out?

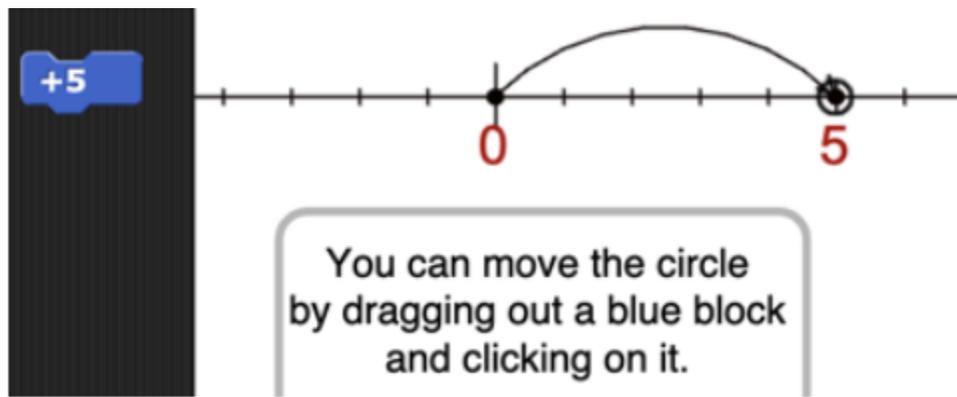


Figure 2: Estela, recently from Guatemala, did not know the + or – symbols or operations. Her Spanish-fluent teacher explained but Estela had no experience to give meaning to the explanation. Playing let her see the effect and build a basis for understanding.

After a few tries, the teacher drags out the green block and asks the class what it says and what they think might happen if they put a different number in place of the 0. In a class of 20, there’s always at least one ready to demonstrate.

Teacher: When you are done with a puzzle and want a new one, click the next button, here.

The teacher demonstrates by clicking Exploration 2.

Teacher: OK! Now you know everything you need. You can work on your own.

Introductions can be brief and interactive for all ages, all programming, and all mathematics—angles, arrays, coordinates, fractions, decimals, attributes of number sets, prime factorization. Children can be independent researchers quickly.

Five design principles we began with

Design principle 1: Treating children like mathematicians—experience before formality. Our EDC mathematics group sees similarities in the way mathematicians work and children learn. Mathematicians often approach new problems by tinkering. Their tinkering isn’t random, of course—they know enough to have ideas about what might be productive—but experimenting and looking for pattern and structure is a common start. Then they look for ways to generalize. *Then* formalize results and reduce them to neat presentations that skip over the messy exploratory period and dead ends and make the path look straightforward. Children learning on their own also start with play and build experience from which they generalize. Instruction that skips the development of familiarity with the territory and jumps straight to formality leaves many learners without the experiences on which that formality can be based. Instead, they may simply get rules. Even if the rules are “explained,” those explanations need a firm base to rest on or they, themselves, are just more rules. Because learners are ultimately the constructors of the knowledge/understanding, they need a basis in experience.

Design principle 2: Mathematics with “legs.” To be accepted by teachers, MWs must immediately be recognized as on topic. But age/grade-level-appropriate content can be taught in ways that serve only the immediate goal or in ways that foreshadow and support future ideas. For example, without using any terminology or formal notation of algebra, arithmetic, can be taught in ways that prepare students for algebra. *Math Workshop* [8] has many elegant

examples. Rather than introducing notation just as “this is how it’s done,” it introduced the idea that the notation meant something and that children could read it *without instruction*, from context, the way they learn *all* language. Where it was relevant, it used the name “pattern indicator” for algebraic (or algebra-like) notation but *nowhere* was there blather about “variables” or about symbols or letters “standing for numbers,” or “rules.” It was just there and not distracting. (See [2] for detailed description.)

Our MWs use the same principle: restricting focus to grade-level, the *ways* children explore, learn to experiment and search for abstractions foreshadow mathematical ideas through and beyond high school and keep the activity interesting for a wide range of students. We introduce elements that *can* be ignored and are not distracting (like the pattern indicators, or numbers to the left of 0 on the number line as in Figures 1b and 2), but interestingly are generally not ignored by children.

Design principle 3: Leaving room for happy accidents. To achieve our goal—use in “ordinary” classrooms with diverse children—our environments must feel accessible to teachers: low overhead, promise of immediate relevance and “pay back” for time invested, and no surprise content that might make a teacher feel obligated to explain things that she is not ready for (or feels her kids are not ready for). Even if the MWs taught no math “content” other than what is called for in class, the fact that children are learning it through active experimentation and evaluating their own results would feel like an achievement to us. But we’re greedy. We want more. We want children’s exploratory steps and slips and accidents to build ideas on the side or to confirm (or disconfirm) ideas they already have and to allow children to move beyond the experiments we scaffold and explore ideas beyond those we imagine: a mathematical lab (maker space?) that attracts children who were not curious and serves those who are.

Not starting a number line with 0 even for 7-year-olds is part of that. They don’t have to pay attention to it, but they can. Over time, we also learned that children need latitude where they type in numbers. A fractions MW doesn’t expect children to type decimals. A few do! Children try all kinds of crazy experiments we didn’t anticipate and so didn’t design for—biggest number is a favorite. So we redesigned. Experiments that have meaning should be honored. In a fractions MW about eighths, a child who types 0.375 should get the right result. We’ve never seen 7-year-olds use start at to start at 1.5 or $1\frac{1}{2}$, but if they did, the MW should not break or scold them. Only when we cannot act “sensibly” (e.g., for sheer lack of space) does the MW say “I can’t do that.” The message is that the *machine* can’t do it. Perhaps the child can! Children also add extraneous spaces and make other typos. We have redesigned so that if we can infer the intent in otherwise coherent and correctly communicated ideas, we handle them properly even if the form is not yet conventional.

Design principle 4: Students judge their own work. Designing so children can *easily* tell if they’ve done what they intended serves fidelity to mathematics as well as personal autonomy and confidence. Assessing a solution’s correctness must take less work than *finding* the solution and not require redoing the problem or undoing the solution. Solutions should be *actions* children take, *things they build*, programs.

Design principle 5: Cognitive load of non-mathematical elements must be low. Non-mathematical elements add load that competes with the mathematics. Presentation must be clear (unambiguous, not distracting, readable by young children). Word problems have their roles but add challenge that is not always mathematical and should be used thoughtfully. More generally, reading and writing add cognitive load for children, especially the youngest. Mathematical notation and visual representations are concise and precise but readable only after mastering the conventions. Its concision makes it highly demanding and unforgiving. Copying problems (from a book or app) to paper before solving them is also time off task. Drawing is also slow, and both children and teachers vary in the level of precision and neatness they tolerate. Our MWs also require a language—block-based programming—for children to express and explore their mathematical ideas but its overhead seems very low, and learning the language is interactive the way children learn their natural language.

What We Learned From Three of Our Many Types of Microworlds

Four number line microworlds. No puzzles use numbers to the left of 0 in the 7-year-olds' number line (Figs 1, 2). But nearly all children land there by accident or on purpose. Many recognize those numbers (older siblings?) and call "Oooh! Negative numbers!!" Even the ones who don't recognize them aren't put off. The notation looks like subtraction, so children know how to get back to "normal" numbers and often know which number they'll reach. No teaching needed. For some, this is intriguing and accessible enough to attract further play without luring the teacher into unexpected territory.

That early MW foreshadows the idea of linear combinations (of 3 and 5). A similar MW for older children uses ± 9 and ± 15 to create surprise around the study of common factors which children have practiced *finding*, but with little sense of the mathematical implications and no opportunity to explore or generalize. We haven't yet been able to try MWs that let children *pick* pairs of numbers and explore how their linear combinations do or do not limit what numbers they can reach.

Our first cohort of 7-year-olds asked for capabilities we hadn't offered. After figuring out how to go from 0 to 1 (e.g., using +3, +3, -5) they wanted to create a single *block* that did that, like the blocks we provided. We unhid that option. But many wanted more—our blue blocks drew a single arc but theirs still drew three—so we created **combine steps** to take a script that the children wrote and perform the desired arithmetic before drawing an arc for the result. Children, themselves, took the lead in requesting more and better abstractions. We've now incorporated these ideas in some of our puzzles.

Fraction and decimal number line MWs for older children are crafted to look and feel like the integer MW to show that arithmetic with $\frac{1}{2}$ and $\frac{1}{3}$ or ± 0.3 and ± 0.5 behaves like arithmetic with ± 3 and ± 5 . Experiments manipulating eighths and seeing results give children experience that makes feel natural, just like three goats plus three goats. This helps dispel the add-everything-in-sight idea that the written notation lures them into, making so many write despite lessons, until they've built their own body of experience and derived a logic from it—another data point supporting experience before formality. Formalisms don't *have* meaning until they are seen as shorthand for things one already understands. Seeing the current number described as $\frac{1}{2}$ when the number is marked as $\frac{1}{2}$ on the number line gives early experience with equivalence. Before trying it in classrooms, we were unsure whether this might confuse or distract children. It doesn't.

Two map and coordinate microworlds. Our Map MW lets 6- and 7-year-olds experiment with shape, direction and distance and with using lengths and distances to solve other problems. The MW shows a map personalized with familiar names and places (Fig. 3a), a Smiley icon, and four blue blocks to move Smiley *north*, *east*, *south*, or *west*. Teachers often re-teach these terms before using the MW, but kids seem learn mostly by *using* them. If a block moves Smiley in an unwanted direction, **undo** lets children fix it. This MW also has a block that lets kids rename buildings; and a **repeat** block that lets them make long moves more easily. (Young children don't care about efficiency, as we discuss later, but they do appreciate having fewer blocks to drag out.) For this MW, we use a slightly longer on-the-rug intro to maps. Long strips of paper represent roads to which kids assign names, and cards mark the locations of buildings the kids can name. Few 7-year-olds know names of local roads other than their own and one or two others, but accurate layout doesn't matter. The key idea is that assigning names to roads lets them *use* those names to specify locations of buildings and directions to them.

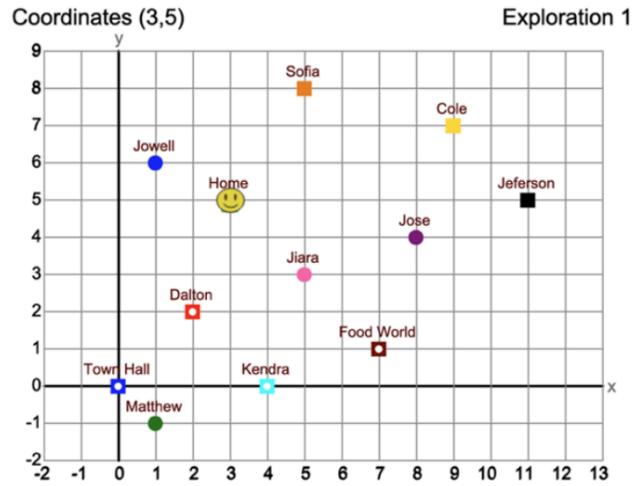
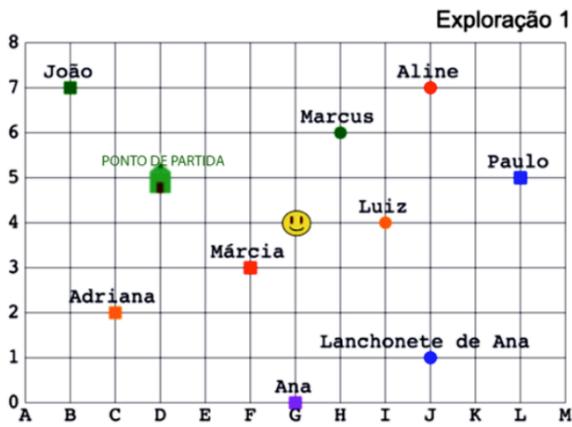


Figure 3: (a) Map of a village (Brazilian version) laid out on a grid showing a luncheonette, a starting point, and homes of 8 kids; (b) The stage image for the Coordinates MW for 9 and 10 year olds.

Children have heard phrases like “the corner of X and Y” or “on X between A and B” so, even though few have used such language and none have heard of coordinates, they *all* (!) readily figure out where ‘Start at: Letter L Number 5’ will place Smiley. Mathematical “legs.” And no explanation needed. And if a puzzle says “Start at Adriana,” children figure out how to specify her address. Naming objects to help us refer to and manipulate them is a major idea in mathematics.

When coordinates formally enter the curriculum for 10-year-olds, our Coordinates MW lets children use them to do things they want, and build experiences that also foreshadow future ideas. The stage layout (Fig. 3b) is like Map, except that it uses numbers for both coordinates, has two darkened lines (axes), and label the top with Smiley’s current location.

Several purple blocks let children build, remove, or rename buildings by specifying their coordinates, enticing most into far more practice with coordinates than our puzzles ask for. And asking children to build a building exactly halfway between Cole and Sofia or between Jara and Jose reminds them that they now *do* know how to specify such numbers. As in the Map MW, we provide blocks for “walking” along streets in the four compass directions. This Coordinates MW adds a new idea: two kinds of direct flight. Starting at Dalton, both ‘FLY to point (5, 3)’ or ‘FLT east(x) 3 north(y) 1’ will fly Smiley to Jara. But only the second then flies to a new place—same *direction*, not same end point! Slope won’t appear until algebra, and vectors might not appear at all, but the idea of specifying a *direction* to fly comes easily to 10-year-olds. As always, we don’t force attention at this age to any sector but the first—some teachers would feel that out of place—nor to any of the formalities of what will later be seen as vector addition, but the experiential seeds are planted.

Properties-of-integers microworlds—visual and active. The currently developed microworld gives children blocks that let them filter integers 0 through 99 by multiples (Fig. 4a), non-multiples, prime, composite, square, >, <, and more, and see the resulting set. They also have a block (Fig. 4b) that lets them combine properties. In both cases, the resulting set is also displayed in bold black on a 0-to-99 chart (Fig. 4c). Children may specify properties not only of the integer but of its digits or their sum or product (e.g., green in Fig. 4b).

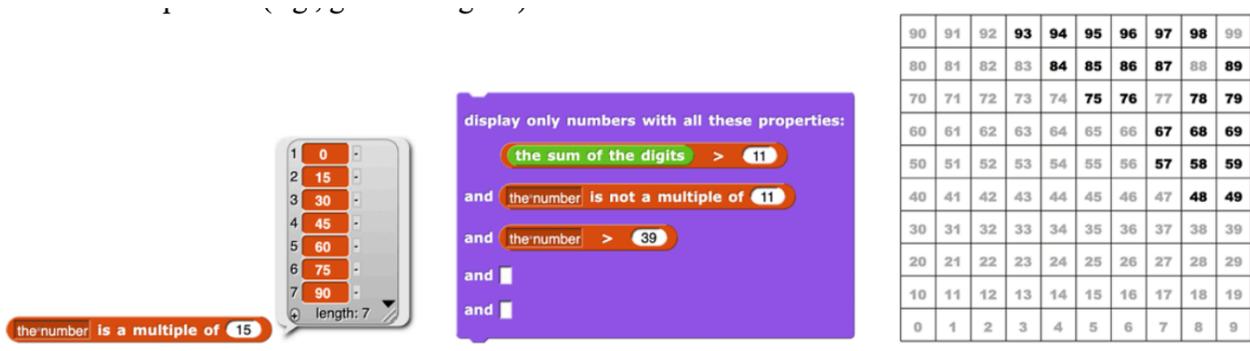


Figure 4: A number set defined by a single property (a). Specifying two properties (b) displays the set shown in 4c.

After children explore the tools, we present the chart with some cells highlighted (Fig. 5). To darken the numbers in those cells, children seek properties of the set. Early puzzles require only a single constraint. Later, easily recognized sets are filtered with a second constraint, e.g., odd and greater than 60 or, e.g., Fig. 5b. And later, challenges like 5c.

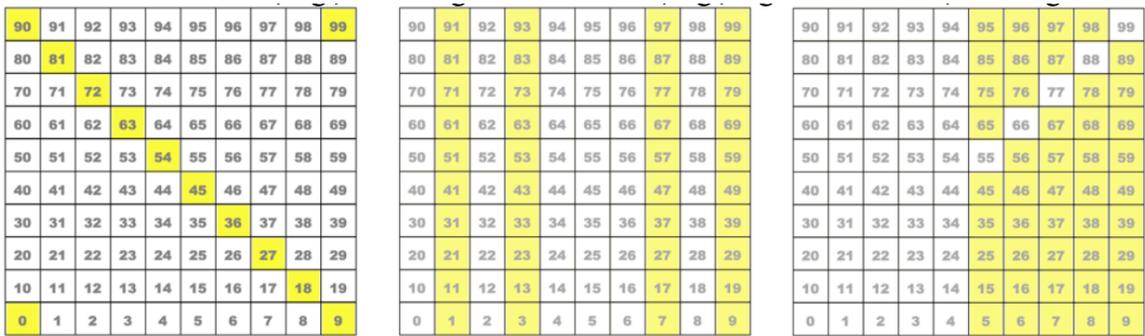


Figure 5: What properties describe these sets of highlighted numbers?

Target topics include multiples, common multiples, or multiples of n but not m . The exploring is what gives this MW “legs.” Sifting through ways to abstract from examples (in this case, numbers) is core to mathematical thinking. We designed this as an advanced MW, but with appropriate puzzles, we now see that it has far earlier entry points. A puzzle that highlights only 5, 15, 25, 35, 45, 55, 65, 75, 85, 95 tempts kids at first to think “easy, multiples of 5” and be surprised that’s not enough and be surprised yet again when they see the varied solutions they and their classmates find.

Design changes derived from our work with the children

We structure puzzles carefully to build on each other. Some kids use that order, some skip around. Originally, we built no paper component for our MWs but, inspired by children’s happy chirp “I did it!” when they finished a good puzzle—in all grades in all schools as if it were built in—we added a sheet with three columns: puzzle name, “I did it!”, and “I showed someone” for kids to track their work. Some didn’t care. But some liked the paper element, familiar but non-intrusive.

We knew at the start that accessibility required brief, clear language, voice alternatives to text, and non-English versions (all MWs are now in multiple languages, and we add others as soon as we get translations suited for kids in school). Over time, we discovered other needs. Our Angles MW for grade 4 required an **undo** button. When we saw how the 9-year-

olds used it for systematic trial and debugging, we started introducing it in earlier MWs where the need hadn't been so obvious.

Many of our ideas about what makes a good puzzle were on target, but some weren't. We asked 7-year-olds to analyze number line scripts to remove unneeded steps (e.g., cutting two steps from the script $+3,+3,+5,-3$ still adds 8). They can, but few find it interesting. They love getting a desired result but don't care to get it more efficiently. In fact, they prefer complexity, the bigger the better. In trying, say, to move from 0 to 4, many wandered all over, ignoring loops in their path—loops that signify jumps that can be removed. Nearly all 7-year-olds love the task of visiting every marked number on the line. Some rework the pattern of jumps to look pretty. This esthetic pull began influencing our design of all MWs.



Kids didn't care about loops, but we did, to foreshadow arithmetic inverses. Children's responses in the Angles MW nudged us toward visual puzzles even in contexts like the number line. The need to limit words also nudged us that way. We created visual puzzles like Figure 6 which *require* concision and focus on inverse steps. Children did like these. Whether they also hatched an inkling of arithmetic inverses is not yet clear. But their ease in solving the puzzles showed their actions to be systematic. Visually presented puzzles became the core of the Number-Properties MWs (e.g., Fig. 5).

Some elements that we added “just for fun” turned out to increase “on-task” play even as children strayed from our puzzles. We first built “put name on building at (0,0)” into Coordinates to allow personalization, but children loved adding friends' names, leading to spontaneous use of coordinates beyond our “assigned” tasks. Similarly, color choice in some worlds was originally just “decorative” until we saw it leading to more spontaneous mathematical actions than we could include. Playful or esthetic elements, well-chosen and designed, can increase on-task behavior rather than distract from it.

Recognizing when a solution to one problem can be applied to another is key to both mathematical and computational thinking, so we built puzzles that asked kids to solve a puzzle and *keep* the script, either to solve the puzzle a different way or to use (with or without modification) in another puzzle. No interest! Kids often didn't even notice the call to save the script. If they did save it, they built a new one for the new puzzle anyway. Classroom discussion *does* serve this goal—kids love to show their work—but that must be left to good teaching, not MW design. Just having the puzzle isn't enough.

Another puzzle type that failed aimed at proof. On the integer number line, we asked, “Is it possible to get from 0 to 1 using only two blue blocks?” The most concise way uses three: $+3, +3, -5$. Most children decided that they couldn't do it with two but then asked for help because they “can't do it.” A few took the question literally as we intended and

concluded “no” without giving reasons. Some did give valid proofs-by-exhaustion, but stunningly remained unconvinced until one of us agreed—the opposite of our aim to make sure they can always evaluate their own results. The problem was not that seven-year-olds can’t reason about or understand proof. The problem was that our question was not interpreted as intended. Young kids expect, perhaps from experience, that tasks they’re given *can* be done. This had two consequences. One, of course, was many defeats, kids who just felt they’re “not good at math.” Another was to reinterpret our question: “I did it! I used only two blue blocks, +3 and -5, but I used one of them twice!” or “I used repeat! It isn’t blue” At age 7, it seems that many kids have the *logic* for (informal) proof but don’t understand requests for proof. Even at 11, many children reinterpret “Is it possible?” to mean “Can you do it?” When we’ve modeled tackling impossible tasks and giving (informal) proof, children have felt permitted to declare a task unsolvable, but we can’t lightly hand that kind of teaching off to others.

We used to have puzzles that involved writing or drawing as part of the response: e.g., “what numbers can you label using only the +3 and -3 blocks” or “find a path...and draw it on your page.” We abandoned those for puzzles whose solution was only the script the child builds, not something to put on paper, scrapping some puzzle types we’d like to have had. “Compare these two scripts” can prompt valuable thinking but is better in class discussion than in puzzle design.

Important Unanswered Questions

A major unknown at this point is how to support teachers. We’ve learned how to design for face validity and appeal to teachers but haven’t yet learned how to optimize *supports* to let teachers pick up these MWs on their own and use them independently and effectively. Guides? Professional development? Video? Supplementary materials for children? This is essential for the ultimate success—and ultimate test—of the use of MWs and exploratory learning.

Assessment is another issue. We see intense engagement of all (!) students and convincing examples of mathematical thinking in the MWs. It is important both to quantify that and to be able to make claims about school performance. The latter requires assessing with measures schools use. The results shouldn’t be expected to match. Children behave differently in different media. We chose our medium, MWs, precisely because it does change accessibility, especially for those who otherwise perform poorly and seem disengaged. But if we haven’t helped kids do better in school (i.e., on school tests), we may not have succeeded. We don’t know. Our work wasn’t funded for comparison or efficacy studies. That is another step.

Weirdly, we can’t say *why* our children are so engaged. Of course, our conjectures are the ones that please us: freedom to experiment without risk, the excited feeling of one’s mind at work, and success. “I did it!” But they’re conjectures. We don’t *know*. We do know that any observer can see that the engagement is real; satisfying but not enough. How much is Hawthorne effect? Some, perhaps, but not all; puzzles varied in their ability to generate thought and interest. More to learn.

Though we *design* for a specific grade, it puzzles us to see almost identical variety in engagement, rate and success both a grade earlier and a grade later. The MWs seem equally useful as introduction, investigation, and review. Because nobody engages when things are opaquely beyond them or boringly beneath them, we assume that “learning trajectories” are not nearly as pure as reported. Kids *experiment* in the MWs, so their experience varies with their knowledge and understanding. The comparable performance may mean that kids get *different* things at these different times. This, like the other areas, needs research. We’ve offered exemplars, ideas, observations, and questions. We’ve also documented technical details [5]—the programming behind MWs—so others can use our MWs or build their own for classrooms or research.

ACKNOWLEDGMENTS

This work was funded by the National Science Foundation grants Nos. 1741792 and 1934161.

References

1. E. Paul Goldenberg. 1979. *Special Technology for Special Children*. Baltimore: University Park Press.
2. E. Paul Goldenberg. 2019. Problem posing and creativity in elementary-school mathematics. *Constructivist Foundations* 14(3), 601–613. <https://constructivist.info/14/3/319.goldenberg.pdf>
3. E. Paul Goldenberg and Cynthia J. Carter. 29 May 2021. Programming as a language for young children to express and explore mathematics in school. *Brit. J. Ed. Tech.* <https://bera-journals.onlinelibrary.wiley.com/doi/epdf/10.1111/bjet.13080>
4. E. Paul Goldenberg, Cynthia J. Carter, June Mark, Kristen Reed, Deborah Spencer, and Kate Coleman. 2021. Programming as language and manipulative for second grade mathematics. *Digital Experiences in Math. Educ.* 7, 48-65 <https://doi.org/10.1007/s40751-020-00083-3>
5. Zak Kolar, Hannah Moser, and E. Paul Goldenberg. 2023. Building a Microworld in Snap! <https://snap.berkeley.edu/static/doc/building-a-Snap-MW>
6. June Mark, J., Paul Goldenberg, Jane Kang, Mary Fries, and Tracy Cordner. 2014. *Transition to Algebra*. Portsmouth, NH: Heinemann
7. Jean Piaget. 1971. *Science of Education and the Psychology of the Child*. NY: Viking Press.
8. Deborah Spencer, June Mark, Kristen Reed, Paul Goldenberg, Kate Coleman, Kathryn Chiappinelli, and Zachary Kolar. Using Programming to Express Mathematical Ideas. *MTLT* 116(5): 322-329 <https://doi.org/10.5951/MTLT.2022.0354>
9. <https://solveme.edc.org/>. <https://SolveMe.edc.org>
10. Robert Wirtz., Morton Botel, Max Beberman and W. W. Sawyer. 1964. *Math Workshop*. Encyclopaedia Britannica Press, Chicago IL.

Iterative Data-driven Optimizing Behavior (IDOB)

A Structural Model for Enhancing Machine Learning Education and Understanding Software 2.0 Production

Uwe Lorenz, Freie Universität Berlin, uwe.lorenz@fu-berlin.de

Ralf Romeike, Freie Universität Berlin, ralf.romeike@fu-berlin.de

Abstract

In this contribution, we introduce the Iterative Data-driven Optimizing Behavior (IDOB) scheme, a structural model for didactical purposes, that provides a more comprehensive understanding of Machine Learning (ML) and helps to explain how “Software 2.0”, software that is a product of data-driven ML techniques, is generated. Our objective is to present a didactical scheme that students help more easily construct new information about any ML methods, such as details of specific algorithms, according to the idea of active knowledge construction upon appropriate pre-conceptions by the learner. We justify our proposal theoretically and by highlighting its applicability across major ML paradigms (Reinforcement, Unsupervised and Supervised Learning), show its ease of use by examples using the Snap! programming language and its potential in interdisciplinary, hybrid software systems, where it facilitates comparative reflections on ML methods and Software 2.0 versus alternative solutions, such as manually implemented models or mathematical representations.

Introduction

Writing programs that emulate human abilities can be one of the most motivating aspects of working with “Artificial Intelligence” (AI). Perhaps it is comparable to the task of developing the abilities of a fantasy character. However, and especially due to the recent very successful subfield of Machine Learning (ML), another aspect of AI has come to the foreground that is much more important from a Computer Science perspective, where a central aim is to make computers more useful: the automatic creation of software functions, or automatic problem-solving through interaction with a data source or dataset (Jormanainen et al., 2023; Karpathy, 2017; Schulte et al., 2018; Tedre et al., 2021). It has been shown that with these ML methods, it is possible to automate many tasks that could not be done with traditionally produced software, or that for quite a few tasks it is easier to apply ML methods with suitable data sets than to figure out the necessary rules for a traditional program (Jormanainen et al., 2023). Software that is produced in this way is referred to by Karpathy as “Software 2.0” (Karpathy, 2017).

So teaching ML is not only important to improve future skills related to a set of new spectacular applications, such as evaluating the outputs of ML applications, making them more useful and innovating with them, and thinking about their possible impact on society, their limitations, and possibilities, etc. but we seem to be witnessing the rise of a new paradigm for developing software and making computers useful in general. Classical problem-solving skills apparently no longer have the same significance here (Tedre et al., 2021).

In constructionist educational settings, students should not just work on puzzles or problem-solving activities, but on meaningful projects based on their passions, in collaboration with peers, and with a playful spirit (Resnick & Rusk, 2020). So AI tools and methods that can relieve this type of activity can fit well with the constructionist approach. They offer

incredibly rich new opportunities for the creation of computational artifacts, including artwork of personal and social significance that have not been possible before – especially for children.

But there are also fundamental challenges that must be considered in the context of constructionist approaches. Even small children can start using these systems intuitively before they have learned anything about them (Tedre et al., 2021). Due to the automatic production of “Software 2.0”, tasks like handling, and preparation of data in the context of a Machine Learning Life Cycle process move to the center. In the case of ready-trained universally or at least very versatile applicable “Software 2.0” like Large Language Models (LLM) and Generative Systems, it is “something of a black art” (Norvig, 2022) to create suitable inquiry prompts. While addressing such issues that arise during Software 2.0 building or its use, these activities can provide little insight into how ML engines work.

Besides the fact that these also would certainly help e.g. to understand the necessary properties of the data to be processed or to develop sustainable prompt engineering competencies, there is a risk that some important elements of constructionist learning will be lost. For Minsky and Papert it was important that the acquisition of concepts by interacting with computers should at the same time foster their own ability to reflect and learn. Kahn and Winters, among others, emphasize this aspect of dealing with “AI” – and here also understood in a broader sense as a simulation of cognitive abilities – namely that modeling AI can lead to reflection and to a better understanding of cognitive processes (Kahn & Winters, 2021) such as perceiving, thinking, decision-making, or learning. It remains important and exciting to learn how it is that ML systems “learn” things. It is desirable for children to ask questions such as “How does this learning in the computer actually work?”, “Can I build something like that myself?” or “Does it perhaps say something about how I learn?” There is, even if it cannot be assured, the hope that with questions like these, children can make themselves better thinkers and learners (Papert, 1986). We should not deprive them of the chance to ask such questions. Furthermore, understanding how AI processes content-related data and thus builds or applies its internal modeling could also provide new insights into domain-specific understanding. But is it even possible to gain such insight, given the vast array of complex algorithms and approaches, and the speed at which this technology is evolving?

Theoretical Framework

The answer we give here to this question is yes, but there are some prerequisites for engaging with this field to make sense in general education contexts. To this end, we will address in this paper four questions that lead from an abstract idea of how machines learn to a concrete modifiable interdisciplinary scenario that enables play in an instructive way.

Powerful Idea: In settings designed to give a behind-the-scenes look, it should be avoided that students only deal with single ones of the numerous ML algorithms and methods, which may become obsolete in a short time, and have to deal with their details without discovering central concepts with relevance in the context of general education. Are there “Powerful Ideas” that underlie ML in general, i.e., that are also valid in the long term and all paradigms?

Structural model for comprehensive understanding: A structure that models the basic components and their interactions that are recognizable in all ML systems, possibly in different manifestations or forms, would be conducive to learning and understanding because such a structure could allow students to more easily construct new information about any ML methods according to the idea of active knowledge construction based on pre-concepts. What can such a structural model for all ML look like?

Implementation: We need learning environments that make it clear how the essential components work and also encourage people to engage with different manifestations of them, e.g., to implement innovative or outstanding approaches to solutions and hopefully discover Powerful Ideas. What do examples of concrete implementations look like?

Comparisons to other solutions in hybrid and interdisciplinary application contexts: When a learning system is applied in a particular context, it is faced with data sets or data sources about which the ML system “learns” something and with which the ML system adopts a behavior desired by the developer. What are the properties of the representation generated by the ML system and the corresponding behavior of the system? How can the properties of such automatically produced solutions be compared with other solutions, e.g., of manually programmed software or explicit calculation rules (mathematical formulas)?

ML as a software development paradigm

A look at the currently used AI definitions shows that emulating intelligence or human abilities is often seen as the essential aspect of AI. This idea in principle also underlies the “5 Big Ideas in AI” (Touretzky et al., 2019). In the current “AI-watch” report (European Commission. JRC, 2020) most of the textual listed definitions are based on psychological terms. A definition of “AI” based on the idea of simulating human cognitive abilities entails some fundamental problems from the point of view of Computer Science (CS), so this cannot fulfill the criterion of unambiguity, e.g. 70 different definitions are given for “intelligence” in (Legg & Hutter, 2007), nor of delimitation since CS has been dealing with the simulation of cognitive activities at least since the first mechanical computing machines. The prevailing notions about AI and also many “definitions” of the term evoke false anthropomorphist associations, which produce misunderstanding and hinder education about the topic (Garside, 2023).

In Karpathy (2017), a qualitative distinction is made between “Software 2.0” and conventional software “Software 1.0” based on their development method. Software 1.0 is created using common software development methods, with phases such as specification, design (e.g. top-down or bottom-up approach), implementation, testing, etc. Software 2.0 is a product of data-driven ML techniques, and the development process here looks quite different and should follow the phases of a Machine Learning Life Cycle with phases like gathering and validating data, dividing data into training, development and test sets, choosing model class(es), train models on training data, validate models on development set, evaluate on test data, deploy, etc. (Norvig, 2022). Karpathy describes the generating process for this type of software as a search in the space of possible functions, which is a key difference from “knowledge-based AI” where suitable outputs are searched for. The product in ML approaches is code that can be executed by the ML engine and continuously evaluated and optimized. However, the codes that are data-driven generated by the ML-Systems are often hardly interpretable by humans, since the resulting code of the “Software 2.0”, has often the form of innumerable parameters and requires a corresponding ML engine to be executed. Due to hardware-technical but also informatic conceptual developments, as well as the easy availability of appropriate datasets, the corresponding methods have become so good that they substitute or even significantly surpass the capabilities of traditional software development in larger problem classes (Karpathy, 2017).

We follow here a view according to which an alternative problem-solving paradigm is applied in ML systems, in which the information-processing process that solves a problem or produces desired outputs need not be described but is data-driven generated. As far as we are aware, there are no contributions from the field of CSE that use the definition of ML as a kind of software development and problem-solving method based on iterative optimization of some kind of initial software for providing a unified explanation of all machine learning.

Iterative Data-Driven Optimizing Behavior (IDOB)

Powerful Idea

The idea of iteratively optimizing behavior by reducing errors or maximizing rewards is central to ML methods as a

whole (Mitchell, 1997). Recent works on the foundations of ML (Jung, 2022) also state that all ML methods operate in such a way, but that they are based on different design decisions for data, loss, and model. According to Jung, ML methods combine these three components within a principle that consists of the continuous adaptation of a hypothesis about a phenomenon that generates data. The adaptation or improvement of the hypothesis is based on the discrepancy between predictions and observed data. The ML methods use a loss function to quantify this discrepancy. According to the “intelligent agent paradigm of AI” (Russell & Norvig, 2021), any purposeful, goal-oriented behavior can be considered “intelligent” to some degree. In (Silver et al., 2021) it is hypothesized that intelligence in general, and its associated abilities, can be understood as subserving the maximization of reward. According to the intelligent agent paradigm of AI, all ML can be understood as improving goal-directed system behaviors by iteratively maximizing a “goal function” through processing feedback (Lorenz & Romeike, 2022).

Structural Model for a Comprehensive Understanding

In an agent-oriented view of problem-solving, the learner imagines the computer to be an agent that produces preliminary error-prone outputs based on the available representations and with its input (“perception”) and then receives feedback with which the goal function produces a loss/reward that the Optimizer uses to improve the model and hence future behavior. Based on these considerations, it is proposed to use a principle of Iterative Data-driven Optimizing (IDOB) as an underlying principle for presenting ML methods and algorithms.

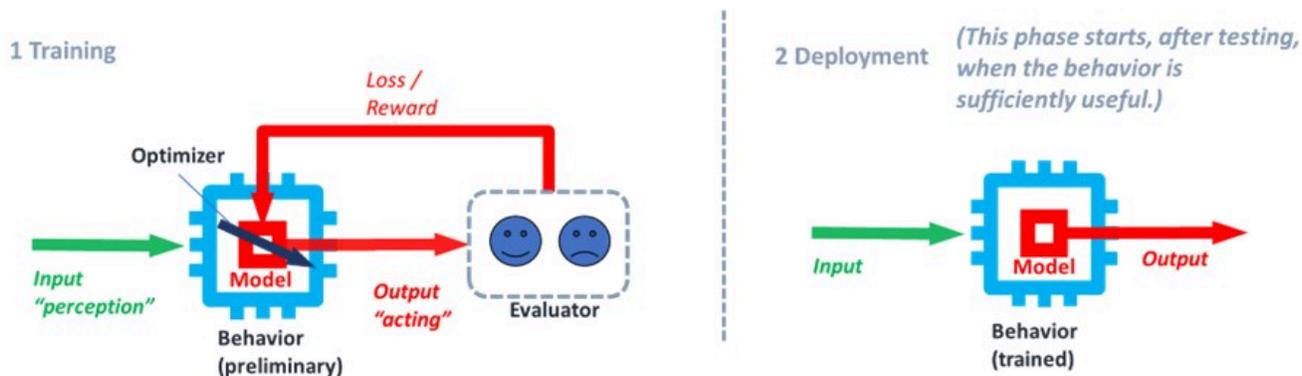


Figure 1 Operating phases of an ML-System: (1) generation and (2) deployment of “Software 2.0”. Shown are the operational components of IDOB (Behavior, Evaluator, and Optimizer) and central data flows.

In all IDOB an Optimizer updates the model based on assumptions about how to improve system behavior using the loss generated by the Evaluator’s goal function. The different ML paradigms, like Supervised Learning, Reinforcement Learning, and Unsupervised Learning, can be integrated into the scheme by considering their different types of feedback and corresponding design decisions for Data, Loss, and Model (Jung, 2022). Supervised Learning: The Optimizer minimizes the “Loss” between true labels and those predicted. Reinforcement Learning: The Optimizer tries to maximize the cumulative reward of episodes the agent receives from its environment during its interactions. Unsupervised Learning: Optimizer here tries to minimize the costs of a model to represent a dataset appropriately, e.g., resources such as memory or computation time, or errors due to improper generalization that diminish predictive ability. Central components of an ML system in the IDOB scheme (cf. Figure 1) are:

Operational components:

Behavior: Produces the output based on the input and internal representations.

Evaluator: contains a goal function and provides the Loss or Reward

Optimizer: uses the Loss/Reward to improve the behavior by updating the model.

Data structures:

Input (“perception”): Sensory input data used to generate the output and, if necessary, to improve future behavior.

Model (“representation”): Contains “software 2.0” encodings that can be interpreted to generate system output.

Output (“acting”): The output that is as appropriate as possible with respect to the given input. Deficits with respect to the desired behavior can be used to generate the Loss.

Loss (“reward”): Represents an evaluation of the preliminary behavior used by the optimizer to improve the system behavior.

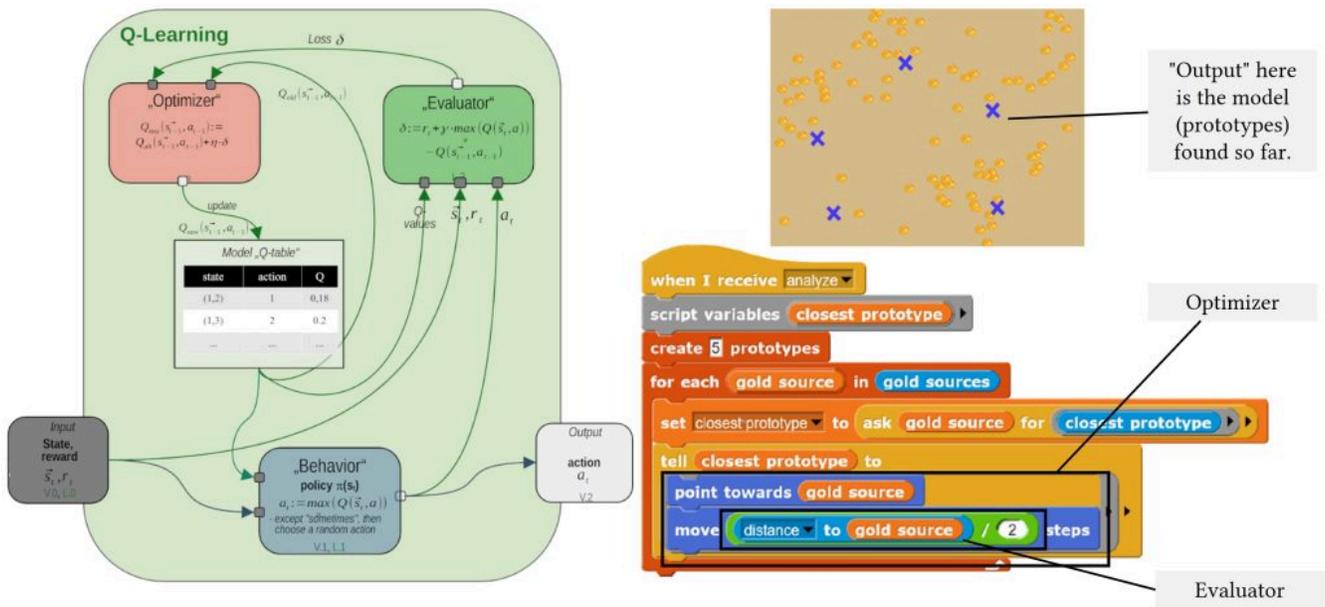


Figure 2 Recognizing IDOB components: Reinforcement Learning (Left: Q-Learning as a data-flow model); Unsupervised Learning (Right: “Gold rush clustering” (Michaeli et al., 2020))

Implementation Using Snap!

Block-based programming embodies the principles of active, hands-on learning while providing a supportive environment for exploration, collaboration, and creativity, focusing on concepts rather than syntax. A predecessor of Snap! (Snap!) is called BYOB, an acronym that stands for “Build Your Blocks”, indicating that it can be used to define new blocks yourself, e.g. for the IDOB components. In comparison with Scratch Snap! also offers some advanced features that allow a deeper exploration of computer science concepts.

We present an example inspired by topics from middle school chemistry and physics classes (“flash point” and “free fall”) including ML in the IDOB scheme (Figure 3). The idea in the chemistry example was that students teach their AI the concepts of flash point and ignition temperature. The perceptron learns here a logical “AND” function. The feedback in this scenario is provided by a “supervisor”, which symbolizes that the correct answer is known during the training with “Supervised Learning”. An interesting learning effect can also result from placing the perceptron in a different context,

where another, e.g. an OR, relation is to be learned. In this case, not the ML system has to be changed, but the behavior of the “supervisor” must be reprogrammed, which leads to the idea that the same system can code and adapt different functions. A modification task that encourages changes in the setup could be concerned with working out the difference between flash point and ignition temperature by adding new conditions and teaching the robot to behave correctly. The limits may quickly become apparent when transferring the perceptron into further contexts. Multi-layer perceptrons (MLP) can overcome these limitations, but the programming on which the IDOB components are based now requires some mathematical knowledge (sigmoid, derivative), c.f. Figure 4.

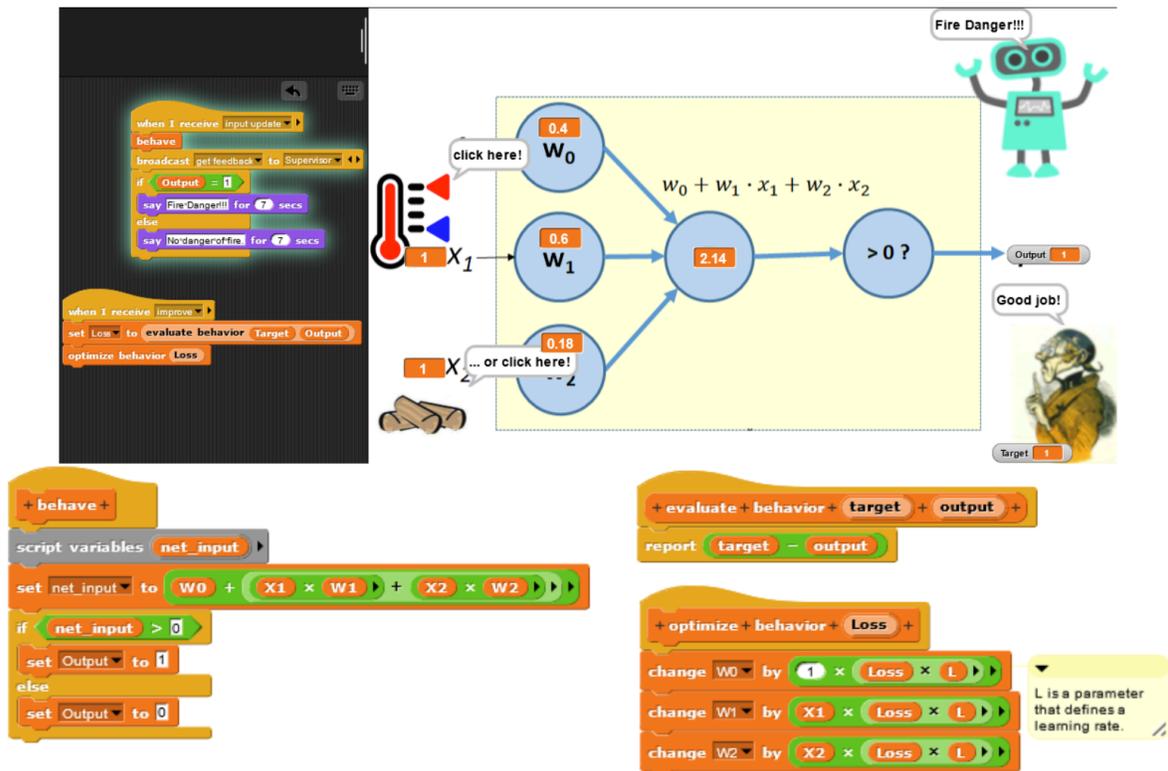


Figure 3 Separate representations of IDOB components: the Behavior component that converts inputs into outputs, the Evaluator that generates the Loss, and the Optimizer that updates the Model, making the processes of “acting” and “learning” transparent and understandable.

IDOB Combined with Other Approaches in Interdisciplinary Contexts

The MLP can “learn” a simulated physical process, in this case, “free fall”. The scenario is handled by various models, that interact with each other. They all can be inspected, modified, or created: an implementation for the simulation as Snap! program (free fall of a ball as default in this case), mathematical descriptions (formulas, function curve), and an MLP in IDOB that can approximate arbitrary functions in a $f(x) = y$ form. It is used here for predictions of the “measurement” results. In this scenario, measurement data must first be collected “experimentally” using the free fall simulation for measuring falling times from different heights, which could also be combined with a real-world activity. Finally, the training of the IDOB system can be started, which stops when all data points displayed are touched by the regression curve. A robot is included here that leads through the scenario. It also implements a small competition setting here where predictions between the robot and the user can be compared. Students can solve the prediction problem better than the AI if they think about the explicit calculation rule because the MLP just does a rough approximation. The robot encourages the students to do so. The curve of the proposed formula can also be added to the coordinate system.

The setup provides several opportunities to encourage students to transform different representations into each other. This could include not only mathematical formulas and the related curves but also the simulation program and the approximated ML model. In mathematics didactics, it is a common term for understanding when students can do so. This transparent combination of content and methods from different disciplines allows for an instructive, critical, reflective comparison not only in terms of the nature of the descriptions and predictions, but moreover in reflections in terms of properties such as effort, reliability, or ethical concerns.

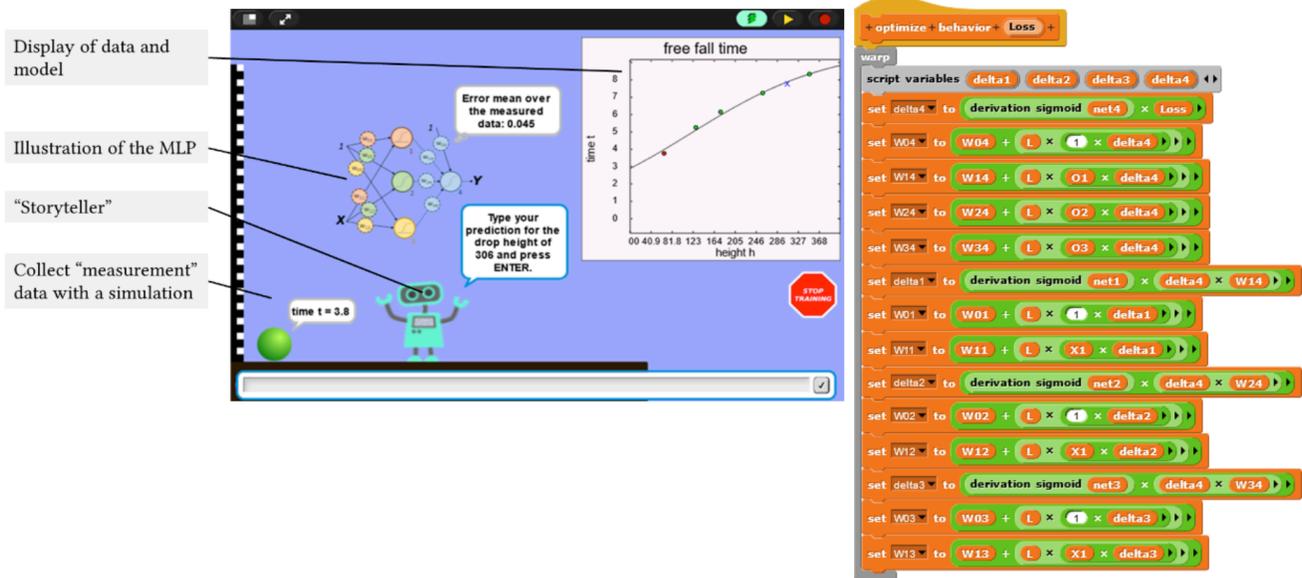


Figure 4: A scenario for the application of an MLP in the IDOB scheme in an interdisciplinary context. The behavior is produced with 1 input neuron, 3 hidden neurons, and 1 output neuron, and the Optimizer is processing the loss with backpropagation in Snap! (Right)

Discussion

It was intended to present a scheme that allows a better understanding of ML techniques and the production processes of “Software 2.0”. Our model consists of three key basic components, Behavior, Evaluator, and Optimizer, which highlight how ML systems learn and operate. The proposed scheme can be found in the central paradigms of ML such as Reinforcement Learning, Supervised and Unsupervised Learning, is easy to use and it is shown that an application in hybrid software systems in interdisciplinary contexts is also possible, which also allows a comparative reflection of ML with respect to other solutions such as manually implemented software.

We tried the scenario with two grade 12 high school students (1 male and 1 female) and student teachers from a CSE seminar. The students indicated that the Snap! scenarios allowed them to gain a deeper understanding of how neural networks work, particularly backpropagation. An interesting observation regarding supportive design features was that when they attempted to change activation functions or learning rules, they first attempted to interact directly at the Snap! stage with the passive illustration of the neurons. This indicates opportunities for a more intuitive design based on direct interaction capabilities with the computational nodes and their connections, combined with an immediate view and more intuitive ways to examine system states and processes. Perhaps data-flow modeling (c.f. Fig 2), as seen in many materials related to ML, could illustrate a better mapping of how the components interact than the sequential scripts.

LLMs are “Software 2.0” programs that have been trained to find useful answers to input prompts using a large corpus of text. They can directly perform a variety of tasks and solve problems of various kinds without training because they are trained with knowledge of a large portion of the Internet. Since they are products of ML techniques, they can be

thought of as a kind of “Software 2.0” problem solvers or expert systems. They use a combination of techniques e.g. Unsupervised ML to pre-train a model with large text sets, Supervised learning for training an Evaluator component, and Reinforcement Learning to fine-tune the Behavior for more natural interaction. IDOB could help to understand the modular structure of such AI systems, but some development and empirical research would be needed here.

References

- Garside, B. (2023, April 13). *How anthropomorphism hinders AI education*. <https://www.raspberrypi.org/blog/ai-education-anthropomorphism/>
- Jormanainen, I., Tedre, M., Vartiainen, H., Valtonen, T., Toivonen, T., & Kahila, J. (2023). Learning Machine Learning in K-12. In S. Sentance, E. Barendsen, N. R. Howard, & C. Schulte (Hrsg.), *Computer Science Education: Perspectives on Teaching and Learning in School* (2. Aufl.). Bloomsbury Academic.
- Jung, A. (2022). *Machine Learning: The Basics*. Springer Nature Singapore.
- Kahn, K., & Winters, N. (2021). Constructionism and AI: A history and possible futures. *British Journal of Educational Technology*, 52(3), 1130–1142.
- Karpathy, A. (2017). *Software 2.0*. <https://karpathy.medium.com/software-2-0-a64152b37c35>
- Legg, S., & Hutter, M. (2007). *A Collection of Definitions of Intelligence*.
- Lorenz, U., & Romeike, R. (2022). Addressing challenges of constructionist modeling of adaptive systems. *Proceedings of the 17th Workshop in Primary and Secondary Computing Education*, 1–2.
- Michaeli, T., Seegerer, S., Jatzlau, S., & Romeike, R. (2020). Looking Beyond Supervised Classification and Image Recognition – Unsupervised Learning with Snap! *Constructionism 2020: Exploring, Testing and Extending our Understanding of Constructionism conference proceedings*.
- Mitchell, T. M. (1997). *Machine Learning*. McGraw-Hill.
- Norvig, P. (2022, Oktober 5). *Education for AI and by AI*. Stanford HAI Weekly Seminar. <https://hai.stanford.edu/events/peter-norvig-education-ai-and-ai>
- Papert, S. (1986). *On Logo New Mindstorms, tape 1–Resonances*. <https://el.media.mit.edu/logo-foundation/resources/onlogo/newmindstorms1.html>
- Resnick, M., & Rusk, N. (2020). Coding at a crossroads. *Communications of the ACM*, 63(11), 120–127.
- Schulte, C., Sentance, S., & Barendsen, E. (2018). Computer Science, Interaction and the World. In *Computer science education: Perspectives on teaching and learning in school* (S. 57–71). Bloomsbury Academic.
- Snap!* [Software]. UC Berkeley and SAP. Accessed at 2023, August 4th, <https://snap.berkeley.edu/>
- Tedre, M., Denning, P., & Toivonen, T. (2021). CT 2.0. *21st Koli Calling International Conference on Computing Education Research*, 1–8.
- Touretzky, D., Gardner-McCune, C., Martin, F., & Seehorn, D. (2019). Envisioning AI for K-12: What Should Every Child Know about AI? *Proceedings of the AAAI Conference on Artificial Intelligence*, 33, 9795–9799.

Mathematical Constructions in Makerspaces

Soobin Jeon, University of Michigan, sbjeon@umich.edu

Jeein Jeon, Dwight School Seoul, jjeon@dwright.or.kr

Abstract

Makerspaces are particularly fruitful spaces for STEM learning where students gather to create, invent, tinker, explore, and discover using a variety of tools and materials. Yet, teachers often lack the support and preparation to meaningfully support students' learning of disciplinary knowledge in the context of makerspaces. This paper illustrates the potential of mathematical constructions of makerspaces, reveals some of its challenges, and suggests ways of implementing mathematically supported makerspace projects. Drawing on the constructivist learning theory and the design-based implementation research, we explore how learning can be enhanced through the collaborative process of constructing mathematics in makerspaces. Examining an 8th grade makerspace project on Kinetic Sculpture, the paper identifies how the role of the mathematics teachers may positively impact students' mathematical learning.

Background And Theoretical Framing

Makerspaces are versatile and vary greatly in shape and size, serving as a hub for tools, projects, mentors, and expertise. The tools available within a makerspace do not define a makerspace (debunking the assumption that makerspaces must be filled with cutting-edge technological tools), but rather what it enables: making. Grounded in constructivism, the act of creating physical artifacts is at the heart of makerspaces, where the learner is positioned to actively construct meaningful objects to share with the world (Papert & Harel, 1991). Constructivism speaks to the value of the students constructing their own knowledge based on experiences and interaction with the world (Davis, Maher & Noddings, 1990; Binguier & Piaget, 1980). These spaces of making provide a collaborative environment that promotes critical creative inquiry, such as student-driven, equitable, and community-oriented learning for social change. They also involve understanding and building upon the skills, practices, and values of marginalized communities in STEM, fostering high-quality life-long learning, and empowering learners as knowledgeable and creative individuals within culturally rich communities.

Hansen et al. (2019) describes "making is the act of creating physical artifacts – using knowledge and skills from the disciplines of science, technology, engineering, mathematics, and art – for the purposes of sharing playful and useful creations with the world" (p. 95). Learning through the construction of artifacts enhances student agency, empowerment, and inquiry-based learning (Papert & Harel, 1991). Constructing encourages students to take ownership of their learning, resulting in empowerment to explore their interests and make choices about what they want to learn. This also gives students opportunities to collectively share ideas, perspectives, and experiences. Inquiry-based learning – central to constructivism – encourages students to ask questions, investigate and seek answers to problems, and construct their own understanding of the world. When students are given agency and encouragement to inquire over their learning, they are more likely to be engaged and invested in the learning process.

Mathematical Constructions in Makerspaces

In K-12 schools, mathematical constructions are often presented as idealized forms of geometry. However, it is important to help students understand how mathematical constructions relate to real-life considerations and encourage critical inquiry into mathematical assumptions throughout the making process. Students can problematize mathematics in the makerspace as they do in real professions such as trade and carpentry, and explore mathematical models in relation to realistic problems. Learners might consider how idealized forms in mathematics differ from real-world problems they encounter in the makerspace, where materials are not infinite, straight, or static as most mathematical diagrams present them. When handling real materials, learners must consider factors such as mass, density, and volume. Carpentry involves many conceptual skills and knowledge that are developed through apprenticeship, resulting in unique forms of mathematical knowledge and refinement of idealized forms of geometry. Consideration of the material is an integral part of the process and not an afterthought.

Mathematics in material mechanics or architecture engineering is not only about aesthetics but also the usefulness and reliability of constructions. Learners realize the construction of design safety through characteristics of materials by measuring how much weight a material can withstand and to what degree materials might change (e.g., modeling change of an object that rotates). Learners are encouraged to express the making process mathematically and consider the decision-making process of materials (e.g., rationalizing the use of hollow materials for economic reasons). Development of students' spatial visualization, orientation, and reasoning, as well as their sense-making and navigation between different scales and spaces increase as a result of these mathematical explorations. As such, the makerspace is an open space to bring seemingly similar but different forms of mathematics and disrupt idealized forms and assumptions of disciplinary knowledge.

Problem of Practice

In spite of the potential of makerspaces to transform mathematics education and the growing body of research focused on makerspaces in K-12 schools (Rouse & Rouse, 2022), the successful integration of maker activities into classroom instruction by teachers remains crucial. Notably, there has been a dearth of research that focuses on factors shaping teachers' implementation of maker activities (Gravel & Puckett, 2023). However, many secondary disciplinary teachers – highly trained within their discipline – lack the specialized design or makerspace knowledge (e.g., MakerPACK) needed for this integration. This limitation can hinder their ability to leverage the full potential of makerspaces, such as due to constraints stemming from curriculum perspectives (Walan & Gericke, 2022).

Gravel and Puckett (2023) highlight a disciplinary “distance” (between practices of a teacher's subject area and work in the makerspace) intrinsic to STEM makerspace implementation, which shapes how teachers engage with newly introduced makerspaces and maker pedagogies. Likewise, the approach to maker pedagogy differs from the pedagogical methods employed by teachers in specific subject-area disciplines (Songer et al., 2002). While there is limited research specifically addressing mathematics within the makerspace context, collaboration between makerspace and mathematics teachers is also often lacking. One key challenge is the insufficient preparation of mathematics teachers in effectively planning and communicating ways for their students to engage in mathematics within the makerspace. While makerspace teachers can assist other discipline teachers in integrating their subjects into the makerspace, there is only so much they can do to support teachers across a range of disciplines and grade levels (there is often a very limited number of makerspace or design teachers in a K-12 school that has a makerspace). The responsibility of ensuring that mathematical learning objectives in makerspaces are met ultimately falls on the mathematics teacher.

A systemic issue in teacher education is the increasing expectation for teachers to integrate technology and

constructionism into the classroom, despite many teachers not being adequately prepared for this task. In spite of significant efforts in recent years to implement innovative and technology-mediated designs into the classrooms, professional development and teacher education programs have not kept pace with these changes (Hsu et al., 2017; Lawless & Pellegrino, 2007). As a result, many teachers are ill-equipped and lack confidence to integrate design and makerspace practices into their curricula. This situation is particularly concerning because students are expected to master 21st century competencies to keep up with the rapidly developing society and to prepare for lifelong learning. There is always a need for sustainable innovation to improve public education to ensure that learners are prepared for the future. At the same time, support for teachers needs to be equipped and flexible enough for teachers to handle the innovative and often systemic changes beyond their control.

Design-Based Implementation Research

In order to address the challenges of implementing meaningful mathematical constructions in makerspaces, a collaborative partnership between researchers and practitioners would be necessary. An approach to research called the Design-Based Implementation Research (DBIR) presents four central principles (Fishman et al., 2013; Penuel et al., 2011):

1. A focus on persistent problems of practice from multiple stakeholders' perspectives.
2. A commitment to iterative, collaborative design.
3. A concern with developing theory related to both classroom learning and implementation through systematic inquiry.
4. A concern with developing capacity for sustaining change in systems.

Unlike Design-Based Research, DBIR goes beyond the classroom and considers the larger, complex educational system. It is not only important for teachers to be directly involved, but also for there to be consideration of the goals of the school, district, and policy-makers. Addressing the problem of practice, such as the lack of teacher support, requires the collaboration of multiple stakeholders to identify effective approaches to providing support to teachers and ultimately enhancing student learning. The iterative improvements in design within DBIR inform the decision-making process and the need for adjustments that are tailored to the specific needs of the context. This includes taking into consideration factors such as the potentials and limitations of mathematical exploration in makerspaces, prior knowledge of teachers and students, the use of curricula and standards shared at the district or school level, and potentials for community involvement in the collaborative design. The role of the student as long-term design partners can also be considered, increasing their involvement in the design process and rationalizing the value of the input (Guha et al., 2013).

According to Penuel, Fishman, Cheng, and Sabelli (2011), an ongoing challenge is “the development of theories and models that can be used to initiate change where capacity is more limited and to develop designs for coordination that are better tailored to different contexts, including those that convene different kinds of institutional and individual actors in and out of school to study and bring about improvements to children’s learning” (p. 335). This is an important practice when considering mathematical constructions in makerspaces because makerspaces, by nature, vary vastly, yet the benefits of mathematical constructions through making should not be limited based on the resources of makerspace. Tailoring to different contexts provides opportunities to scale the potentials of mathematical constructions through making, even in schools without makerspaces. At the same time, DBIR practices help inform necessary support and resources that schools require, even if it is not cutting-edge technology, which is plausible given the increasing accessibility of tools and technology.

A Kinetic Sculpture Project

Let us consider an 8th grade makerspace project on Kinetic Sculpture at an international school in Korea. The school has a tradition where every year, the 8th grade students design new kinetic sculptures to replace the former (broken) sculptures, and they are given a meaningful theme each year. One year, the theme was the emphasis on self expression through mathematical ratios. The theme challenges students to not only consider the aesthetics of the design but also the functionality that makes sense to the user. The hope was for students to bring in their own personal and cultural expression into the international community. The making process involved demonstration of technical skills and exploration of functions that might fail, embracing productive struggle in the making process. The project was student-driven and process-oriented where the students were expected to make decisions about their design, inquire about the use of different materials, and apply techniques that would allow them to transfer their 2D design to a 3D artifact.

Despite the claimed lack of confidence in mathematics, the makerspace teacher incorporated mathematical diagrams that helped students measure, construct, and assemble each part of the kinetic sculpture, and taught the Golden Ratio so that students can design and make sense of 2D constructions of their sculptures, emphasizing the importance of balance and scale. Yet, the makerspace teacher shared that a problem of practice was the lack of mathematical connection that students were able to reflect on and communicate about. Furthermore, students had a surprisingly difficult time transferring from their 2D online construction to 3D physical constructions of their design, illustrating their need for support in spatial orientation and sense-making of scale. Although the mathematics teachers at the school seemed hesitant about integrating mathematically grounded makerspace projects (mainly due to their limited representation among the teachers who utilized the makerspace each year), partnering with the makerspace teacher could prove advantageous for both students and their mathematics teaching.

The nature of the project embedded in the school tradition and being community-oriented would benefit greatly from DBIR. Each year, the stakeholders of the school and community could collaborate to address the problem of practice, providing expertise from their background. Some suggestions for what the mathematics teachers could provide for this project are as follows

1. Encourage students to practice using precise mathematical language to communicate their making process and story.
2. Provide students a sense of where assumptions in building mathematical models come from and learn from any mathematical misconceptions.
3. Support students' reflection process by documenting their artifact.

An iterative process of implementing these practices is key to DBIR. Furthermore, the changing and improving nature of this project allows for exploration of its capacity for scale and sustaining change. Most importantly, the expression of the students in their mathematical constructions should continue being celebrated and embraced.

Conclusion

Makerspaces provide an unique opportunity for students to participate in hands-on, constructivist mathematical learning. By creating physical artifacts, makerspaces encourage critical and creative inquiry, as well as student-driven, community-oriented learning. These collaborative environments promote lifelong learning, empowering students as innovative individuals. Furthermore, makerspaces provide opportunities for mathematical exploration, allowing students to problematize math, explore mathematical models in relation to real world contexts, and develop skills such as spatial orientation and sense-making about scale. However, integrating makerspaces into classroom instruction

poses challenges, particularly for mathematics teachers who may lack design or makerspace knowledge and experience. Collaboration between makerspace and mathematics teachers is crucial for successfully integrating makerspaces into mathematical instruction. Positioning design and construction as vehicles for conveying meaningful mathematics allows opportunities to bridge disciplinary distances. It is also important to acknowledge the systemic issue in teacher education and preparation concerning the integration of technology and constructionism into the classroom. Overall, makerspaces have the potential to transform mathematics education. With support and collaboration between makerspace, mathematics teachers, and multiple stakeholders, students can greatly benefit from engaging in mathematically-grounded makerspace projects.

References

- Bringuier, J. C., & Piaget, J. (1980). *Conversations with Jean Piaget*. University of Chicago Press.
- Davis, R.B., Maher, C.A., Noddings, N. (1990). *Constructivist views on teaching and learning of mathematics*. USA: National Council of Teachers of Mathematics.
- Fishman, B. J., Penuel, W. R., Allen, A. R., Cheng, B. H., & Sabelli, N. O. R. A. (2013). Design-based implementation research: An emerging model for transforming the relationship of research and practice. *Teachers College Record*, 115(14), 136-156.
- Gravel, B. E., & Puckett, C. (2023). What shapes implementation of a school-based makerspace? Teachers as multilevel actors in STEM reforms. *International Journal of STEM Education*, 10(1), 1-22.
- Guha, M. L., Druin, A., & Fails, J. A. (2013). Cooperative Inquiry revisited: Reflections of the past and guidelines for the future of intergenerational co-design. *International Journal of Child-Computer Interaction*, 1(1), 14-23.
- Hansen, A. K., McBeath, J. K., & Harlow, D. B. (2019). No bones about it: How digital fabrication changes student perceptions of their role in the classroom. *Journal of Pre-College Engineering Education Research (J-PEER)*, 9(1), 6.
- Hsu, Y. C., Baldwin, S., & Ching, Y. H. (2017). Learning through making and maker education. *TechTrends*, 61(6), <https://doi.org/10.1007/s11528-017-0172-6>.
- Lawless, K. A., & Pellegrino, J. W. (2007). Professional development in integrating technology into teaching and learning: Knowns, unknowns, and ways to pursue better questions and answers. *Review of educational research*, 77(4), 575-614.
- Papert, S., & Harel, I. (1991). Situating constructionism. *constructionism*, 36(2), 1-11.
- Penuel, W. R., Fishman, B. J., Haugan Cheng, B., & Sabelli, N. (2011). Organizing research and development at the intersection of learning, implementation, and design. *Educational researcher*, 40(7), 331-337.
- Rouse, R., & Rouse, A. G. (2022). Taking the maker movement to school: A systematic review of preK-12 school-based makerspace research. *Educational Research Review*, 35, 100413.
- Songer, N. B., Lee, H. S., & Kam, R. (2002). Technology-rich inquiry science in urban classrooms: What are the barriers to inquiry pedagogy? *Journal of Research in Science Teaching*, 39(2), 128-150.
- Walan, S., & Gericke, N. (2022). Transferring makerspace activities to the classroom: a tension between two learning cultures. *International Journal of Technology and Design Education*, 1-18.

Leveraging the powerful ideas of constructionism to enhance emergent design thinking pedagogy

Carina Girvan, Trinity College Dublin, The University of Dublin, girvanc@tcd.ie

Chronis Kynigos, NKUA, kynigos@eds.uoa.gr

Alkistis Verevi, Academy of Athens, averevi@academyofathens.gr

Abstract

We consider how the design feature in constructionist theory can contribute and draw from a relatively recent movement in education coming from industrial design under the title of Design Thinking. Design thinking is a group project work emphasizing empathy, co-construction and engagement with real life issues. What we suggest is that constructionism can enhance learnability in Design thinking by extending personally meaningful tinkering to rapid prototyping to create artefacts meaningful to others. We showcase a Design Thinking project based on using a constructionist game authoring tool embedding diverse ideas from computational thinking. We discuss the value of connecting constructionist theory and practice with aligned educational innovations thus extending connectivity such as the one in the current conference twinning fab-lab with constructionism.

Introduction

As members of this community we like to think that, implicitly or explicitly, constructionism has underpinned the development of many recent educational movements, from the (re)introduction of programming as a core aspect of computational thinking in school curricula, to the Maker Movement. In this paper we consider yet another such movement, that of Design Thinking. Design has of course been a prevalent feature of constructionist theory (see, e.g., Kynigos, 2015). But as we know at least from the mathematics education community, terms and theories do not emerge in a systematic hereditary way. Rather, they lie, as Michele Artigue has put it, in fragmentation in a landscape of constructs and frames with little work and thought in forging connections between them (Artigue & Mariotti, 2014). As a movement under that title, Design Thinking (DT) has recently taken the form of a promising innovation for mainstream education, which has nonetheless fallen short of its initially envisaged potential. DT was originally developed and established in tertiary and technical education in the context of industrial design. Like constructionism, it has its roots in the 1960s and was a movement towards the use of new, scientific and computational methods to address the novel and pressing problems of the time (Cross, 2007). The big idea therein was that of entrepreneurship through co-construction of solutions to problems by small diverse groups of individuals investing seriously in empathy in order to conceive and develop an artefact or a solution for someone else to benefit from. As constructionists we may claim that the origin of DT as it emerged in industrial design has its roots in Mindstorms but if that is the case it has remained very implicit at the very best.

A few years ago, colleagues from communities such as “Interaction Design and Children” began considering the necessary transformations of DT in its implementation and pedagogical worth so as to try it out in mainstream education as early as at the primary level (Bekker et al., 2015). Design Thinking thus developed into a rapidly advancing, yet under-theorized, pedagogic approach appearing in classrooms today in the form of a special type of project work. Based on the industry approach to problem identification and solution development by interdisciplinary teams, its

perceived potential was to provide a context for the development of transdisciplinary skills (to join what the EU terms “21st century skills”) through engagement with real life problems and issues and an explicit focus on group work, empathy and co-construction.

As we discuss in this paper however, transforming an established coursework method from industry to mainstream education is proving to require a lot more work. DT has been implemented with very little attention to the use of digital media so far and at the same time focus on its merits has perhaps taken away attention to what is learned, the value of what is produced (and the process of production) and the educational quality in group work. We argue that there is an opportunity for Constructionism to be pivotal in the transformation of DT from an industry approach which is clunkily shifted into mainstream schooling to problem identification and solution development to theoretically informed pedagogic praxis. At the same time, Design Thinking provides a lens through which to re-examine and re-frame the ways in which we think about some of the big constructionist ideas.

Design in Constructionism

As a theory of learning, constructionism is unique in its attention to the ways in which the creation of artefacts can not only reflect the knowledge of the individual or group, but become a tool to generate knowledge through bricolage. In particular, Edith Ackerman long drew particular attention to the importance of design and its iterative nature as a reflection of the learner’s understanding and development of abstract ideas. Creating artefacts that are malleable allows the learner to explore their nascent understanding, make changes based on their observations and through discussions with others.

Given that it is at the core of the theory, it is unsurprising that the literature on constructionism in action is replete with examples of students constructing and co-constructing personally meaningful artefacts. The creation of something personally meaningful is a particularly powerful way to engage learners and maintain that engagement as they engage in increasingly complex activities and this has been particularly apparent through Maker activities. Yet the process of design, other than it being iterative, is often left unattended.

As Orkan Telhan notes “one of the most important things that constructionism did is that it took certain domains of knowledge or expertise from the hands of engineering and sciences and make it accessible to the rest of us” [ibid] (Telhan & Kafai, 2020, p. 376). Yet design, whilst essential to constructionist activity, remains inaccessible to many. Of course there are powerful examples of how design processes and tools can be integrated into constructionist activities (e.g. Kafai et al., 2014; Wolz et al., 2019, Grizioti & Kynigos, 2021), but the emancipation of “design” as a domain worthy of understanding and the skills it necessitates is left relatively untouched by constructionism beyond simply making personally meaningful artefacts.

Personally Meaningful Design

The constructionist focus on the creation of “personally meaningful” artefacts in order to engage and maintain engagement in learners as they explore, test and extend understanding is highly individualistic. This makes sense given the origins and early definitions of constructionism. What is personally meaningful to me is not necessarily personally meaningful to you. Yet, while constructionist theory and practice has successfully evolved to incorporate emerging understandings of learning as distributed, situated and inherently social; there has been little reconsideration of what we understand as “personally meaningful” to the individual or to the group in such learning contexts.

In our own work, we acknowledge that in the past we have unproblematically described the co-creation of artefacts

as personally meaningful (Girvan, 2014; Kynigos & Yiannoutsou, 2018). We should question whether these artefacts are more or less meaningful to individual members of the group and what effect does that have on learning? In cases where groups have failed to collaborate, could a measure of personal meaningfulness have been valuable in understanding why (e.g., Girvan & Savage, 2019) and how might we go about measuring this?

There has been relatively little feminist critique of theory and practice which perpetuates hegemonic masculinity in constructionist activities, although there are growing moves towards inclusive design. One notable exception to this is Roque's (2020) work in which she engaged with families to find out what would be a personally meaningful experience for them and other families, which informed the design of the subsequent activities. Another is Thanapornsangsuth & Holbert (2018) who explore a pedagogical approach to Maker activities which center on making to meet the needs of others. This way of approaching making aligns with Design Thinking (DT), highlighting potential synergies between constructionist theory and DT.

If constructionist artefact creation is egocentric, then Design Thinking is altruistic. Emerging pedagogic models, such as Design Thinking, provide us with a way to rethink the role of "personally meaningful" artefact construction in group or team-based constructionist learning activities. While the constructionist is concerned about making an artefact that addresses some personal need or desire; Design Thinking decenters what is meaningful by emphasizing empathy before developing any initial ideas and focusing on a final solution that is for others. Similarly, while both emphasize the importance of sharing artefacts "under construction", Design Thinking is explicit in setting expectations that this should be with stakeholders.

Rethinking Design Thinking

Design Thinking describes a dynamic process with specific steps for the collaborative design of innovative, sustainable and feasible product solutions for an end-user through a human-centered approach (Brown, 2008). It consists of distinct but interconnected and usually repeated stages including empathizing with the user, ideation and brainstorming, prototyping, testing and refinement, sustainability planning and delivering of the final solution. It is considered as a key competency of 21st-century education and a highly valued asset in the industry where it originated. It has also been perceived as a user-oriented approach to grappling with wicked problems (complex, real-life, contentious, socio-scientific issues) such as finding innovative solutions to sustainability challenges, an argument that has not been tested so far. DT projects involve students in multi-disciplinary co-creation activities, which are missing from the current educational paradigm despite being valued by educational science as an important element of 21st-century pedagogical transformation (Panke, 2019; Bekker et al., 2015). A number of education studies have shown the opportunities and benefits of implementing educational DT projects in order to enhance students' 21st-century skills (Scheer et al., 2012), such as computational thinking, collaboration, critical thinking and creativity, putting STEAM knowledge to use, and better understanding of real-world problems.

Yet, critics claim that DT does not provide or increase specific knowledge or competences (Vinsel, 2018). Students learn to think about design but they do not obtain the actual skill to design, create or craft (Kolko, 2018). DT per se when applied to schools doesn't usually follow particular scientific paradigms, phase models, tools or process models as the actual design thinker does, because the hard part is in the discipline of follow-up in the prototyping and testing phases (Laursen & Haase, 2019).

Critics also maintain that DT does not seek explanation and prediction (like the sciences) nor insightful understanding (like art and the humanities), but rather to change and (re)construct aspects of the world (Hernández-Ramírez, 2018a, 2018b). DT stands beyond critical and analytical thinking and is only peripherally related to specific subject matters (Bereiter, 2018). Since DT goes beyond analytical thinking it could be addressed as an opportunity to promote a different

mindset that does not head for a specific job, but “can be beneficial and rewarding in all walks of life” (Bereiter, 2018). Thus from an epistemological viewpoint we move from deductive and inductive thinking to abductive thinking and reasoning (Laursen & Haase, 2019), to a selfconscious bricoleur (Louridas, 1999).

We suggest that the necessary transformation from its origins in industrial design in order for it to gain added pedagogical value in schooling, has not been fully understood or put into practice. Although DT consists of simple steps easy to grasp, it is argued that it follows a loose framework through ambiguous and vague procedures (Morrison, 2014; Vinsel, 2018). The starting point of this ambiguity is the absence of specific learning goals and the reasons of using it, although the very nature of DT requires stakeholders “to be open and start a vaguely defined idea” (Louridas, 1999). “The dozens of versions of the Design Process” (Panke, 2019, p. 296) lead many educators to consider DT poorly defined, confusing and without focus. The student uses elements both abstract and concrete without seeking hypotheses, theory, generalization, reinforcing the view that DT does not follow a scientific paradigm. The student in such a context reacts to external events and stimuli using the force of tradition (sometimes in the form of misconceptions) and the direct response to misfits (Louridas, 1999, pp. 523-526), standing “in-between intuition and (logical) rationality” (Hernández-Ramírez, 2018a, p. 41, 2018b). Disregarding acquired scientific knowledge and its maintenance, professionalism, need for evidence (Jen, 2017) or lessons learned from cultural tradition could eventually obfuscate “the truth”, not even acknowledging its existence, which consequently raises moral issues (Hernández-Ramírez, 2018b, pp. 49, 52-53).

Through such loose procedures DT gives to students an unrealistic picture of how DT can create positive technological and social change (Vinsel, 2021). DT pushes the idea of “social innovation”, free of politics, financial and environmental struggles (Vinsel, 2021), as if it could be possible to accomplish a significant social change solely based on empathy, brainstorming and post-it notes, without taking into account the scientific infrastructure already produced in several disciplines (economy, sociology, social policy, etc.).

If this is the case it is essential for teachers using DT to turn the unselfconscious design as bricolage to a self-conscious design (Louridas, 1999). Therefore, it is important to set out how DT corresponds with specific learning goals of DT, the reasons of using it and its reference to specific disciplines, science, humanities and/or arts, even though “there is no single rationale for using design thinking in education” and “different setting provide specific advantages” (Panke, 2019, p. 288). It is also essential to make clear that DT could only be used as a caricature simulating social innovation and make students understand that genuine social change does not happen in a vacuum and entails a versatile endeavor.

How Can One Enhance the Other?

We argue that Design Thinking as a pedagogy can be significantly enhanced through meaningful engagement with constructionist theory and praxis and by doing so make it more viable for educators to consider its adoption. Evidence from constructionist literature highlights the importance of time for students to meaningfully engage in the development of artefacts/prototypes, making mistakes and learning to learn in the process of developing a solution. Most significant is the opportunity for constructionist theory to inform how we engage students beyond surface-level prototyping and bring depth to that phase of DT activity. It is through this process, using technology as a tool to create living artefacts that can rapidly be revised and shared, that learners can engage deeply in the process of trialing, developing and extending their understanding of domain knowledge, a challenge thus far in DT projects in schools.

At the same time, DT widens the potential scope of constructionism and provides us with new ways of thinking about authenticity and the value of empathy and when we decide that sufficient time has been spent developing a solution. Particularly interesting to us is the potential for DT to provide a way to make artefact construction less ego-centric yet

still motivating, by changing the way in which we consider the ways in which artefacts can be personally meaningful outside or beyond the individual.

Extending Design Thinking with Emerging Constructionist Technologies

To explore the potential synergies and value of bringing together constructionism and DT, the authors are engaged in a 3-year international research project Exten (D.T.)² which aims to develop a critical understanding of the potential, opportunities, barriers, accessibility issues and risks of using constructionist and emerging technologies in DT learning activities. It involves professional development with pre and in-service teachers and co-design of learning activities. It uses a participatory design-based research approach (Barab & Squire, 2004), comprising of three cycles. The first is exploratory. Given the dearth of knowledge at the outset of the Exten (D.T.)² project and the need to develop an in-depth and contextualized understanding of the action, exploratory case studies are used to find out, at its simplest level, “what happens”. Qualitative data, primarily from observations, reflections, and interviews, provide an opportunity to explore, in-depth the interactions between participants and technology as well as with each other. It provides an opportunity to consider not just what, but also how students learn, including subject specific knowledge, Design Thinking attitudes and 21st Century skills.

In this paper we present preliminary findings from a junior high school in Greece. 6 computer science classes, with a total of 69 students participated in DT projects across 8x 1-hour sessions. Students participated in small groups of 2-3 pupils to design and create a socio-scientific game (see also Kafai & Burke, 2015) with an authoring system called “ChoiCo – Choices with Consequences” (<http://etl.eds.uoa.gr>).

When playing a ChoiCo game, the player can make choices placed on a map. Each choice has conflicting consequences on each of a set of fields (values) applying for every choice. The point of the game is to sustain playing by avoiding to go below (or above) pre-set “red lines” i.e. field values. But ChoiCo is centrally about constructionism through game modding (Kynigos & Grizioti, 2020). So, the user acts as prosumer, eternally questioning and changing the affordances of a game which are transparent, i.e. the point geolocation, name and number, the fields and the choice consequences (numerical, functional, random, text or picture and video) and the game rules via a blockley language. The students had no previous experience with the ChoiCo system.

The first session provided students with an opportunity to familiarize themselves with ChoiCo through exploration and playing games made by others. In the second session, students then modified an existing game to familiarize themselves with UI elements and design tools. From the third session onwards, students engaged in the DT activities: building empathy, divergent thinking, defining the enterprise, convergence, rapid prototyping of their game, testing and gaining feedback. Data analysis takes a constant comparative and critical incident approach. At the time of writing this, we have only had the chance to undertake a preliminary analysis of the large volume of data. Nevertheless, we did identify some critical episodes which we feel will help the discussion herein.

Critical Incidents

The findings presented here have emerged from a single group of students. We employed a short analysis of consecutive snippets of incidents to show how DT can provide a context where students engage in rapid prototyping which extends from being personally meaningful to mutually meaningful (as a joint enterprise) and then on to a design for the result to become meaningful to others. At the same time the rapid prototyping process maintains the constructionist idea that

when scientific ideas and practices of scientific thought are embedded in a tool, users are bound to put concepts to use and immerse in such practices.

The three students chose their project to be about an environmental issue. Their idea was to create a game where the player is an energy factory manager! He/she starts off with environmentally unfriendly production of electricity, unhappy workers and little money. The goal is to sustain making choices by juggling with energy production and selling on the one hand and to making the employees happier and the environment better on the other!

The students firstly designed their game with only one pin (choice) but full of game rules, trying out the blockley coding. Then they put more pins on the map and set the attributes to each pin. They tried playing the game as a kind of rapid prototype testing and found it to be boring, so they decided to add one more layer and more pins on the new layer. Eventually they tested the game again as players, decided this time they needed to make it more realistic and as a result one suggested for them to insert a “cheat pin” in the game. In fact it was not a real cheat but a new pin that fills in the gap that the “money” attribute causes on game flow.

<p>S1 It seems to me a little bit boring. What must we put in to make it more interesting?</p> <p>S2 We could put.....</p> <p>S1 Ah! Build a new factory!</p> <p>S2 So to change layer? [refer to the player]</p> <p>S1 Let's put a new layer that says....that....and also at that factory...that...</p> <p>S1 If we do play we can go to another layer? No we can't! So we will insert another layer that shows “make new factory” and give us 50000 euro and if you click it, it shows one new layer with new stuff.</p> <p>S2 That's what I 'm saying. Yes, this!</p> <p>S1 Search for a factory! One new one this time! [they are searching for a new factory picture]</p>	 <p>Figure 1 First game version: One pin but full of rules</p>
---	---

This snippet shows how the students' attention was on the socio-scientific issue at hand as the forum for building a cool game idea and game flow. What they needed to do however to make such changes was to make changes to a database, to the blockly-defined rules and the geolocated choices.

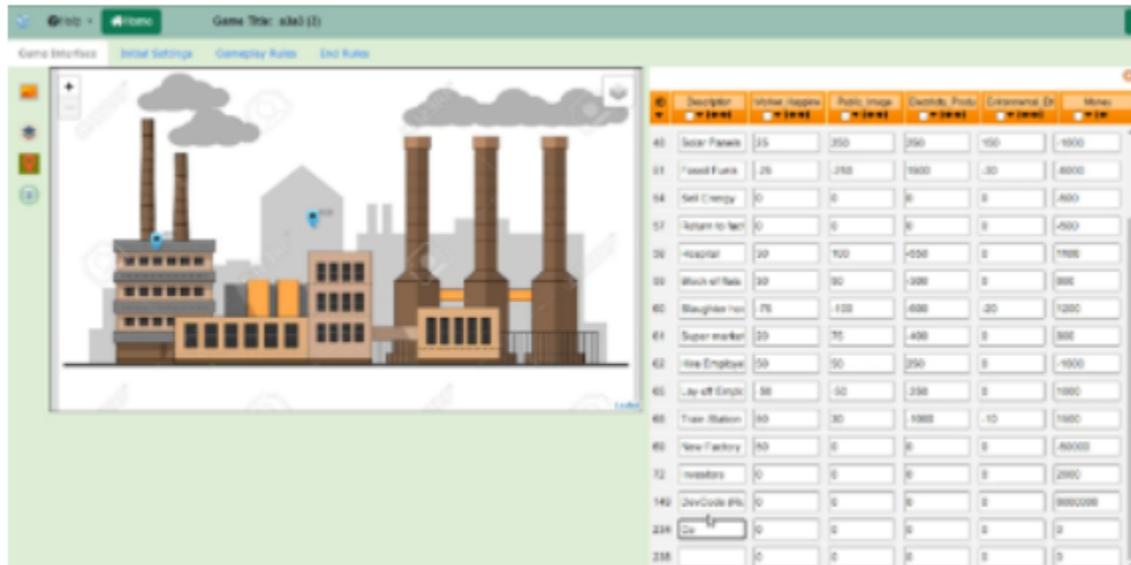


Figure 2: the new layer

Testing out the game with the new layer – factory, the students found that they ran out of money too soon for the game to be a challenge. The snippet that follows shows their thinking to be about juggling the values connected to money and considering the “red lines” of the game which were defined in the blockley part.

<p>S1 Well, I have an idea! We have already done all the new things that we want...</p> <p>S2 We have to find a way to get money inside the factory so no need to go We have “Higher wages” and “Lower wages”. Let’s find a way with a cheat code [a new pin] and take much money.</p> <p>S1 Why? For us?</p> <p>S2 For you! Yes for us.</p> <p>S1 Mmm! We can simply put one. For example this is what I was saying [he put a new pin]</p> <p>S2 Code? [the pin name] Why did you put this?</p> <p>S1 To test the... [new factory]</p> <p>S1 [He modifies the properties values of new pin]</p> <p>S2 60000 set the money! So not running out of money. [After the new pin they play the game]</p>	
--	--

Conclusion

Much like Martinez & Stager (2013) did for the Maker Movement in schools, we view constructionism as providing an essential theoretical and evidence informed foundation for teachers interested but uncertain about using DT in the classroom. At the same time, DT provides opportunities to rethink some core constructionist ideas which have been slow to evolve. In this paper we problematised the idea of personally meaningful tinkering with artefacts. We argued that although this may be the essence of constructionism, nevertheless there is value in considering a context where tinkering is a means to a designed ending, the DT “product”. The product may be the end result of a DT project but

still maintains the status of a living, malleable artefact maybe for a subsequent project. The point is that the process of tinkering acquires the idea of a negotiated objective, a joint enterprise towards an end. The second point enabled by DT is the idea that personally meaningful does not exclude the mutually meaningful and furthermore that the meaning involves the design of an artefact for someone else to use or to enjoy. But what is particularly exciting are the potential and, as yet, unknown synergies we predict will emerge from combining DT and constructionism.

Answering the question “What are some of the big questions or issues the constructionist community should be addressing?”, Shapiro (2020, p. 372) states that “there’s a lot of fine-grained classical learning sciences work to do... If we do that then we can start to think about the ways in which constructionist activities can build on each other, can be jumping off points for doing work that looks more like “spiralling” in traditional schoolwork”. We believe that bringing constructionist theory and tools to bear on DT activities provides just such a way to create a spiral curriculum. Digital constructionist tools ensure that there is a living artefact that learners can return to year-by-year and the “wicked problems” of DT are (unfortunately) unlikely to be resolved in the school-life of the child.

Acknowledgments

This research has received funding from the European Union’s Horizon Europe Framework Programme for Research and Innovation under the Grant Agreement No. 101060231 (Exten.D.T.2 – Extending Design Thinking with Emerging Digital Technologies). Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union. Neither the European Union nor the granting authority can be held responsible for them.

References

- Artigue, M., & Mariotti, M. A. (2014). Networking theoretical frames: the ReMath enterprise. *Educational Studies in Mathematics*, 85(3), 329–355. <http://www.jstor.org/stable/43589825>
- Barab, S., & Squire, K. (2004). Design-based research: Putting a stake in the ground. *The Journal of the Learning Sciences*, 13(1), 1–14.
- Bekker, T., Bakker, S., Douma, I., Van Der Poel, J., & Scheltenaar, K. (2015). Teaching children digital literacy through design-based learning with digital toolkits in schools. *International Journal of Child-Computer Interaction*, 5, 29–38. <https://doi.org/10.1016/j.ijcci.2015.12.001>
- Bereiter, C. (2018). *Applying Design Thinking in School Subjects*. <https://www.ikit.org/KBSI2018/Presentations/11b-Bereiter.pdf>
- Brown, T. (2008). Design thinking. *Harvard Business Review*, 86(6), 84–92.
- Cross, N. (2007). From a Design Science to a Design Discipline: Understanding Designerly Ways of Knowing and Thinking. In R. Michel (Ed.), *Design Research Now: Essays and Selected Projects* (pp. 41–54). Berlin, Boston: Birkhäuser. https://doi.org/10.1007/978-3-7643-8472-2_3
- Girvan, C. (2014). Constructionism, creativity and virtual worlds. In G. Futschek & C. Kynigos (Eds.), *Constructionism and Creativity: Proceedings of the 3rd International Constructionism Conference 2014* (pp. 367–377). Vienna, Austria: Austrian Computer Society.

- Girvan, C., & Savage, T. (2019). Virtual worlds: A new environment for constructionist learning. *Computers in Human Behavior*, 99, 396–414.
- Grizioti, M., & Kynigos, C. (2021). Code the mime: A 3D programmable charades game for computational thinking in MaLT2. *British Journal of Educational Technology*, 52(3), 1004–1023. <https://doi.org/10.1111/bjet.13085>
- Hernández-Ramírez, R. (2018a). Design Thinking, Bullshit, and what thinking about Design could do about it. In A. Rangel, L. Ribas, M. Verdicchio & M. Carvalhais (Eds.), *Proceedings of the 6th Conference on Computation, Communication, Aesthetics & X* (pp. 37–46). Universidade do Porto.
- Hernández-Ramírez, R. (2018b). On design thinking, bullshit, and innovation. *Journal of Science and Technology of the Arts*, 10(3), 45–57. <https://doi.org/10.7559/citarj.v10i3.555>
- Jen, N. (2017, August). *Natasha Jen: Design thinking is bullshit* [Video]. <http://99u.com/videos/55967/natasha-jen-designthinking-is-bullshit>
- Kafai, Y. B., & Burke, Q. (2015). Constructionist gaming: Understanding the benefits of making games for learning. *Educational Psychologist*, 50(4), 313–334.
- Kafai, Y., Fields, D., & Searle, K. (2014). Electronic textiles as disruptive designs: Supporting and challenging maker activities in schools. *Harvard Educational Review*, 84(4), 532–556.
- Kolko, J. (2018). The Divisiveness of Design Thinking. *Interactions*, 25 (3), 28–34. <https://doi.org/10.1145/3194313>
- Kynigos, C. (2015). Constructionism: Theory of Learning or Theory of Design? In S. J. Cho (Ed.), *Selected Regular Lectures from the 12th International Congress on Mathematical Education* (pp. 417–438), © Springer International Publishing: Cham, Heidelberg, New York, Dordrecht, London, Switzerland. DOI 10.1007/978-3-319-17187-6
- Kynigos, C., & Grizioti, M. (2020). Modifying games with ChoiCo: Integrated affordances and engineered bugs for computational thinking. *British Journal of Educational Technology*, 51(6), 2252–2267. <https://doi.org/10.1111/bjet.12898>
- Kynigos, C., & Yiannoutsou, N. (2018). Children challenging the design of half-baked games: Expressing values through the process of game modding. *International Journal of Child-Computer Interaction*, 17, 16–27. <https://doi.org/10.1016/j.ijcci.2018.04.001>
- Laursen, L. N., & Haase, L. M. (2019). The Shortcomings of Design Thinking when Compared to Designerly Thinking. *Design Journal*, 22(6), 813–832. <https://doi.org/10.1080/14606925.2019.1652531>
- Louridas, P. (1999). Design as bricolage: anthropology meets design thinking. *Design Studies*, 20(6), 517–535. [https://doi.org/10.1016/s0142-694x\(98\)00044-1](https://doi.org/10.1016/s0142-694x(98)00044-1)
- Martinez, S. L., & Stager, G. (2013). *Invent to learn. Making, Tinkering, and Engineering in the Classroom*. Torrance, Canada: Constructing Modern Knowledge.
- Morrison, D. (2014, January 2). *Why 'Design thinking' doesn't work in education*. Online Learning Insights. <https://onlinelearninginsights.wordpress.com/2013/08/06/why-design-thinking-doesnt-work-in-education/>
- Panke, S. (2019). Design Thinking in Education: Perspectives, opportunities and challenges. *Open Education Studies*, 1(1), 281–306. <https://doi.org/10.1515/edu-2019-0022>
- Roque, R. (2020). Building projects, building relationships: Designing for family learning. In N. Holbert, M. Berland & Y. B. Kafai (Eds.), *Designing Constructionist Futures: The Art, Theory, and Practice of Learning Designs* (pp. 195–203). Cambridge MA: MIT Press.

- Scheer, A., Noweski, C., & Meinel, C. (2012). Transforming constructivist learning into action: Design thinking in education. *Design and Technology Education: An International Journal*, 17(3), 8–19.
- Shapiro, R. B. (2020). New and Future Coding Paradigms: Interview with R. Benjamin Shapiro. In N. Holbert, M. Berland & Y. B. Kafai (Eds.), *Designing Constructionist Futures. The Art, Theory, and Practice of Learning Design* (pp. 369–374). Cambridge MA: MIT Press.
- Telhan, O., & Kafai, Y. B. (2020). Advancing Making with Biology: Interview with Orkan Telhan and Yasmin B. Kafai. In N. Holbert, M. Berland & Y. B. Kafai (Eds.), *Designing Constructionist Futures. The Art, Theory, and Practice of Learning Design* (pp. 375–380). Cambridge MA: MIT Press.
- Thanapornsanguth, S., & Holbert, N. (2018). Exploring girls' values and perspectives in making for others. In V. Dagiene & E. Jasutė (Eds.), *Proceedings of Constructionism 2018, Constructionism, Computational Thinking and Educational Innovation: conference proceedings* (pp. 460–471). http://www.constructionism2018.fsf.vu.lt/file/repository/Proceeding_2018_Constructionism.pdf
- Vinsel, L. (2021, December 6). The Design Thinking Movement is Absurd – Lee Vinsel – Medium. *Medium*. <https://sts-news.medium.com/the-design-thinking-movement-is-absurd-83df815b92ea>
- Vinsel, L. (2018, May 21). Design Thinking Is a Boondoggle. <https://www.chronicle.com/article/design-thinking-is-a-boondoggle/>
- Wing, J. M. (2006). Computational thinking. *Communications of the ACM*, 49(3), 33–35. <https://doi.org/10.1145/1118178.1118215>
- Wolz, U., Auschauer, M., & Mayr-Stalder, A. (2019). Code crafting with turtlestitch. In *ACM SIGGRAPH 2019 Studio (SIGGRAPH '19)*, (pp. 1–2). Association for Computing Machinery, New York, NY, USA, Article 2, p. 1–2. <https://doi.org/10.1145/3306306.3328009> .

NEW TECHNOLOGY FRONTIERS AND CULTURAL MAKING

Musical Manipulatives

Devin Ulibarri, MAP Family Learning Center, devin@devinulibbarri.com

Walter Bender, Sugar Labs, walter@sugarlabs.org

Abstract

Manipulatives are physical and virtual objects that are used as teaching tools in mathematics and music education. Music Blocks software is designed for teachers and learners to explore the fundamental concepts of music in a visual-coding environment, largely through the use of virtual manipulatives that target powerful ideas in music theory and practice. In this paper, we describe the use of music manipulatives and how they are embodied in the Music Blocks software. We also describe lesson plans that we have been developing since first introducing Music Blocks at Constructionism 2016.

Introduction

Manipulatives are physical objects that are used as teaching tools in mathematics to help students visualize and understand mathematical concepts. The use of manipulatives in mathematics education can be traced back to ancient times, where counting stones, sticks, and shells were used to teach basic arithmetic. In the 19th century, Friedrich Froebel developed the concept of kindergarten, which emphasized the use of manipulatives as teaching aids. Froebel's approach used a series of wooden blocks to teach children spatial relationships, geometric shapes, and arithmetic. In the early 20th century, Maria Montessori developed a method of education that also used manipulatives. Montessori's method used materials such as colored blocks, beads, and rods to teach mathematical concepts such as number sense, addition, subtraction, multiplication, and division. In the 1960s and 1970s, the use of manipulatives in mathematics education gained popularity in the United States as part of the New Math movement, which aimed to introduce abstract mathematical concepts to students at an earlier age by using manipulatives such as base-10 blocks, Cuisenaire rods, and geometric shapes to teach addition, subtraction, multiplication, and division. Efforts have been made to catalog on-line math manipulatives (Utah State University 1999). Manipulatives help to make mathematics (and the related discipline of computation) more accessible to children who might otherwise struggle with the subject. By providing a visual and tactile representation of abstract concepts, manipulatives can help to bridge the gap between theory and practice, making mathematics more engaging and meaningful.

Through the invention of the Logo language (Solomon et al., 2020), Seymour Papert, Wally Feurzeig, and Cynthia Solomon pioneered the use of virtual manipulatives. Using Logo, children are able to explore mathematical concepts in a concrete, hands-on way. As they maneuver the Logo Turtle, they discover relationships between the numbers and the physical world and thus develop a more intuitive understanding of the underlying concepts. Students use the Turtle to create geometric shapes to learn about area, perimeter, symmetry, scale, and transformations. Logo manipulatives are a tool for promoting creativity and problem-solving skills. By giving children the freedom to experiment with different materials and approaches, manipulatives can encourage them to develop their own solutions to mathematical problems. Logo can be used to create new math manipulatives through the use of Logo procedures. Students can create their own Logo procedures, which can then be used to further explore math problems. The generative nature of Logo programming enables the learner to invent new manipulatives (and perspectives).

Music also has a long tradition of manipulatives. Until the advent of recorded music, the only way to create music

was through the manipulation of a physical object. One could argue that everything from humming a tune to striking sticks together to define a rhythm to strumming a chord on the strings of a guitar are examples of deploying musical manipulatives. At the same time, music is similar to math in that it has many layers of abstraction, so it stands to reason that manipulatives have long been employed in the development of its pedagogy. Imaginative music teachers use many types of manipulatives with their students. Some of the more common ones are: instruments themselves, including one's voice; physical blocks; instrument building; writing the music down (including invented notation); conductor's baton; metronome; and tuner and tuning fork. Improv teachers also use manipulatives, e.g., different color lights to conduct an ensemble in an improvised group performance; hand signals to conduct an ensemble in an improvised group performance; and a ball falling against a surface to help with timing.

There are many eclectic collections of music manipulatives found on the web. They span the gamut of flash cards (for drill and practice) to dice or spinners (often used for generating random sequences of notes) to a variety of reading and notation tools (often in the guise of games). While many of these manipulatives are in service of rote instruction, many of the more basic manipulatives, such as simple percussion instruments, can be used as a vehicle for guiding a learner towards some of the powerful ideas in music, such as polyrhythm, phrasing, intervals, etc. Examples of the latter include the work of Scripp, et al. (2014). The challenge is to go from artifacts to ideas.

Virtual music manipulatives have been part of the Logo repertoire since the 1970s. Inspired by Papert and Marvin Minsky, Jeanne Bamberger, Hal Abelson, and Terry Winograd created MusicLogo, “whose commands controlled a sound-emitting box (originally Minsky and Ed Fredkin's Music Box), allowing a tune to be written in code and then immediately played aloud.” Exposed by the language and built into some of Bamberger's pedagogy were some “powerful ideas”, such as some of the higher-level structural elements of music: e.g., phrases and scalar steps (Bamberger, J., 1991; Bamberger and Hernandez 1999). Bamberger demonstrated that virtual music manipulatives, like math manipulatives, help a person to think on an abstract level.

Music composition and performance require practitioners to follow basic control flow such as: sequences; conditionals and loops; data abstractions such as changes in timbre, tone, and meter; functions and operators such as transpositions, inversions, and retrograde; and debugging—making corrections to a composition, perfecting a transcription, or working through a section of music on an instrument—that leads to a deeper understanding of music (and computation) theory (Bender and Ulibarri, 2021). The social aspect of musical performance also parallels the perspective that computing is both collaborative and creative (Brennan and Resnick 2012). An analog can be built between the way programmers work together, building communities around sharing and remixing code, and the way in which musicians build communities of interest through performance, sharing, and debating best practices. Programmers review code and musicians critique performances. Both musicians and programmers modify, improvise, and derive inspiration from the work of peers and mentors. They also share lesson plans and innovations around the use of manipulatives.

Music Blocks Manipulatives

The authors created Music Blocks, a Logo-inspired visual programming language and collection of manipulative tools for exploring musical and mathematical concepts in an integrative and fun way (Bender et al., 2016). With Music Blocks, we try to emphasize some of the benefits of music that the traditional computing pedagogy does not, including the potential to improve social-emotional skills. When we presented Music Blocks at Constructionism 2016 in Bangkok, we did not yet have much experience using the language in the classroom. In the years that have followed, Music Blocks has been used in large-scale deployments in Japan and Peru and we have developed a number of lesson plans that highlight its use as a musical (and mathematical) manipulative. The remainder of this paper describes some of the language affordances that support its use as a manipulative and examples of some of the lessons and lessons learned.

Music Blocks is explicit about exposing core ideas: not just notation, but the ideas behind the notation, for example, the relationship between a quarter note symbol and the fraction $1/4$. Also, because Music Blocks has built in the concepts of meter and beats per minute, the note value can be tied to time and to events within a measure. This is in contrast with the musical extensions more recently applied to block-based programming languages such as Blockly (Fraser et al., 2012) or Scratch (MIT Media Lab, 2003), which either operate in hard-coded time or a notation that is unconnected to a measure (See Table 1). The insights of Bamberger are absent—musical structure is largely an afterthought. A more detailed comparison of Music Blocks and Scratch can be found in (Ulibarri, 2022)

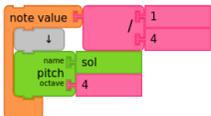
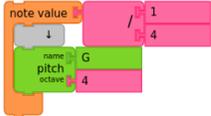
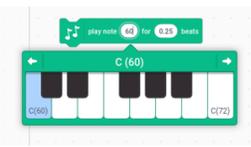
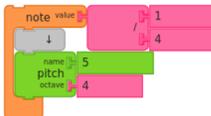
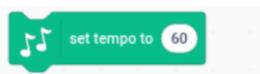
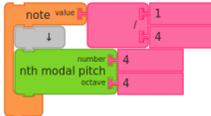
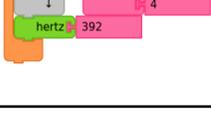
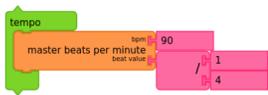
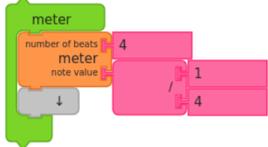
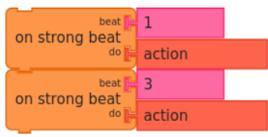
Music Blocks	Blockly and Scratch
	
	
	
	
	
	
	
	
	

Table 1: Specifying pitch, note value, tempo, and meter

In many cases, the Music Blocks interface itself is a manipulative. For example, when selecting pitch, instead of a flat list of letters, the choices are arranged in a menu that reflects the cyclic nature of pitch notation, reinforcing the musical concept of octave (See Figure 1). Music Blocks supports many representations of pitch—solfege, letter class, pitch number, midi, semitone and scalar step, and hertz—enabling the learner to compare and contrast these common variations.

Layered on top of rhythm and pitch are common musical transformations, such as transpositions and intervals (both scalar and semitone), chords, arpeggio, inversions, retrograde, and effects, such as timbre, chorus, neighborhood, etc. (See Figure 2). The program building blocks lower the floor to engagement with their analogous composition and performance building blocks. An additional set of affordances provided by Music Blocks are program parameter blocks that expose state. In Logo, there are provisions to access the current x, y, heading, and color of the Turtle. Added to that list In Music Blocks are current pitch, note value, beat, measure, tempo, volume, mode length, etc. (Figure 2, right). Access to these parameters enables access to the underlying musical structure and thus provides much of the scaffolding to enable learners to become builders of their own manipulatives.

Music Blocks exposes powerful ideas, such as polyphonic rhythms, key and mode, intervals, tuning, and temperament,

through manipulatives called “widgets”. Widgets don’t just produce music, they output code that is descriptive of concepts found in music, such as generating rhythms, changing tempo, and using samples. Most of the widgets are inspired by the things a music teacher might draw on a whiteboard—now in the form of a manipulative. You can find examples of many of those diagrams on music blogs and websites. For example, the illustrations on (Hahn, 2018) are very similar to the interactive Mode widget (found in Table 2).

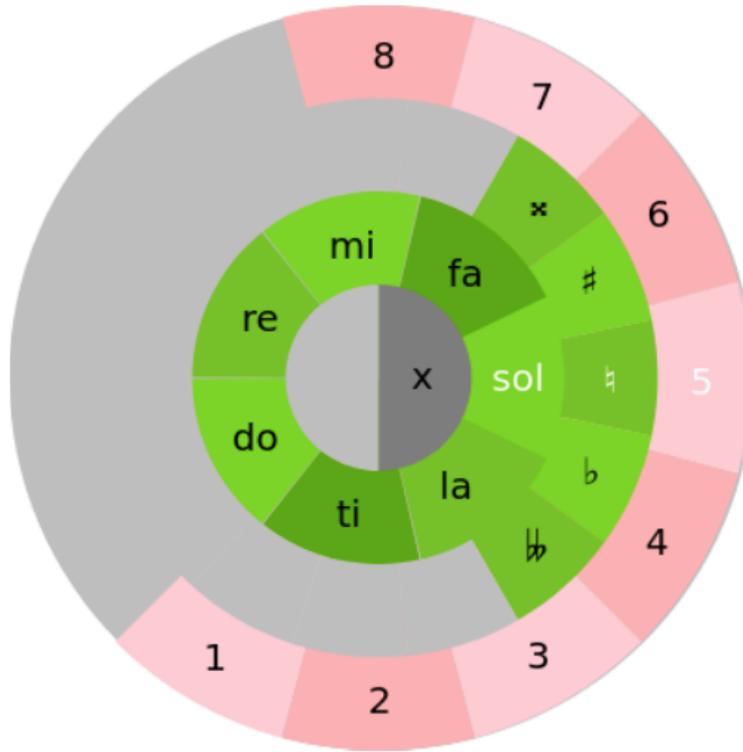


Figure 1: The Pitch menu

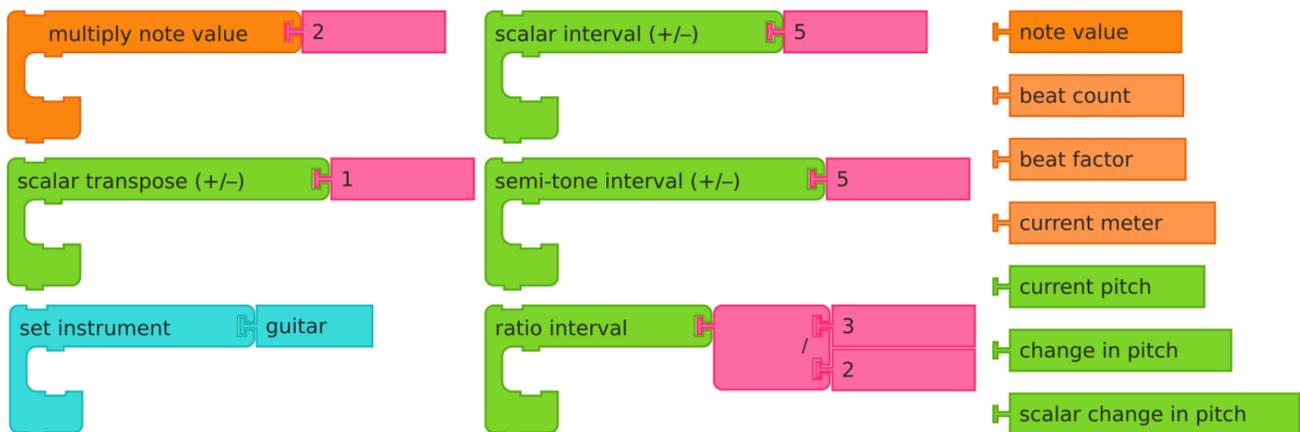


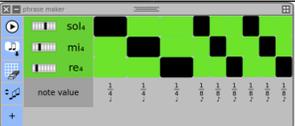
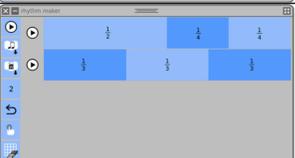
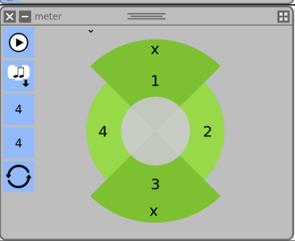
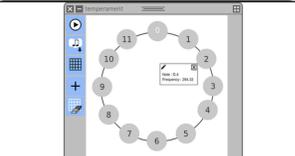
Figure 2: Some of the common musical transformation and parameter blocks built into Music Blocks.

The configuration of each widget is programmable (using blocks) and every widget can be used to write and export code (as blocks). Along with the activities defined by the widgets, students also: identify and differentiate patterns; explore proportions, ratios, and relationships expressed through chords and intervals; read and represent musical ideas with a graph; use conditionals to express a melodic sequence; and program canons to explore concurrency. Many widgets, such as the mode, rhythm, and temperament widgets, explicitly draw connections between music and math. Some Music Blocks widgets are described in Table 2.

Music Blocks Lesson Plans

We have developed dozens of lessons for beginner, intermediate, and advanced students. The typical Music Blocks lesson plan is a one-hour block, where the first 15 minutes is a hands-on activity (often using a physical manipulative) and discussion. This is followed by a series of programming activities. The final 5-10 minutes are used for group demonstrations, discussion, and reflection. Most lessons also pose additional “stretch” goals, for the learner who wants to push the lesson concepts further. Some beginner lessons are described here in brief.

Lesson: Spelling Actions (learning the musical alphabet). Whether using “C, D, and E” or “Do, Re, Mi,” musical pitch can be expressed in a musical alphabet. That alphabet is one of the fundamental building blocks of understanding music. One of the teaching interns created the following lesson plan.

Widget/Description	
<p>The Phrase Maker widget lets you “paint” notes in a grid and export these phrases as actions, reinforcing the musical idea of the phrase. The grid is a programmable Cartesian coordinate space, where the x axis represents divisions in time (specified in both traditional note notation and fractions) and the y axis represents frequency (specified in any of the many pitch representations). In the example, the y axis is mapped to solfège. Phrase Maker is inspired by Scripp, et al. (2014).</p>	
<p>The Rhythm Maker widget contains a row for each rhythm ruler. A subdivision of a musical measure is created within a cell whenever it is clicked. The cells, which represent note durations, can be further subdivided. The denominator of the subdivision can be any number the user specifies. The 1/2 represent note value of half, which is half the duration of a whole. The 1/4 represents the note value of quarter, which is a quarter the duration of a whole. The 1/3 represents the note value of a half note triplet, which is a third the duration of a whole. The rhythms can be exported as phrases and incorporated into drum machines.</p>	
<p>The Meter widget is used to explore strong and weak beats. (In the example, the meter is 4 beats per measure, where each beat is one quarter note.) The measure provides important scaffolding to musicians. Among other things, it helps to organize long pieces of music into smaller units; to control the rhythm and meter of the piece; to keep track of the time; to provide a framework for improvisation; to create a sense of structure and order; to help musicians communicate with each other. Defining the beat structure within a measure enables the Music Blocks programmer to trigger events on strong and weak beats.</p>	
<p>The Tempo widget sets one or more tempos and serves as a metronome. It makes concrete the relative nature of music note value notation. A fun activity is to open multiple metronomes, set them to different beats per minute, and listen as the beats go in and out of phase.</p>	
<p>The Temperament widget enables the user to visualize and edit notes within an octave. It not only lets the user explore different 12-tone tuning systems popular in Western music, e.g., Equal Temperament, Just Intonation, Pythagorean tuning, etc., but also explore arbitrary divisions of an octave and even redefine the octave itself. A fun example we’ve explored is tuning the Kite Guitar (Giedraitis et al., 1999) which has 41 notes per octave instead of the usual 12 of most modern tuning systems.</p>	

Widget/Description

The **Mode** widget lets the learner explore musical modes and to generate custom modes. Mode is a core attribute of music. Most music is composed using a subset of the chromatic scale called a scale. Mode has a direct corollary in set theory and algebra. The choice of which semitones are in mode (“scalar”) has a direct impact on the intervals that can be expressed and this defines the tonal mood (or “flavor”) of the music. A common exercise in Music Blocks is to transpose a composition with a mode (and to observe that the mood does not change) and to switch modes, which results in a discernible mood change.

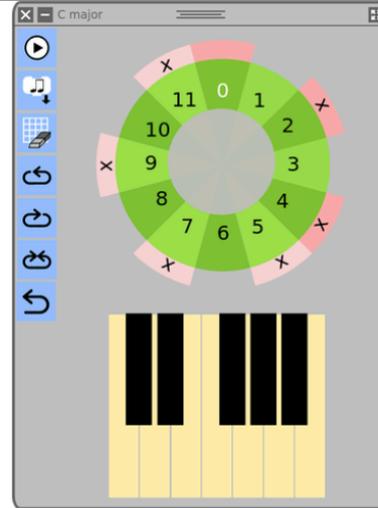


Table 2: Music Blocks widgets

Students create words using the musical alphabet, which they later string together to make short melodies. In the lesson, they explore the musical concepts of pitch, alphabet/solfege, and melodic sub-phrases and the programming concept of subroutines. Steps: (1) During the hands-on activity time, the students are asked to write down as many words as they can using the seven letters of the musical alphabet (C, D, E, F, G, A, and B); (2) They share their word lists and then, as a group, they review how those seven letters map to solfege; (3) Students write their words out as notes using the note and pitch blocks in Music Blocks; (4) When they complete a word, they put it into an action; (5) Once they have programmed a few words, they compose word songs by putting the action blocks together into different musical “sentences”. Having this familiarity with note, pitch, and action blocks has helped students navigate subsequent lessons.

Lesson: “Alligator, Monkey, Zoo” and “Cups” (exploring basics in rhythmic and pitch phrases). There are two different versions of this lesson: (1) In “Alligator, Monkey, Zoo”, the students explore rhythmic phrases—alligator has four syllables, monkey has syllables, and zoo has one syllable; (2) In “Cups”, the students rearrange the phrases of a familiar song (“Hot Cross Buns”). In both cases, students begin by using a physical manipulative and then program the same sequence using action blocks in Music Blocks.

Students explore the musical concept of phrases, a basic building block of music. In programming, there is a direct analogy to subroutines. Steps: (1) Start by chanting “alligator, monkey, zoo” or singing “Hot Cross Buns”. See if the students can identify the individual phrases; (2) Ask the students to associate each phrase with a magnetic tile or paper cup of a different color; (3) Have them arrange the manipulatives in order and sing the phase associated with each object; (4) Have the students rearrange the manipulatives and sing the phases in a new order; (5) Open a Music Blocks project with pre-programmed actions defined for the phrases; (6) Have the students explore different arrangements of the action blocks. Students are encouraged to reorder them to make unique rhythmic patterns, taking turns creating rhythms and conducting the rest of the group.

After a number of years working with Music Blocks, we have observed that beginning students can get frustrated when forced to work entirely with the smallest musical components. Making music without defining phrases or functions (e.g. action blocks) is tedious. Therefore, one of the first lessons we do with students has “Hot Cross Buns” transcribed in action blocks for them (in a way that is very similar to Bamberger’s “Tune Blocks”). That being said, the students do look inside the action blocks to see what the notes are in them. We encourage students to “remix” the notes and structure in the latter half of this lesson.

Lesson: Drum Machines. Students learn to identify and synthesize beat and rhythm. They will use these skills to express themselves musically. They use observational and compositional skills to explore these musical concepts. The musical concepts explored include beat and rhythm; whole notes, half notes, quarter notes, etc.; programming concepts include fractions, iteration, actions, and animation. Steps: (1) A student creates a rhythmic pattern (using sticks, claps, or some other physical device); the other students copy the pattern; (2) Introduce a second pattern and alternate between the patterns; (3) Open Music Blocks and find the “rhythm maker” widget; use the widget to create different rhythmic patterns; (4) Save the patterns as actions; program the actions using “repeat” blocks; (5) Introduce graphics with the “on every beat, do” block.

Students were able to understand what is meant by a steady beat and rhythm. They composed their own rhythms and programmed a composition. Each beat was associated with a frame in an animation, grounding the rhythm in something physical. See Dildine (2020).

Lesson: Staff Whiteboard (programming a virtual whiteboard). Students explore standard notation of pitch over time using a virtual whiteboard project. The musical concepts include melody, key, alphabet/solfege; programming concepts include heap, interaction, conditionals. Steps: (1) Open the example project; (2) Sketch out a melody with the virtual whiteboard. The melody is recorded and can be played back.

This manipulation was useful when giving instrument lessons during the pandemic; during a video lesson it was difficult to see students’ papers as they were writing their music down. Using Music Blocks, the teacher could be sure that everyone was clearly seeing and hearing the same thing and give students feedback as they compose and transcribe their musical ideas. Another unintended, but delightful, consequence of this feature was that students found the interface so empowering that even students who were previously anxious about learning to read music began to smile and re-engage after seeing their music notated in Music Blocks.

Lesson: Create a Metronome. Metronomes are important tools to practice timing for a piece of music. The basic features of a metronome are easy to put together in Music Blocks. By creating a metronome, students discover important components of timing such as “pulse”, “beat”, and “meter”. Steps: (1) Ask students to feel their pulse and discuss how a pulse might speed up or slow down; (2) Ask students to describe the important features of a metronome; (3) Create a simple metronome with a drum block that moves the mouse performer from left to right; (4) Ask the students to design their own movements.

Why did we design a lesson around building a metronome when there is already a metronome widget? As Idit Harel demonstrated, children learn when they are designers (Harel, 1991). And they are empowered when they discover that they can build their own tools (and often improve upon the existing tools). The Music Blocks students were likewise empowered. At the end of one class, a student exclaimed, “I love metronome.” This relationship with the time-keeping tool was quite the contrast from the way that same student’s mother described the metronome as her “arch-nemesis.” By creating a tool, rather than being prescribed the tool, the student felt ownership and had a positive relationship with her creation.

The lessons described above are targeted at elementary school-age learners. We have also used Music Blocks with middle-schoolers, with whom we have explored music theory in more depth. Sixth graders wrestle with concepts such as the Circle of Fifths. This is brought to life in Music Blocks, making more accessible some of the complexities of intervals and modes. Examples of more advanced music theory we’ve explored in Music Blocks include: musical canon and imitation; rhythmic syncopation (a string of notes on offbeats, played successively); odd meters (meters other than 2/4, 3/4, and 4/4, which are the most common); polytonality (multiple key signatures à la Béla Bartók); timbre and sound; and tuning and temperament.

We continue to push the limits of Music Blocks both technically and pedagogically. The biggest stress test for Music Blocks is when a musician uses it in a performance. (Many of the Music Blocks students are also learning an instrument.)

While not optimized for performance, it has been used in some limited capacity. For example, musician and educator Rob Flax has performed together with Music Blocks, exchanging melodic phrases every four measures (i.e. “trading fours”). See Ulibarri (2020).

Conclusion

Learning to play an instrument is inherently a hands-on experience; it requires the student to physically manipulate the instrument in order to produce sound. This hands-on experience is important because it allows students to develop a deep understanding of how music works as they learn how to control the instrument and how to coordinate their movements with the music. We have found that this hands-on experience is further enhanced through the application of supporting manipulatives, including virtual manipulatives, such as Music Blocks widgets.

While it is not typical for elementary music education to emphasize invention or composition, by applying Constructionist principles, we can design numerous opportunities for learners to build their own manipulatives and instruments, compose their own music, or incorporate music in their personal expression, e.g. games. Composition and computation require a learner to think creatively and to solve problems; to engage with powerful ideas. It allows students to develop an understanding of how music works, to realize its connection to math, to learn in more than one way, to have fun, and—very important—experience music’s strong social ties.

In the early days of the Apple iPhone marketing campaign, their tagline was, “There’s an App for that.” One could say the same for Music Blocks: there is an interactive widget for many (but notably not all) of the manipulatives commonly used in a music classroom. But Music Blocks goes a step further. Through Music Blocks lesson plans we encourage teachers and learners to construct their own apps, whether it be invented notation, metronome, listening exercise, or musical game. The essential enablers of this musical construction are the affordances in the language itself—a musical microworld populated by “powerful musical ideas”.

References

- Bamberger, J. (1991) *The Mind Behind the Musical Ear: How Children Develop Musical Intelligence*. Harvard University Press, Cambridge, pp. 104
- Bamberger, J. and Hernandez, A. (1999). *Developing Musical Intuitions: A Project-Based Introduction to Making and Understanding Music Complete Package*. Oxford University Press
- Bender, W. and Ulibarri, D. (2021). #11 paper: Twenty Things to Do with a Computer. *Forward 50: Future Visions of Education Inspired by Seymour Papert and Cynthia Solomon’s Seminal Work*. Gary S. Stager (Editor), Cynthia Solomon (Foreword). Constructing Modern Knowledge Press.
- Bender, W., Ulibarri, D., and Khandelwal, Y. (2016). Music Blocks: A Musical Microworld. *Construtionsim 2016 Constructionism in Action*. Brennan, K. and Resnick, M. (2012, April). New frameworks for studying and assessing the development of computational thinking. In *Proceedings of the 2012 annual meeting of the American educational research association*, Vancouver, Canada (Vol. 1, p. 25). Dildine, T. (2020) *Teddy music blocks*. <https://www.youtube.com/watch?v=AZLQCDIKqdc>
- Fraser, N., Neutron, Q., Spertus, E., and Friedman, M (2012) *Blockly*. <https://blockly.games/music>
- Giedraitis, K., Wolf, A., Spathas, A. and Barnett, T. (1999) *The Kite Guitar*. <https://www.kiteguitar.com/what-it-is/>

Hahn, M (2018). *Music Modes: How to Enrich Your Songs with Modal Color*. <https://blog.landr.com/music-modes/> Harel, I. (1991) *Children Designers*. Praeger.

MIT Media Lab (2003) *Scratch*. [https://en.wikipedia.org/wiki/Scratch_\(programming_language\)](https://en.wikipedia.org/wiki/Scratch_(programming_language))

Scripp, L., Ulibarri, D., Southerland, S., Gilbert, J., Sienkiewicz, F., Swihart, A. N., and Swihart, E., (2014) Principal Investigator's Final Report: The Oakland Unified School District's Music Integration Learning Environment (MILE), Arts in Education Model Development & Dissemination (AEMDD) Project.

Solomon, C.; Harvey, B.; Kahn, K.; Lieberman, H.; Miller, ML; Minsky, M., et al. (2020). History of Logo. *Proceedings of the ACM on Programming Languages*, 4(HOPL), 1-66. Report #: ARTN 79.

Ulibarri, D. (2020) *Rob Flax Kicks Off Music+Code Video Campaign with Style*. <https://remakemusic.net/2020/11/20/rob-flax-kicks-off-musiccode-video-campaign-with-style/>

Ulibarri, D. (2022). *Criticisms of Scratch vs. Music Blocks, a Comparison*. *Music Blocks Learn Coding through Music and Music through Coding*. <https://musicblocks.net/2021/09/01/criticisms-of-scratch-vs-music-blocks-a-comparison>

The Emergence of the Samba School as a Learning Society

Eliton M. Moura, Columbia University, tommeireles@gmail.com

José A. Valente, State University of Campinas, joseavalente4@gmail.com

Paulo Blikstein, Columbia University, paulob@tc.columbia.edu

Abstract

This article describes the creation of a Samba School as a Learning Society in Brazil. The samba school is a cultural and community organization that has been studied mostly as an artistic and community organization. In this study, we investigate the origin of the samba school as a Learning Society and relate it to affective and emotional ties with the community. We also discuss the peer learning process, which is akin to legitimate peripheral participation (LPP), describing how newcomers become experienced members and eventually old-timers of a community of practice or collaborative project, with examples from the Samba School.

Introduction

Papert observed the existence of a powerful learning organization within a samba school in just one visit to a rehearsal. Observing the participants' behavior, he understood the samba school as a community that can create a "Learning Society." And although our initial motivation in this research was to understand if and how the samba school can be a makerspace, We were also able to study how the community is structured and how different emotional and affection bonds are formed among the various community samba school participants.

Samba Schools are foundational elements of Brazilian culture and have been mainly studied as artistic and community organizations (Ferreira, 2012). One of the early mentions of Samba Schools in the learning context was a talk by Seymour Papert in 1975 at the HUMRRO Conference. His interest was evoked from a single participation in a rehearsal session of a Samba School in Rio de Janeiro in 1975. From this experience, Papert observed that "...It would be more likely to describe itself as a "club," for although it is a school in the sense that people do learn there, it is not a school in that learning is no more the primary reason for participation in the Samba School than it is for membership in a baseball team or for playing any game." (Papert, 1976, p. 2)

A few years after his encounter with the Samba School, Papert expanded his observations in one of the chapters of *Mindstorms* (Papert, 1980). He describes how community members would meet frequently every weekend throughout the year to learn about the music, costumes, and dance routines in preparation for the samba school parade that takes place in February during Carnival. This experience inspired him to see a samba school as a "Learning Society." He noticed that "learning is not separate from reality. The samba school has a purpose, and learning is integrated into the school for this purpose. A novice is not separated from an expert, and the experts are also learning." (p. 179).

After Papert's remarks, samba school started to be perceived as an environment designed to stimulate creativity and learning within learning research circles. Several authors have made an analogy between constructionism and the process that takes place in a samba school community in Brazil, such as Zagal and Bruckman (2005) with respect to

computer clubhouses; Rose's (2020) work related to the engagement of kids and parents in constructionist experiences with computing; developing Scratch educator meetups as playful learning spaces (Brennan & Jimenez, 2020); shaping learning online for making and sharing children's do-it-yourself media (Fields & Grimes, 2020); and as a model for the Constructing Modern Knowledge (CMK) Institute (Stager, 2020).

Despite being influential, samba schools were never studied as a learning community. To date, there is a surprisingly small amount of research on samba schools as learning organizations. Our goal was to immerse ourselves in this environment and answer the following questions: (1) how the learning community is created and (2) how it operates in terms of its practice and learning.

The article is organized into four sections, including this Introduction. The following sections discuss the methodology used in the study, the results describing the creation of a learning society, and finally, the discussion and conclusion.

Methods and Methodological Procedures

The method used in this study is based on a qualitative field study taking an ethnographic approach (Creswell, 2013). The locus of the study was one of the samba schools of São Paulo city, Social Cultural Recreational Guild Samba School "Unidos de Vila Maria" (Grêmio Recreativo Cultural Social Escola de Samba Unidos de Vila Maria). The research took place in two settings: the school headquarters and the "samba factory," where many of the allegorical floats and costumes were created for the carnival parade.

The study population was participants from the samba school who work in these two sites as administrators as well as people developing different activities. Most participants were intentionally chosen because of their extended involvement in the production processes. The objective was to observe and interview as many people as possible to understand how the samba school community was created and operated. In typical situations, two to four hundred people work daily on producing costumes and allegorical floats. Due to the COVID pandemic, only a reduced number of people, a maximum of fifty, were working at the two sites.

The data collection consisted of participant observations and semi-structured interviews. During the years 2020, 2021, and 2022 one of the authors visited both sites regularly, with 30 visits and 224 hours of observations, gathering data about the physical spaces and people working in different activities. These observations were kept as written notes, photos, and videos. The interviews recorded in videos were transcribed, and together with the field observations, interview recordings and photos were analyzed. The authors held periodic meetings from the end of 2020 to mid-2022 to understand and categorize the collected data.

The Origin of the Samba School Learning Society: Affection Ties

The samba school parade consists of wings of costumed people and allegorical floats presented in a logical sequence that it is possible to tell a plot. The costumes and the floats production processes are accomplished by workers from the samba school community who are passionately involved in their activities, as we observed in the Vila Maria Samba School.

The Unidos de Vila Maria Samba School got its name from the Vila Maria neighborhood in the northern region of the city of São Paulo, where the samba school was founded and remains headquartered. The fact that it bears the name of the neighborhood creates an identification tie with that community. Although it does not generate a strong connection, it is essential for being the first affective tie created between the samba school and the community.

The second affective tie is the result of embracing the residents, supported by the structure set up at the samba school's headquarters. Embracing communities in social actions is characteristic of samba schools, but in Vila Maria this is highlighted due to the president's involvement in social projects. The Vila Maria Samba School offers free cultural and artistic workshops to the community, professional training courses, also medical and dental consultations, and treatments. These services, which generally are not offered by governments to the population, are widely valued by residents. In this way, the embracing of the local community generates a strong gratitude tie to the samba school.

Another affective tie comes from the short-term job offers for young people in the community, usually in the making of costumes and of allegorical floats. For the costumes, "They come asking for a job, and we teach them the difference between hot glue and cold glue, and we put them on to replicate a costume's glove, for example," explains Vila Maria "Carnavalesque." For the floats they do simple tasks such as painting small objects or bending wires for the float structure. The most skilled and interested in a career end up being incorporated into a permanent team, enabling them to develop professionally and culturally. However, whether for a career or not, the school manages to create a significant belonging tie with the workers. However, much more significant than the monetary rewards is the opportunity of seeing the product of their labor (even if a small contribution) presented to millions of people at the carnival parade, which has a considerable effect. It generates the pride of belonging to that community, to that samba school, which is often different from their feeling of belonging to society in general, where these young people from poor neighborhoods—primarily black and brown—often perceive themselves as devalued and excluded. The samba school community encourages them to continue in the carnival production process during weekend dance meetings or in other nearby venues. With this, the samba school community provides "...social interaction, respectability and an alternative universe where the reinvention and inversion of values is the norm: individuals excluded from society, in general, will find an environment where they can grow as citizens and develop fully." (Tramonte, 2001, p. 129).

Finally, a fourth affective tie is developed from the return of those interested in continuing in the carnival production process. After their first experience, youth feel committed (almost obligated) to teach and involve those who are there for the first time. At the same time, he or she continues to learn from those who know more about production processes. This way, experts and novices are all seen as apprentices. The teachings one shares are open, without restrictions, as is the teaching he or she receives, stimulating a community that encourages learning. At this point, the community participant becomes the samba school itself, thus creating the becoming tie. It is not by chance that these people refer to their participation using a phrase that is common on the social networks of Vila Maria Samba School, "I am Vila Maria" ("Eu Sou Vila Maria"). It is more than a feeling of belonging, as they perceive themselves as the institution itself.

Discussion

During a three-year immersion process in Vila Maria's two sites, we studied how people are engaged in making the costumes and allegorical floats for the carnival parade. We were able to understand how the practice and learning community is created through a series of affective ties. These ties include identification with the samba school region, cultural and social embrace, belonging to the production process, and finally, becoming Vila Maria. All of these ties contribute to establishing a relationship among participants, involving them in the practice as well as in the learning activities related to the production of the carnival parade. The affective ties that bind people together in a practice and learning community are essential for its success. They provide a sense of belonging and identity, which motivate people to work to collectively achieve the incredibly complex Carnival parades, all the while, in the case of the Vila Maria samba school, also creating a vibrant and successful goal-oriented community.

Papert was correct in making the analogy of a samba school as a club. In fact, the headquarters functions as a cultural and social club for the community in which several types of practices and learning happen. It certainly is an essential context in the creation of the community. However, the "samba factory" site that Papert never saw, in which the making

of the costumes and allegorical floats takes place, constitutes another context for engaging people as part of the practice and learning community.

Thus, the Samba “Learning Society” observed by Papert was, in fact, much more than the peer-based learning that he was able to see and went much beyond the dancing and percussion rehearsals that he experienced. There were other crucial components: first, the entire process of production of the carnival costumes and allegorical floats, and second, the year-long creation of affection ties with the community through services, activities, and ultimately making participants feel that “they are” the samba school.

This peer learning process is akin to legitimate peripheral participation (LPP), which describes how newcomers become experienced members and eventually old-timers of a community of practice or collaborative project (Lave & Wenger, 1991). LPP identifies learning as a contextual social phenomenon achieved through participation in community practice. Also, this peering process does not only occur among individuals but between communities. With the growth of the samba parade show in São Paulo, the samba schools sought out renowned professionals from large festivals who could add to the work already done in the school’s sheds. Specifically, in the São Paulo carnival, less traditional than in Rio de Janeiro, there is the participation of several professionals from Rio de Janeiro, a small “community” with extensive experience of other carnivals acting in prominent positions, such as carnival artists and decorators.

Due to COVID, we were not able to observe in action the hundreds of people who are part of this practice and learning community. We observed and talked to artists and professionals who have a significant role in the making process. By observing and documenting how activities were done at the factory site and at the headquarter as well as how people behaved in these environments, we were able to categorize the data in terms of the affection ties we describe. However, it will be an essential part of the study we continue to do to go deeper into the observation and examine people in action to further examine our findings.

Conclusion

The process of creating carnival costumes and allegorical floats is a multifaceted and time-intensive endeavor that involves the participation of many individuals. Given the complexity of this process, it would be financially impractical to pay all those involved market rates for their services. Thus, the Samba School, which coordinates this effort, cannot be thought of as a traditional business or non-profit organization by the standards of countries in the Global North. It is an entirely new type of organization that, while having a very well-defined, competitive goal, operates in very particular ways. One key element is how the Samba “Learning Society” plays a role in building a sense of community and identity among its participants. By offering a variety of activities that bring people together, the society fosters strong emotional connections and a shared sense of belonging and becoming part of the community. Although learning how to dance, make costumes and allegorical floats, and play percussion are significant parts of the process for preparing for the carnival parade, the society’s overarching goal is to create a community where members can develop new skills, explore their creativity, and forge meaningful relationships. Ultimately, the Samba “Learning Society” is about more than simply creating elaborate carnival floats and costumes. Instead, it aims to foster a deep sense of connection, and belonging among its members. By creating a sense of community and shared purpose, the society ensures that this cultural tradition continues from generation to generation, providing a vital context for these communities to create, year after year, one of the greatest spectacles on Earth.

Acknowledgments

We gratefully acknowledge the supporters of the National Council of Technological and Scientific Development (CNPq) grant #310854/2019-9.

References

- Brennan, K. & Jimenez, R. (2020). The Scratch Educator Meetup: useful learning in a playful space. In N. Holberg, M. Berland, & Y. B. Kafai (Eds.), *Designing Constructionism Futures: the art, theory, and practice of learning designs*. Cambridge, MA: The MIT Press
- Creswell, J. W. (2013). *Qualitative Inquiry and Research Design: Choosing Among Five Approaches*. Third edition. Washington DC: Sage.
- Ferreira, F. (2012). Escolas de Samba: uma organização possível. *Revista Eletrônica Sistemas & Gestão*, 7(2), 164-172. DOI: 10.7177/sg.2012.v7.n2.a3.
- Fields, D. A. & Grimes, S. M. (2020). Shaping Learning Online for Making and Sharing Children's DIY Media. In N. Holberg, M. Berland, & Y. B. Kafai (Eds.), *Designing Constructionism Futures: the art, theory, and practice of learning designs*. Cambridge, MA: The MIT Press
- Lave, J. & Wenger, E. (1991). *Situated learning legitimate peripheral participation*. Cambridge: Cambridge University Press.
- Papert, S. (1976). Some poetic and social criteria for education design. Massachusetts Institute of Technology, AI Memo no. 373. <https://dspace.mit.edu/handle/1721.1/6250>.
- Papert, S. (1980). *Mindstorms: children, computers, and powerful ideas*. New York: Basic Books.
- Roque, R. (2020). Building Relationships and Building Projects: designing for family learning. In N. Holberg, M. Berland, & Y. B. Kafai (Eds.), *Designing Constructionism Futures: the art, theory, and practice of learning designs*. Cambridge, MA: The MIT Press.
- Stager, G. (2020). Connecting Modern Knowledge: crafting the next generation of Constructionists. In N. Holberg, M. Berland, & Y. B. Kafai (Eds.), *Designing Constructionism Futures: the art, theory, and practice of learning designs*. Cambridge, MA: The MIT Press.
- Tramonte, C. (2001). *O samba conquista passagem: as estratégias e a ação educativa das escolas de samba*. Petrópolis: Vozes.
- Zagal, J. P. & Bruckman, A. S. (2005). From Samba Schools to Computer Clubhouses: Cultural Institutions as Learning Environments. *Convergence*, 11(1), 88-105.

Empowering Youth for Climate Action Creative Learning in a University Museum Workshop Series

Goki Miyakita, Keio University, 5ki-miyakita@kmd.keio.ac.jp

Yu Homma, Keio University, homma@art-c.keio.ac.jp

Abstract

This research explores the potential of implementing creative learning practices in a university museum-led workshop series focused on climate change education. Participants, ranging from junior high to university students, engaged in interdisciplinary, project-based learning experiences across four phases: Learning, Creating, Exhibiting, and Reflecting, which made the climate issues personal and actionable.

Introduction

As the world faces persistent challenges related to sustainable development, which came to be known as the Sustainable Development Goals (SDGs), it is crucial to equip the next generation with the mindset, knowledge, and skills necessary to address global issues. While every Goal is deemed of equal importance, climate change (Goal 13: Climate Action) represents one of the most urgent challenges for the young generations, where, in recent times, environmental education has focused on offering young individuals the essential understanding and capabilities to address climate change (Kuthe et al., 2019). However, climate change is a complex issue that encompasses a wide range of scientific, social, economic, and political aspects. Knowledge can be interpreted diversely, and there is a notable difference between factual understanding and its practical application (Jurek et al., 2022; Whitmarsh et al., 2021). In dealing with these issues, past studies have adopted learning approaches that stimulate active learner engagement; for instance, through game design, collaborative learning, or community engagement (Amato et al., 2020; Demssie et al., 2020; Plate et al., 2020). Thus, building on these previous studies, the purpose of this research is to explore the impact of implementing creative learning practices in teaching climate change in a university museum-led workshop series, and further share the findings and learning we gained.

Background and Foundations

Needs for Climate Change Education

In Japan, the logo of SDGs is displayed “everywhere, proudly displayed in hip boutiques, at children’s playgrounds and on the websites of Buddhist temples” (Dooley & Ueno, 2022), where government agencies, companies, and schools are actively working to integrating it into educational activities. However, a study shows that in Japan, the national curriculum frameworks cover the term: *Environment* (79%), *Sustainability* (14%), and *Biodiversity* (7%), whereas 0% for *Climate change* (UNESCO, 2021, p. 33), and there is an increasing demand to educate individuals about climate change.

Bridging Arts, Maker Culture, and Climate Education in a University Museum

This study is being developed at a university museum named Keio Museum Commons (KeMCo) which opened recently, in April 2021. Besides its conservation and exhibition-related works, KeMCo acts both as a research institution and as a public museum, bringing together research entities with artistic collections. One of the features is the in-house makerspace; KeMCo Studio/O, which is equipped with a range of digital and physical fabrication facilities. The space enables students, scholars, and the wider community to engage in hands-on experience and develop their maker habits of mind.

Leveraging the integrated educational environment of the university, where both primary and secondary education are provided alongside university management, KeMCo has been hosting fabrication workshops for junior high and high school students. Participants consisted of students belonging to the calligraphy club, students taking the art class, as well as undergraduate and graduate student staff members who have also been active as facilitators. Given this context, this workshop series involved participants of different ages and backgrounds. In total, 32 individuals participated in the sessions: 15 were from junior high school, 9 were from high school, and 8 were from the university.

Creative Learning as the Foundational Framework

As outlined, climate change is embedded in highly complex and various subjects, which demand “more experiential, project-based activities” (UNESCO, 2022, p.9). Accordingly, this paper primarily draws upon the framework of “creative learning” (Resnick, 2017) to foster children’s creativity and imagination while cultivating the ability needed to tackle climate-related challenges. Aligning the four pillars: *Projects, Peers, Passion, and Play* (4P’s) as a key foundation, the driving force of this study is the “creative learning spiral” (ibid.), where the sequence (*imagine, create, play, share, reflect, imagine...*) functions as a spiral to explore complex ideas in tangible representations within the university museum.

Workshop Design

The workshop series were entitled ‘Climate Change × Creative Learning: Me, You, and Each Other’s Vision of Tomorrow,’ and were held from July 21 through July 30, ending with a final reflection session on September 13, 2022. The entire process consisted of four phases: *Learning, Creating, Exhibiting, and Reflecting*, wherein the overall procedure was designed carefully in a learning spiral fashion. During the execution of activities, we collected multimodal data through video/photo capturing, observation, dialogue, and several paper/online surveys.

In the following, we describe the activities and outcomes of each phase.

Learning Phase (3 days): During this phase, introductory lectures were presented on climate-related topics (such as the Paris Agreement, climate justice, and carbon emissions reduction), environmentally-themed art, and potential actions to be taken to tackle climate issues. After the lectures, participants exchanged, shared, and reviewed their insights. Besides, they were asked to imagine what kind of future can be expected if each one of us continues to take action to solve climate change. The ideas were summarized as a personal statement; an Action Declaration that verbalized concrete actions they could take. For example, the following are excerpts of the declarations:

- *Considering the environmental destruction caused by waste, I’ll always separate my trash when throwing it away.*
- *From now on, I’ll brew tea with a teabag and carry it in a flask to avoid using plastic bottles and reduce waste.*
- *Being aware that our everyday actions are changing the world, I strive to achieve zero emissions and the 3Rs (Reduce,*

Reuse, Recycle) in my daily life, for instance, by selecting non-disposable products when feasible.

Creating Phase (3 days): Advancing from the Action Declarations, three multi-generational groups were formed and created artworks expressing each message. For the artworks, the participants used digital and physical fabrication tools at the makerspace (laser cutters, tablets, calligraphy tools, etc.) alongside reusing the trash and waste generated at the junior high school and on campus, such as plastic bottles, umbrella ribs, and scrap materials from the makerspace (See Figure 1).



Figure 1: Reused trash and waste (plastic bottles, umbrella ribs, and scrap materials)

Exhibiting Phase (3 days): For the exhibition, every group filled the space with their artworks, exemplifying climate awareness through close attention to our daily life (See Figure 2). The students captured the exhibition venue as an environment representing the ‘ocean’ and the ‘forest’ and expressed the place to convey messages about climate change as, *Message from the Sea* and *Message from the Forest*. Besides, during the exhibition, the participants showed around the artworks to the visitors by themselves, which was full of interaction and experience-based works. For example, the quiz-format artworks allowed visitors to test their climate knowledge and also share their thoughts (See Figure 3A). Another highlight was the *Mother Tree* which allowed visitors to explore and write their own short *Action Declarations*, which by the end of the exhibition, ended up with a total of 126 declarations written by the diverse visitors (See Figure 3B).



Figure 2: A) Portrays our everyday lives and the conditions in the Arctic through objects and images, B) Graphically represents two diverging timelines (scenarios) when actions are taken to limit global warming below 1.5 °C or 2.0 °C increase, C) Visualizes global warming by placing a tree made from ‘dead’ materials (recycled plastic bottles and waste materials) near a living tree.

Reflecting Phase (1 day): This phase was conducted to exchange the thoughts and actions that each participant experienced after participating in the workshop series (See Figure 3C). Many found that they had not only acquired new knowledge, but also new attitudes and behaviors geared toward sustainability. Their personal experiences added richness to the collective understanding of climate change. As for their *Action Declarations*, almost every student was continuing in their daily life. Besides, many students told us that the image of climate change became much clearer. As one high school student wrote in a survey that “Until now, there have been many opportunities to learn about the environmental destruction caused by human activities through textbooks and other materials. However, this time, I was able to feel these issues more realistically, and my awareness of climate change-related problems increased more than ever before”.

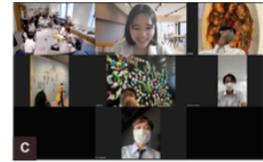


Figure 3: A) Students interacting with the visitors, B) A photo of the Mother Tree which shows the Action Declarations written by the visitors, C) A photo of the Reflecting Phase (held remotely).

Findings and Discussion

Enhancing ‘Creative’ Learning of Climate Change

In the context of museum practices, there are multiple ways to raise awareness and tackle climate change (e.g., Sogabe et al., 2022; Domingues et al., 2023), however, the results suggest that through incorporating creative learning practices, the overall workshop series helped students understand the causes, impacts, and potential solutions to climate-related issues. During the four phases, the spiral of creative learning repeatedly guided students in the iterative process of imagining, creating, playing, sharing, and reflecting, where students not only grasped the theoretical aspects of climate change but also developed a personal connection to the subject, inspiring them to take practical steps in their everyday lives.

Provoking ‘Tangible’ Conversations

During the exhibition phase, visitors wandered around the venue and provoked conversation with the students while reflecting on the artworks. One visitor commented in a survey that *“I was impressed by the diligent study and problem awareness of the students. As a middle-aged person, I’ll keep in mind that my selfishness could unintentionally contribute to environmental destruction”*. Since the topic of climate change involves potentially devastating consequences, where the young generation tends to feel a strong sense of anxiety (known as *eco-anxiety*), visitors’ feedback was essential and encouraged students to be involved in discussions and further share and reflect on their perspectives on climate change.

Empowering ‘Peer-to-Peer’ Connections

In this unique university museum-led workshop setting, experienced participants like university students served as both participants and facilitators, providing direction and assistance. In contrast, the younger participants provided fresh ideas and perspectives, enhancing the collective learning process. This shared learning atmosphere fostered personal growth and development for everyone engaged in the study. As one junior high school student said that *“Engaging in conversations with university students was uncommon for me, so it was a novel experience and provided an opportunity to learn new things”* and a graduate student commented in a survey that *“There was a sense of familial closeness and celebration, much like a year-end gathering, and I think it was a wonderful initiative that embodied KeMCo’s concept as being a Commons”*.

Conclusion

In this paper, we illustrated the potential of implementing a creative learning approach in teaching climate change through a university museum-led workshop series. Throughout the workshops, the students were able to make informed decisions, engage in discussions, and further influence visitors' attitudes and behaviors toward climate change, encouraging them to adopt more sustainable lifestyles. The results suggest that through interdisciplinary, project-based learning experiences, students can develop the mindset, knowledge, and skills necessary to address climate change and further take action.

References

- Amato, A., Matuk, C., & Hurwich, T. (2020). Modding for Change: Promoting Empathy and Agency for Climate Systems. In *Proceedings of the FabLearn 2020 – 9th Annual Conference on Maker Education* (pp. 126-129). ACM.
- Demssie Y. N., Biemans H. J., Wesselink R., Mulder M. (2020). Combining indigenous knowledge and modern education to foster sustainability competencies: Towards a set of learning design principles. *Sustainability*, 12(17), Article 6823.
- Dooley, B. & Ueno, H. (2022, August 26). Why Is This Colorful Little Wheel Suddenly Everywhere in Japan? *The New York Times*. <https://www.nytimes.com/2022/08/25/business/japan-sdg.html>
- Domingues, A. R., Mazhar, M. U., & Bull, R. (2023). Environmental performance measurement in arts and cultural organisations: Exploring factors influencing organisational changes. *Journal of Environmental Management*, 326(Part B), 116731. <https://doi.org/10.1016/j.jenvman.2022.116731>
- Jurek, M., Frajer, J., Fiedor, D., Brhelová, J., Hercik, J., Jáč, M., & Lehnert, M. (2022). Knowledge of global climate change among Czech students and its influence on their beliefs in the efficacy of mitigation action. *Environmental Education Research*, 28(8), 1126-1143.
- Kuthe, A., Keller, L., Körfgen, A., Stötter, H., Oberrauch, A., & Höferl, K-M. (2019). How many young generations are there? – A typology of teenagers' climate change awareness in Germany and Austria. *The Journal of Environmental Education*, 50(3), 172-182.
- Plate, R. R., Monroe, M. C., Friedrichsen, C., Bowers, A. W., & Chaves, W. A. (2020). Recommendations for Early Phases of Engaging Communities in Climate Change Adaptation. *Journal of Human Sciences and Extension*, 8(2), 8. DOI: <https://doi.org/10.54718/XYGW8706>
- Resnick, M., (2017). *Lifelong Kindergarten: Cultivating creativity through projects, passion, peers, and play*. MIT Press.
- Sogabe, M. T., Milano, B., Santos, C. N., Gazana, C., Alencar, D. C., Nunes, F. O., Fogliano, F., Hildebrandt, H. R., Steinberg, M., Carvalho, R., Marques, R. D., Braz, S., & Rubini, T. (2022). Water, Sustainability and Poetics in the Works of the cAt Group. *ARTECH 2021: 10th International Conference on Digital and Interactive Arts*. Association for Computing Machinery. <https://doi.org/10.1145/3483529.3483708>
- UNESCO., (2021). *Learn for our planet: a global review of how environmental issues are integrated in education*.
- UNESCO., (2022). *Youth demands for quality climate change education*.
- Whitmarsh, L., Poortinga, W., & Capstick, S. (2021). Behaviour change to address climate change. *Current Opinion in Psychology*, 42, 76-81.

Culinary Making

Democratized, Cultural Playgrounds of Possibility Democratized, Culturally-situated Learning in Culinary Making

Phebe Chew, University of California, pfchew@uci.edu

Abstract

This work seeks to present culinary making as a frontier of possibility for democratized, culturally-imbued making. The essential nature of food provides many access points to which learners bring inherent cultural contexts—which can provide personally-relevant, culturally-situated opportunities of learning. Through an emergent analysis of a virtual cooking challenge hosted during the 2020 COVID-19 pandemic, I show: a) the complex culturally-situated opportunities for learning possible in culinary making, and b) the ways that ancillary, short form food media technologies such as TikTok, Instagram, and Pinterest, can enhance learning around culinary artifacts and processes. I highlight the potential culinary making holds to address calls for culturally-sustaining learning, and push for future critical constructionist work leveraging culinary tools and mediums in education.

Introduction

Learning through making is an innovative approach with the potential to bridge educational gaps across social and cultural contexts, mediums, and socioeconomic levels (Halverson & Pepler, 2018). However, inequities in access and resources have led to calls to consider new contexts and tools that can further democratize learning. Such calls for equity expand to making educational approaches culturally-sustaining (Paris & Alim, 2019) rather than deficit-oriented—towards “Freirian opportunities for empowerment and consciousness raising” for nondominant learners (Blikstein, 2013, as cited in Halverson & Sheridan, 2014, p. 500).

Such expansions are possible through *culinary making*—spaces of everyday culinary practice where nondominant learners may explore and tailor learning to the positionalities they inhabit. Through analysis of a virtual cooking competition held during the 2020 COVID-10 pandemic, I highlight engagement in culinary making—especially during and after the pandemic—in tandem with short form food media tools, like TikTok and Instagram, as a promising frontier for democratized cultural making processes. This paper furthers two aims: first, it demonstrates daily culinary practice as a promising venue for rich, interconnected learning opportunities. Specifically, it explores complex culturally-situated identity learning through food as a basis to raise critical consciousness. Secondly, it shows how technology extends culinary making through amplified sharing and broadened notions of expertise. This work is guided by the research question: *What opportunities are possible for democratization and culturally-situated identity learning through culinary making?*

Related Work and Description of Culinary Making as a Learning Frontier

Pre-existing work on culinary arts as an educational context has pointed to the ways in which food can be leveraged

to cultivate “life-relevant” STEM learning experiences and dispositions for underrepresented learners in STEM (Clegg & Kolodner, 2014; Yip et al., 2012). As a domain in which everyone has some sort of cultural history or prior/daily experience, food—and culinary making by extension—can serve as an accessible vehicle for meaningful culturally-situated learning, particularly for historically underrepresented learners (Rankin & Thomas, 2017). This paper highlights the potential and reach of this frontier by bringing attention to the ways culture and technology undergird how culinary makers “engage in a conversation with [their own or other people’s] artifacts, and how these conversations boost self-directed learning, and ultimately facilitate the construction of new knowledge” (Ackermann, 2001, p.1).

Culinary making amplified by short form food media technology (e.g., Instagram, TikTok, Pinterest) through posts (photos) and reels (short videos) allows makers to make, document, and share artifacts through online portfolios at incredible rates and scales. Take for example, the “coronavirus baking boom,” proliferated through short form food media, which resulted in shortages of flour and yeast reminiscent of scarcities during WWII (Rude, 2021). Whether for daily meal preparation or leisure, makers can learn in connection with ingredients, dishes, tools, and practices across local, national, and global communities of practice (Lave & Wenger, 1991). Digital technologies introduce possibilities of democratization to this everyday making process, through broad access and flipped notions of expertise. News outlets remark how “the biggest names in food are now regular people on TikTok”—rupturing traditional qualifications for expertise in food (Kennedy, 2023). Similarly, viral recipes demonstrate how of interest to the masses are easy dishes made with accessible ingredients: such as the feta pasta (a block of feta, tomatoes, and olive oil baked until saucy, then tossed with pasta) which tracked three million views within two weeks of sharing (Hutcherson, 2021); or the salmon rice bowl—leftover salmon, rice, and a handful of condiments, which has tracked 7.8 million views to date (Emilymariko, 2021). Furthermore, mass digital participation in culinary making means shifts in the cuisines and cultural narratives that circulate pop culture. Makers of color online often share “third culture” dishes—improvisations in the kitchen featuring “in-depth and nuanced knowledge in two cultures”—like Jamaican curry dumplings, which present narratives of culture of more nuance and fidelity to the complexity of lived experience (Jonkung, 2022). Such culinary artifacts present possibilities to critically assess dominant cultural narratives and stratified notions of whose expertise is legitimized—redirecting mass gaze to intergenerational, experiential, and heritage expertise.

Data, Context, and Analysis

This work provides initial analyses around a video of winners from an asynchronous, virtual cooking challenge hosted by a public university during the 2020 COVID-19 pandemic. Competitors made a dish incorporating the following chosen ingredients: tofu, scallions, cinnamon, and pasta. In the video, three winners (a student, staff, and faculty member) spoke about their dish (artifact), and their inspirations for their culinary practice.

This challenge’s improvisational nature presented opportunities for culinary interpretations through each participant’s pantry ingredients—which often reflect the cultures present in one’s life. I deductively coded video transcripts and winners’ culinary artifacts (Fereday & Muir-Cochrane, 2006) using the codes *culture* and *sharing of artifacts* (Harel & Papert, 1991). I wrote analytic memos around the nature of culture in each of the coded excerpts to inductively generate sub-themes of *heritage*, *geospatial* (immediate or broader geographic context), and *relationally* imparted culture (Weston et al., 2001). I used these sub-themes to analyze the cultural underpinnings of winners’ artifacts in conjunction with their mentioned food histories and influences.

Findings

An initial analysis reveals insights around complex culturally-situated opportunities for learning, and the ways food

media can amplify the sharing and discussion of culinary artifacts. Table 1, below, outlines the dishes each winner created, as well as any (sub)coded mentions for *culture* or *artifact sharing* (in bold).

Complex Culturally-Situated Learning in Culinary Making

Artifacts reflected not only playfulness with features and forms of ingredients, but imaginative recreations around culturally coded dishes which reveal nuanced applications of culture. The competition’s improvisational nature presented opportunities for “third culture” reimaginings of dishes reflecting the various cultures—either *heritage*, *geospatial*, or *relationally* introduced—which border makers’ lives. For instance, the graduate student winner’s pasta dish incorporated techniques derived from Korean heritage cultures in her home (marinating scallions in “soy sauce and some other spices”), as well as improvisatory cross-cultural concepts—utilizing tofu out of its typical cultural context, using it as a stand-in for ricotta cheese from Italian culinary contexts from scientific observation of its creamy properties. Similarly, the staff winner’s dish featured a tofu taco which blended Asian and Mexican cuisines, and a Mexican street corn pasta salad blending Italian and Mexican culinary concepts. Both staff and faculty winners created dishes influenced by their geospatial surroundings rather than heritage culture—as residents of Southern California with exposure to both Mexican and Thai dishes and people—but cited heritage inspirations (“my great aunt [...] cooks a lot of soul food”; “growing up...with a Cajun background”).

	Artifact Description	Culturally Coded Mentions	Culture Subcode	Artifact Sharing Coded Mentions
Graduate student winner	Pasta in tofu ricotta sauce, atop a bed of cinnamon and paprika roasted sweet potatoes, topped with coconut amino marinated scallions	“I topped that with a scallions that were marinated in a coconut amino type of marinade which is kind of similar to, you know my dad’s Korean, he often marinates like in soy sauce and some other spices um sesame seed oil scallions so I put that.” Pasta in tofu ricotta sauce	Heritage, relational Geospatial	“Now is a great time to be able to cook and maybe learn some new skills or try some things out we follow quite a few food accounts so I think it can be helpful to try to see if there’s a few that you like and then if there are any recipes that you want to try out then i think it’s a good time as well.”
Staff winner	Cinnamon spiced tofu taco and a side of Mexican street corn pasta salad	“I get my inspiration from a few things so one is my great aunt. She is an amazing cook. She cooks a lot of soul food. ” Tofu taco Mexican street corn pasta salad	Heritage, relational Geospatial Geospatial	“I also watch a lot of Food Network so um I love the show Chopped and then I also get a lot of my um ideas from Pinterest , so Pinterest is my best friend um during quarantine I’ve actually been trying to do more social media content with my cooking so I’m pretty active on Instagram um to make videos of my process for cooking and I’ve been getting like a lot of inspiration from friends and motivations to say you should keep going with this and so um you know I just post things here and there and try to see what people think. ”
Faculty winner	Pad Thai noodles with cinnamon dusted tofu in a peanut sauce with scallions, chili paste	“Having grown up in New Orleans uh with a Cajun background cooking is always been such a huge part of my life.” “Peanuty pad Thai noodles”	Heritage, geospatial Geospatial	“We had a lot of fun making the dish. It became sort of a family affair where we’re all in the kitchen together making it and getting the photos.”

Table 1: Competition Winners’ Artifacts and Culturally Coded and Artifact Sharing Mentions

Short Form Food Media as Democratizing Artifact Sharing Platforms

As demonstrated through this culinary competition, technological mediums were crucial in keeping culinary makers creative and connected during the pandemic. The faculty winner described social, potentially intergenerational making through the virtual competition (“It became sort of a family affair”). In addition, both the graduate student and staff winners ascribed some of their interests and making practices to their use of food media—whether they follow “quite a few food accounts” in the case of the graduate student winner; or watch Food Network, follow Pinterest boards, and create an Instagram account to “make videos of [her] process for cooking” and “see what people think” in the case of the staff winner. These uses of social media allow for access to cultural artifacts beyond geospatial borders, and show how culinary makers engage with artifacts through portfolios to form communities of practice through which they learn from one another. These portfolios are fueled by “inspiration from friends and motivations,” indicating the ways expertise is distributed, as well as how self-directed endeavors and learning are supported throughout these communities.

In all three winners’ cases, sharing artifacts through social media broadened engagement with culinary making and others, either in physical space, or across relational, geospatial, and heritage cultural borders. We highlight the ways that short form food media amplifies culinary making and introduces new forms of making within culinary making (i.e., food content creation) that expand possibilities for learning, connection, and the democratization of culinary knowledge and expertise.

Conclusion, Implications, and Future Work

Culinary making is a promising frontier for opportunities around complex cultural learning, especially for nondominant learners from diverse cultural backgrounds. Additionally, short form food media presents potential as an increasingly democratized participatory space where everyday culinary makers are able to share artifacts and expertise, form supportive communities, and engage in making relevant to their identities.

Possible future applications can leverage this nuanced cultural learning as a backdrop to domain-specific or interdisciplinary learning (e.g., writing, social sciences, math, science, etc.) to result in personally-relevant, culturally-sustaining learning opportunities which address, through content as well as larger endeavor, inequities faced by nondominant learners (Paris & Alim, 2017). As technology and cultural borders proliferate and continue to blur, we look to incisive applications of culinary making that allow nondominant learners to accessibly a) contribute to the democratization of learning and b) complexify prepackaged, essentialized notions of culture that form the basis of societal inequities and oppression.

References

- Ackermann, E. (2001). *Piaget’s constructivism, Papert’s constructionism: What’s the difference?* Future of Learning Group, 5(3), 438.
- Clegg, T., & Kolodner, J. (2014). *Scientizing and cooking: Helping middle-school learners develop scientific dispositions.* Science Education, 98(1), 36-63.
- Halverson, E., & Peppler, K. (2018). *The maker movement and learning.* In International Handbook of the Learning Sciences (pp. 285-294). Routledge.

Harel, I. E., & Papert, S. E. (1991). *Constructionism*. Ablex Publishing.

Hutcherson, A. (2021). *TikTok's viral baked feta pasta is worth the hype*. The Washington Post.

Jonkung. (2022, May 15). *3rd culture food, fashion, and art will be the greatest expressions to come from younger American generations*. [Video]. Instagram.

Kennedy, A. (2023). *The biggest names in food are just regular people on TikTok*. Vox.

Emilymariko. (2021, September 21). *Best lunch of the week!* [Video]. TikTok.

Paris, D., & Alim, H. S. (Eds.). (2017). *Culturally sustaining pedagogies: Teaching and learning for justice in a changing world*. Teachers College Press.

Rankin, Y. A., & Thomas, J. O. (2017). *Leveraging food as the context for developing computational algorithmic thinking in an entry-level college course*. In *Moving Students of Color from Consumers to Producers of Technology*. pp. 113-130. IGI Global.

Rude, E. (2021). *The coronavirus baking boom has made it hard to find flour. Here's how Americans coped with "wheatless Wednesdays" in WWI*. Time.

Weston, C., Gandell, T., Beauchamp, J., McAlpine, L., Wiseman, C., & Beauchamp, C. (2001). *Analyzing interview data: The development and evolution of a coding system*. *Qualitative Sociology*, 24, 381-400.

Yip, J., Clegg, T., Bonsignore, E., Gelderblom, H., Lewittes, B., Guha, M. L., & Druin, A. (2012). *Kitchen chemistry: Supporting learners' decisions in science*.

SHORT PAPER

Agile Methods as a Methodology for Implementing Collaborative Constructionist Learning in Computer Science Education and Beyond

Peter Brichzin, Erasmus-Grasser-Gymnasium München, schule@brichzin.de

Petra Kastl, Jack-Steinberger-Gymnasium, kastl.petra@jack-steinberger-gymnasium.de

Ralf Romeike, Freie Universität Berlin, ralf.romeike@fu-berlin.de

Abstract

In start-ups today, almost nothing works without agile software development. In schools, agile methods may be used to implement constructionist learning by helping the students to collaboratively create meaningful artifacts. This paper reports on how agile methods can be used as a methodology for conducting school software projects and evaluates, in the light of Constructionism, how collaborative learning in school projects can be supported.

Introduction

Constructionist learning approaches share the idea that learning “happens especially felicitously in a context where the learner is consciously engaged in constructing a public entity, whether it’s a sand castle on the beach or a theory of the universe” (Papert and Harel, 1991). In computer science education, the idea of giving students the opportunity to create meaningful software artifacts has, over time, paved the way for learning for all. Since software is usually created in collaborative projects, school software projects are typically organized in a similar way as they are in professional settings. Traditionally, school projects, similar to professional projects, proceed in sequential phases (Frey, 1983). At the beginning, the task is analyzed. From there, the requirements are defined, followed by a design phase. Only then does the implementation take place, which is tested against the requirements at the end. In school projects, however, sequentially organized projects often turn out to be difficult, since the students initially usually do not have the necessary experience and “soft skills”, which are prerequisites for successful project work (Meerbaum-Salant and Hazzan, 2010). The constructionist learning theory can help us to understand the issues students have with a linear approach. If constructionist learning involves going through iterative cycles of step-by-step creation and understanding an artifact, it seems obvious to use an approach for school software in which students develop increasingly complex prototypes in order to not only create, but also to establish a better understanding of the artifact created, including the process of doing so.

Agile methods have spread rapidly throughout work environments since the 2000s, functioning as an alternative to sequential approaches in both small and large companies. Agile teams are often particularly motivated, work in a focused manner, treat each other with respect, and see mistakes as an important opportunity to grow. They determine their own path to reach their goal, reflect on it regularly and see change as an opportunity. By doing so, agile thinking and action change the corporate culture, as they are associated with a series of central values, such as open communication at eye level and self-responsibility in the team. Thus, teams and customers who have had a taste of agile team work usually do not want to go back. In agile projects, teams develop prototypes iteratively and incrementally. They test and review their interim results and regularly obtain feedback. Concrete practices such as user stories, project boards, stand-up

meetings, and team retrospectives support the teams in project organization and execution. These methods can also enrich teaching (Romeike and Göttel, 2012). Both for teachers and students, agile approaches almost always quickly produce many positive and motivating effects, because students usually succeed a lot better in organizing themselves, creating great results in joint responsibility, and achieving pleasing professional and social learning successes (Kastl and Romeike, 2018). This greatly underlines the social dimension of learning: “What is created and learned in the construction process is greatly affected by who we build with, and for whom we build” (Holbert, Berland, Kafai, 2021). However, since “creating communities around creativity and technology is hard, and success is not ensured” (ibid.), strategies are needed to support students in learning to collaborate in developing an artifact and to organize the process in a meaningful way. We will provide an overview of the agile process and explain some practices that are recommended for getting started with agile project work (Brichzin, Kastl, Romeike, 2019) in more detail in the following, since such agile practices can support constructionist learning (Kastl, Kiesmüller and Romeike, 2016; Meerbaum-Salant and Hazzan, 2010; Monga et al., 2018).

Agile Practices for Structuring and Supporting the Constructionist Learning

Agile practices help teams to act on values that are appreciated in constructionist learning as well. Core agile values include communication and simplicity, but also transparency, self-organization, and feedback. In addition, focus (devoting your undivided attention to a specific task), courage or commitment (dedicating yourself to your team to fulfill the mutually set goals) can also be emphasized.

Constructionist Learning in an Iterative Process

Instead of running through the project phases only once in a sequential manner, agile projects process the phases cyclically in so-called iterations or sprints (cp. fig. 1) using short, fixed time windows. The iterations follow one another directly, are all of the same length, and are each concluded with a functioning, incrementally growing interim result. Clear communication structures and visualization are also anchored in the process to ensure transparency. The iterative approach allows learners to grow with the project and gain confidence in project execution. Experience shows that the first iteration may be experienced as chaotic by students and teachers alike. However, the structure and practices help students learn self-organization and collaboration. The first successes are quickly visible, motivate the students and help them to regularly review the objectives. The teacher can now provide regular feedback and, if desired, integrate new learning content into the project work flow step by step to match the product development.

User Stories – Scaffolding Construction

User stories describe software requirements from the customer’s point of view. They consist of a few sentences and are formulated in everyday language. They help the students to divide the extensive technical functionalities of the overall system into easily manageable parts and thus give the software development process a clear structure. Even students with a weaker technical background can contribute to this process. In this way, user stories become the basis for communication about the sub-goals, teachers can discuss them with the teams and, if necessary, can intervene at an early stage. User stories support learning in the sense of scaffolded construction.

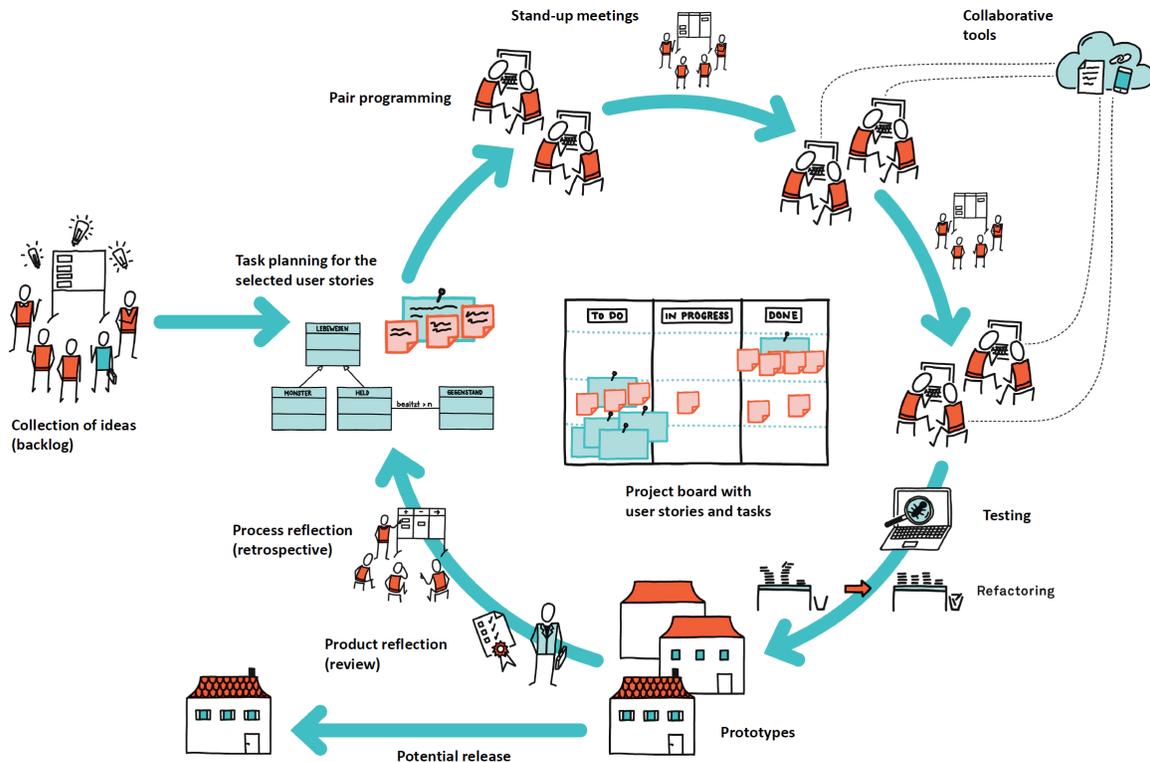


Fig. 1. A typical agile process adopted for school.

Project Board – Managing Collaboration

The project board (cp. fig. 1, center) not only visualizes the goals and task packages, but also illustrates the current work status (and thus the project progress) as well as the work distribution. The visualization provides transparency, supports self-organization, and illustrates the team’s (and the individual team members’) commitment. It also demands simplicity in planning and ensures focused work. Along with the prototypes, it is a basis for feedback discussions. Agile project participants report: “We’re working on fewer things now, but they’ll get done,” and “You always know right away where you stand and what’s next. You don’t have to have so much on your mind and don’t get bogged down so easily.”

In the simplest case, the project board consists of three columns: “To Dos”, “In Progress” and “Done”. On the left, in the “To Do” column, the user stories (index cards) hang in descending order of priority, alongside the sub-subsequent tasks determined (sticky notes), in case the user story has already been specified. During the work phase, each team member or pair selects a task, writes his name on it and places it in the middle column titled “In Progress”. After completing it, it can then be moved to the column at the right titled “Done”. In this way, you can see at a glance who is currently responsible for which work package and which tasks and user stories have already been completed. The active reassignment of completed tasks motivates the students, is an occasion to celebrate what has been achieved and provides the teachers with a basis for assistance.

Stand-Up Meetings – Encouraging Communication

Stand-up meetings help the group to organize itself. Like all other meeting forms, a stand-up meeting relies on openness, respect, and the courage to address, for example, mistakes or poor work performance, in addition to focus. It encourages and requires communication, brings the team to a common level of information, and gives the teacher insight into the teamwork taking place. The daily stand-up meeting is held by the teams at the beginning of each lesson at school. It replaces the usual in-class recap. Team members take turns answering three questions: “What tasks have I completed since the last meeting? What tasks do I want to work on next? Were there any problems and with what?” To ensure that only the essential information is exchanged, the meeting is held standing up and in front of the project board. Problems are only named and, if necessary, help is requested. Consequently, standup-meetings help regularly structuring the social dimension of learning.

Pair Programming – Structured Working in Pairs

Structured partner work helps students to organize collaborative work without active-passive division, to support each other and to exchange knowledge and information about concrete implementations. The practice thus ensures transparency, immediate feedback, planned and focused action, and simple solutions. Hence, it is a good method to implement structured partner work in computer science classes. The partners take on defined roles that are regularly exchanged. The driver works on the task and informs the navigator about his intentions and his approach. The navigator checks the processing, considers whether there are alternative, simpler ways of solving the problem, makes sure that the driver stays with the actual task, and addresses possible misinterpretations. In school, partner work increases self-confidence, demands a description of the procedure, initiates discussions about approaches and solution strategies, prevents mistakes and thus supports the learning process.

Reflection – Understanding Learning Progress Through Review and Retrospective

Even though it is considered an important aspect of teaching and learning processes, reflection often falls by the wayside due to time constraints. Also, the learning impulses may peter out due to the following project taking place too late for applying what has been learned. Here, the iterative approach is a clear plus. Regularly pausing after each work phase to get feedback on the product in a so-called review moves the team forward, but it also has to be learned. By comparing the goals set with what has been achieved, it promotes self-regulation skills. At the same time, it is an occasion to celebrate what has been achieved. Possible problems in the work process or in the team can be openly addressed and tackled in a retrospective. This requires courage, respect, and openness. The recurring opportunity to practice this supports the development and strengthening of team skills and prevents frustration from building up.

Discussion

Even though computer science education nowadays profits from the ideas and tools of constructionist learning, the constructionist roots were often not sufficiently taken into account while developing into a more mature subject. Instead, methods gained from practice have been applied which do not always serve the pedagogical purpose. With agile methods, professional practice and constructionist learning find themselves together again. Not only do they match the iterative character of the constructionist circle of creating an artifact and enhancing the understanding of

the artifact, they match the process of creating such an artifact as well. Furthermore, agile practices can help support the learning process by structuring, scaffolding, and providing transparency. Experience shows that students who have gained experience with agile projects in computer science lessons also use their competencies for work and self-organization in other subjects. Thus, the entire school can benefit from such collaborative constructionist learning with agile methods.

References

- Brichzin, P., Kastl, P., and Romeike, R. (2019) *Agile Schule. Methoden für den Projektunterricht in der Informatik und darüber hinaus* (Agile school. Methods for project-based learning in computer science and beyond). Bern: hep Verlag.
- Frey, K. (1983) *Die sieben Komponenten der Projektmethode – mit Beispielen aus dem Schulfach Informatik* (The seven components of the project method – with examples from the school subject of computer science). LOG IN, 3(2), 16–20.
- Holbert, N., Berland, M., and Kafai, Y. B. (2021) *Introduction: fifty years of constructionism*. Designing constructionist futures, 1-20.
- Kastl, P., Kiesmüller, U., and Romeike, R. (2016) *Starting out with projects – Experiences with agile software development in high schools*. In ACM International Conference Proceeding Series (Vol. 13-15).
- Kastl, P. and Romeike, R. (2018) *Agile projects to foster cooperative learning in heterogeneous classes*. In IEEE Global Engineering Education Conference, EDUCON (1182-1191).
- Meerbaum-Salant, O. and Hazzan, O. (2010) *An Agile Constructionist Mentoring Methodology for Software Projects in the High School*. ACM Transactions on Computing Education, 9(4), 1-29.
- Monga, M., Lodi, M., Malchiodi, D., Morpurgo, A., and Spieler, B. (2018) *Learning to program in a constructionist way*. In Proceedings of Constructionism 2018. Vilnius, Lithuania.
- Romeike, R. and Göttel, T. (2012) *Agile Projects in High School Computing Education – Emphasizing a Learners' Perspective*. In Proceedings of the 7th WiPSCE'12 (pp. 48–57). ACM New York, NY, USA.
- Papert, S. and Harel I. (1991) *Situating Constructionism*. Ablex Publishing Corporation.

Pedagogy Scientists

Enhancing the practices conducted by classroom educators

Mariana Lederman Edelstein, Teachers College, Columbia University, ml4794@tc.columbia.edu

Andréia Maria de Lima Assunção, University of São Paulo, amlassuncao@gmail.com

Daniela Andrade Cordeiro, Teachers College, Columbia University, da3037@tc.columbia.edu

Tomás Gallo Aquino, Columbia University, tg2863@columbia.edu

Abstract

The *Cientistas da Pedagogia* (“Pedagogy Scientists”) project addresses the lack of representation of classroom teachers with expertise in academic institutions and conferences in kindergarten and elementary school education by providing tailored mentoring activities for academic literacy and research paper development. The initiative seeks to create an enabling environment for Brazilian primary education teachers to engage in introspection, organize their experiences, and publish their findings at international conferences. By participating in mentoring activities, teachers are encouraged to develop research papers that enhance their teaching practices and serve as objects of reflection. The project acknowledges the challenges faced by educators, such as low social prestige and remuneration, and aims to provide opportunities for sharing knowledge, promoting recognition, and fostering international engagement. The findings highlight the project’s positive impact on teachers’ metacognitive competence and their perception of the value of their experiences. The paper concludes with recommendations for improving the project’s effectiveness and promoting equitable representation in the diverse Brazilian context.

Introduction

This paper describes and analyzes the implementation of the first edition of the *Cientistas da Pedagogia* (in English, “Pedagogy Scientists”) research front, a program for the professional development of Brazilian teachers promoted by graduate students at a research university based in the United States. This project aims to develop mentoring activities for academic literacy (Thesen & Pletzen, 2006) tailored explicitly to primary education teachers. By engaging in these activities, teachers are encouraged to develop a research paper that serves as an object to think with and enhances their teaching practices aligned with constructivism and constructionism (Papert, 1980; Ackermann, 2020). In this way, the project establishes an enabling environment for primary education teachers in Brazil to engage in introspection, organize their experiences, and publish their findings at international conferences. The choice for these learning theories comes from the goal of empowering these teachers to create a product that shares their experiences and perspectives while supporting reflections about their learning process.

The Brazilian National Education Plan (2014–2024) establishes the parameters and goals for valuing Brazilian public education, such as continuing education and the implementation of career plans for education professionals, which consider aspects such as length of service, degree and working hours as references for establishing salary improvements (Brasil, 2014). According to data released by the Statistical Synopsis of Basic Education, the percentage of basic education teachers who have postgraduate training is low, namely 4.31% with a master’s degree and 1.19% with a doctorate (Brasil, 2022).

Early childhood and elementary school educators feel overwhelmed and undervalued (Gomes & Palazzo, 2017) in the face of a career with low social prestige and remuneration. Those workers mainly belong to the disadvantaged social classes and have found professionalization for teachers, a form of insertion in the formal job market concerning opportunities previously accessed by their home groups (Gatti & Barreto, 2009; Yada, 2015). Brazilian government policies promote professional qualification at the graduate level as actions to combat the devaluation of the teaching career in primary education (Clímaco, Neves & De Lima, 2012). However, one of the requirements to access *stricto sensu* graduate courses in Brazil or abroad is published papers (Silva, Gonçalves-Silva & Moreira, 2014; Saviani, 2020).

As a result, educators need opportunities to share their knowledge and projects with a broader audience and be recognized for their efforts and capabilities. *Cientistas da Pedagogia* hypothesizes that the access of Brazilian educators with classroom experience to academic literacy projects may reflect on their presence in conferences in the area and teacher training institutions. Similarly, this participation holds the potential to enhance research and international scientific production by facilitating the engagement of teachers who are non-native English speakers and have long been marginalized in educational discourse. By providing academic mentorship for these teachers, the project seeks to enable the international science education community to address different perspectives and experiences, allowing for a more comprehensive and diverse understanding of educational practices (Castano Rodriguez, 2015).

Methods

To address this goal, the team, formed by graduate students, two psychologists, and one primary education teacher, developed 30 hours of mentoring activities for five educators in early childhood and elementary education to provide a supportive space for these educators to discuss their ongoing projects and to structure their publications. In this first edition, the educator's group was based on professionals that the team already knew since there were time constraints. The group consisted of four teachers from a private school in Sao Paulo and one from a public school in Mato Grosso. In São Paulo, the educators have post-graduate degrees and over a decade of teaching experience, while in Mato Grosso the teacher has been in early childhood for 5 years.

As a theoretical-methodological approach, the team's role in this project was to conduct the tutoring activities attentively to the participants' zone of proximal development (Vygotsky, 2001), facilitating qualitative leaps in their understanding of their pedagogical practices. Furthermore, through the mediation relationship, these educators were encouraged to learn to organize and redirect their teaching experiences based on the codes of the scientific method and qualitative analysis, thereby aligning this practice with the perspective of academic literacy (Thesen & Pletzen, 2006). The backward design theory (Wiggins & McTighe, 2019) and the prior-knowledge consideration (Piaget, 1984) also supported the activities, as the *Cientistas da Pedagogia* focused on understanding their target audience and creating a personalized plan for each mentoring session.

For this project version, the team selected three experiences in Brazil related to the "Constructionism Conference" theme and theory. The whole process happened in the educator's first language, Portuguese, and the mentor was responsible for translating the paper and assuring an intentional decision in the vocabulary. The reflection moments with the educators were intended to go beyond a summary of their classes and offer a safe environment for metacognition and reflection on educators' teaching experiences.

Implementation

The implementation of the project occurred in four phases. Firstly, the teachers shared their documentation, data, and

artifacts with the mentor, revisiting their research while presenting the development of each step of the experience – e.g., videos, audio recorded, Sway boards, and ThingLink created with the students. Secondly, the mentor facilitated the educators' study and review of constructionism literature theory, aiming to deepen their knowledge and identify the meeting points between their practice, reflection, and theory – e.g., how the documentation could be used as an object to think with and become a publicly shareable product. Group work was encouraged to create strategies to help organize the learning, such as using Miro, a collective online board, to register the relationship between the theory and their classroom experience.

The third phase focused on writing the papers, ensuring a comprehensive understanding of each text part, referencing, and adhering to the standards. Examples from previous conferences were analyzed and discussed to provide guidance. The writing process took place synchronously with the mentor. The educators were also encouraged to write small pieces asynchronously, allowing them to reflect on the moments discussed during the meetings. During each session, the mentor would review the writing and leave comments for the group to reflect.

Lastly, the mentor translated the paper, and the groups received feedback from senior academic researchers. The teachers engaged in discussions about the critiques and reviewed their papers accordingly. This feedback loop ensured the refinement of their work and contributed to their professional growth, as they could reflect on different feedback and perspectives.

Findings

According to the team's observations and the educator's speeches, reflecting and discussing their teaching process while learning academic writing suggests that the paper became an object to think with. Throughout the meetings, it was possible to observe that the educators assimilated their projects, re-examined their documentation, and introspected their methods as they discussed and exposed the reasons for their decisions while conducting the activities. As the educators told the team, the senior research feedback also improved the understanding of clarity of the paper's goal and word choice. These deliberations resulted in the emergence of novel research ideas, as some educators have already asked about continuing to be part of the project next semester. The mentoring activities afforded the educators insights into the potency of their work and engendered a newfound appreciation for the value of their experiences. Two educators also decided to write about a project they are conducting this year in Portuguese for a local magazine. Additionally, it underscored their metacognitive competence to reflect on their actions and practices, as articulated by one of the educators:

While writing a scientific article about the practice, we are led to become aware of the different processes involved in making decisions at each moment lived with the children. Justifying and connecting the ideas to theoretical concepts broadens our view of ourselves and our pedagogical practices, thus gaining intentionality, depth, and openness to new possibilities. (Educator 1, 2023)

From the initial gathering, all teachers recognized the project as a means for disseminating their research findings and showed interest in engaging in meaningful discourse with the academic community. They also saw it as an opportunity to study the constructionist theory and practice meaningfully, recognizing elements (e.g., project-based learning, student-centered learning, making meaningful products, documenting the process) already present in their teaching.

One of the educators, while inspired to explore technology use in education further, faced the challenge of time constraints. The educator asked for more time to deepen her understanding of the constructionist theory and how it could be applied to such young learners. The project team understood the potential challenges that educators might face and pursued strategies to offer support, such as facilitating the selection of conferences with more flexible deadlines and alleviating the possible overwhelm experienced by teachers.

Conclusion

In conclusion, data suggests that *Cientistas da Pedagogia* contributes to the existing literature on inclusive practices within the academic literacy framework, exploring a constructionist approach. The project has provided insights that can enhance the design of educational and professional development opportunities for educators. The team aims to implement improvements next semester, such as facilitating introductory meetings among educator groups to encourage information exchange and feedback on individual research. Furthermore, it emphasizes the significance of allocating dedicated time to studying theoretical concepts and applying them to classroom practices more systematically and precisely during educator meetings. These measures will help create a more effective professional development program for educators. For the next edition, it is expected to gather and train more interested mentors so that it will be possible to cover a more significant number of participants per semester to expand the potential of action and diversification of the project. There is also a commitment of the group to achieve a more diverse group of educators in other parts of Brazil. Given the complex task of enhancing access to academic discourses and their associated conventions (Thesen & van Pletzen, 2006) to foster increased involvement of primary educators in international conferences, this project necessitates refining teacher selection strategies to ensure equitable representation of the diverse Brazilian context.

Acknowledgments

We thank the support of Paulo Freire Initiative and Lemann Center for Brazilian Studies (Columbia University). We thank the teachers Andréa Felix Dias, Camila Campello, Thatiany Candido, and Andréia Rodrigues Silva for participating in the project. We also thank the financial support of the Coordenação de Aperfeiçoamento de Pessoal de Nível Superior (CAPES) and the Conselho Nacional de Ciência e Tecnologia (CNPq), Brazilian research agencies.

References

- Ackerman, E. K. (2020) Experiences of Artifacts: People's Appropriations/ objects "Affordances". In Holbert, N.; Berland, M. & Kafai Y. B. (Ed.). *Designing Constructionist Futures: The Art Theory, and Practice of Learning Designs*. MIT Press, Cambridge, MA.
- Brasil. 2014. Lei n.13.005, de 25 de junho de 2014. Aprova o Plano Nacional de Educação – PNE e dá outras providências. Diário Oficial da União, Brasília. https://www.planalto.gov.br/ccivil_03/_ato2011-2014/2014/lei/l13005.htm.
- Brasil. 2022. Instituto Nacional de Estudos e Pesquisas Educacionais Anísio Teixeira. Sinopse Estatística da Educação Básica. Brasília, DF, INEP. <https://www.gov.br/inep/pt-br/aceso-a-informacao/dados-abertos/sinopses-estatisticas/educacao-basica>.
- Castano Rodriguez, C. (2015). The dilemma of inclusivity in the globalization of academia. *Cultural Studies of Science Education*, 10, 1057–1062. <https://doi.org/10.1007/s11422-015-9691-7>
- Clímaco, J. C. T. de S., Neves, C. M. de C. & De Lima, B. F. Z. (2012). Ações da Capes para a formação e a valorização dos professores da educação básica do Brasil e sua interação com a pós-graduação. *Revista Brasileira de Pós-Graduação*, [S. l.], v. 9, n. 16, 2012. DOI: 10.21713/2358-2332.2012.v9.286.
- Gatti, B. A. & Barretto, E. S. de S. (2009). *Professores do Brasil: impasses e desafios*. Brasília, DF: UNESCO.

- Gomes, C.A., & Palazzo, J. (2017). Teaching career's attraction and rejection factors: analysis of students and graduates perceptions in teacher education programs. *Ensaio: aval. pol. públ. Educ.*, 25(94), 90-113.
- Papert, S. (1980). *Mindstorms. Children, Computers and Powerful Ideas*. New York: Basic books.
- Piaget, J. (1984). *La representación del mundo en el niño*. Ediciones Morata.
- Saviani, D. (2020). Half-century of postgraduate studies in brazil: from heroic period to productivism by mediating of a superior model to its matrices. *Movimento-Revista De educação*, 7(14). <https://doi.org/10.22409/mov.v7i14.46475>
- Silva, J. V. P. da, Gonçalves-Silva, L. L., & Moreira, W. W. (2014). Productivism in Graduate Studies: it can always get worse. It's time for graduate student! *Movimento*, 20(4), 1423-1445. <https://doi.org/10.22456/1982-8918.46187>
- Thesen, L., & van Pletzen, E. (2006). *Academic Literacy and the Languages of Change*. Cape Town, South Africa: Continuum International Publishing Group.
- Vygotsky, L. S. (2001). Estudio del desarrollo de los conceptos científicos en la edad infantil. In J. M. Bravo (Trans.), *Obras Escogidas II. Problemas de Psicología General* (2nd ed., pp. 181-285). Madrid, Spain: Antonio Machado Libros.
- Wiggins, G. P., & McTighe, J. (2019). *Understanding by design framework*. ASCD.
- Yada, J. K. (2015). *O magistério como opção de carreira: estudo sobre os fatores contributivos para a escolha do curso de Pedagogia em uma universidade pública*. (Master's thesis, Escola de Filosofia, Letras e Ciências Humanas, Universidade Federal de São Paulo, Guarulhos, Brazil).

Visible learnings

Shared digital tools for a Kindergarten investigation

Andrea Felix Dias, Escola Vera Cruz, andreafeixedias@gmail.com

Mariana Lederman Edelstein, Teachers College, Columbia University, ml4794@tc.columbia.edu

Camila Urquizas Campello, Escola Vera Cruz, camilacampello@gmail.com

Thatiany Candido, Escola Vera Cruz, thatylimal211@gmail.com

Abstract

After the intense use of remote learning technology during the Covid-19 pandemic, this short paper presents a case study about integrating technology into face-to-face project-based learning. Conducted with a kindergarten class in Sao Paulo, Brazil, this research explores how children adopted digital tools as technologies to think with and how those tools enabled the unusual, collaborative construction of documentation in ways that likely would not have been possible without them. Specifically, digital documentation expanded the possibilities for data gathering and presentation, created new avenues for constructing collaborative knowledge, and afforded opportunities for children and adults to co-author the project artifacts. These technologies enhanced the in-person work of learning about space and place in ways that were clearly and necessarily mediated by teachers. Implications for kindergarten teaching and learning include the extension of and reflection on collaborative, project-based work.

Introduction

The Covid-19 pandemic revived decades-old discussions about the importance of digital technologies as extensions of the human mind (Papert, 1980; 1993) rather than a tool to replace teachers. One way technology can support face-to-face teaching is as a documentation tool. By continuously students' investigations through various media and supporting the creation of narratives about their experiences, documentation makes learning visible and allows for collaborative reflection (Rinaldi, 2021). These records, shared with peers, teachers, and other members of the community, facilitate the exchange of ideas, where feedback enriches the learning process and promotes a culture of collaborative and reflective learning (Bereiter & Scardamalia, 2014). Documentation also allows students to develop essential skills of observation, critical reflection, argumentation, creativity, communication, self-regulation, and metacognition (Papert, 1980; Martinez & Stager, 2013; Rinaldi, 2021). Metacognitive reflection, in turn, helps students improve their learning practice (Lai, 2011) and generalize their knowledge and skills to other areas, becoming more independent and effective learners (Zimmerman, 2000).

This case study focuses on the impacts of technology used by children and educators to develop and document a project about school spaces. Two teachers and a documentation educator (co-authors of this paper) designed a study to introduce and test the contribution of digital tools for documenting group work in their kindergarten classrooms. Records made at each step of the project served as the starting point for subsequent steps. The teachers analyzed this documentation, aiming to answer the following research questions: (i) how do children adopt digital documentation tools as objects to think with? (ii) in what ways these tools enable collaborative documentation construction?

Methods

Participants

This case study was conducted from March to July 2022 in a private school in São Paulo, Brazil, committed to constructivism and Reggio Emilia pedagogies. Documentation is a central part of educational work Reggio Emilia schools, allowing children to create, design, experiment, explore, and constantly reflect on their practice (Resnick, 2007). The project's two teachers, who each have post-graduate degrees and over a decade of teaching experience, were studying how to incorporate digital tools in the kindergarten classroom to support students' exploration and learning. A documentation educator, who had 12 years of classroom experience and 6 years as the school-appointed documentation expert, collaborated with teachers to plan and analyze data of their classroom work. The teachers and documenter analyzed artifacts (e.g., notes, photographs, 10 hours of video, and 12 hours of audio recordings) produced during a project with one classroom of 18 five-year-old children. In weekly meetings, the teachers and documenter created a Sway board (web application) where they were able to share their reflections and design interventions.

Project Design

To support their students in developing key geometry and humanities skills, the classroom teachers designed a project in which students explored and generated inquiries about different spaces in their school (e.g., stairwells, classrooms, a storage space). The kindergarten geometry curriculum expects learners to understand reference points, interpret and construct spatial representations, discern sizes and proportions, and communicate positions and displacements. The humanities curriculum includes the notion of place as occupied by various people, serving certain functions, and carrying a sense of belonging. Learners are expected to understand that affective relationships, and ultimately intimate connections, form in these spaces (Brasil, 2018). To move across and become familiar with various target spaces in their schools, children participated in various on-site activities – talking with people there, building a digital map, creating a model with blocks, etc. 2 or 3 times a week for four months. According to Reggio Emilia's philosophy, the design of the activities happens during the project and in dialogue with the documentation in an investigation cycle. Prior planning of activities, preparation, execution, intervention, observation, recording, and listening to hypotheses and questions from children, as well as learning and discoveries, returning to the beginning of the pedagogical documentation cycle.

When planning the activities register, the educators based their choice of modality – i.e., recording video, audio, or still images – on their communication goals, placing static photography collages on classroom walls and using video recordings to analyze students' speech and movements. Children's maps, models, and other representations were also displayed in a Sway, which allowed teachers and students to revisit and modify these images, audio, video, and text during group reflections. These materials made it possible to design a sequence of activities driven by the students learning inquires. They were also curated and organized to be shared with other educators and students' families, primarily by posting printed materials on the classroom's outside wall.

Implementation

To begin the project, the educators invited their students to explore the different environments of the school, including a stairwell, unfamiliar classrooms, and a storage space. Two groups, each led by a teacher, walked through the spaces,

and poses questions such as: What is this place? Who works here? What do other kids do here? Proposing these questions helped identify children's interests in and about these areas. Next, students explored the school's floor plan on paper (Figure 1, top left) and using ThingLink, they created drawings of the different spaces. ThingLink allowed children to interact with different types of media (e.g., photo, video, audio) overlaid onto the school floorplan, expanding the means through which they could appreciate spaces' functionalities and uses (Figure 1, top right). Then, children modeled the school using large wood blocks and cardboard tubing (Figure 1, bottom left). A ceiling-mounted GoPro camera recorded children's actions, allowing educators and students to analyze their movements from a top view. As a final product, students and their teachers constructed a new ThingLink map of their school with novel photos and audio narrations. Through these activities, groups shared their discoveries and learnings in different modalities: individual drawings, collective maps, and construction with wooden blocks.



Figure 1: (clockwise) Consultation of the floor plan; collective construction of the school ThingLink map; 3D modeling the school with blocks; sharing posted documentation with families.

As students created narratives about spaces in their school (e.g., a stairwell and storage room), one group suggested there was a witch and started to search for her. They planned to locate her using the teachers' cellphones to film and take photos. In talks with the educators, students identified, validated, and shared knowledge about technology, such as "Can we watch the video in slow motion?", "Have you uploaded the video from your phone? Can we watch it on the computer?", "It is better to take a photo because the video is too big!". The choice of the tool by the students demonstrated how much they learned, in previous stages, about the different school spaces and technological affordances they could use to solve their investigation.

These audio recordings children created for their final ThingLink map also evidenced their newfound familiarity with their school environment. During the map's development, students requested that certain spaces be photographed or

filmed for extended periods and proposed using ThingLink for the final documentation instead of more familiar paper records.

Continued interaction around the documentation – such as circles of conversations, appreciation, reflection, and debriefing – enabled children to navigate the new school environment, propose continuations for their research, and present their findings to family members (Figure 1, bottom right). They infused each space with individualized meaning, familiarized themselves with the people who worked there, and gained insight into the habitual uses of various spaces and the potential for creating new ways of using them. The children demonstrated problem-solving abilities by suggesting using slow-motion footage to recover details that were overlooked. They clearly indicated the routes necessary for moving from one space to another using reference points and communicating positions. They identified places that needed to be photographed and creating detailed maps and constructions (representations). Moreover, they demonstrated autonomy in school space, checking the day's snack on the blackboard and requesting specific games from Pedagogical Support.

Conclusion

The project highlighted an example of an object to think with for using digital tools during in-person, collaborative, and constructionist learning. The research sought to answer two initial questions: (i) how children adopted the digital tools as objects to think with and (ii) how those tools enabled the collaborative documentation.

Regarding the first question, the children suggested techniques to gather data in their search for the witch, justifying their choices based on knowledge about the different media. Digital tools (e.g., Sway, ThingLink) complemented their analog experiences (e.g., blocks, draws maps), making it possible for children to reflect on the school spaces and produce an interactive map. As in Reggio Emilia, we see the possibility for students to document with their teachers and create publicly shareable products, such as in Constructionism. Addressing the second question, the digital tools enabled the collective construction of artifacts supporting collective reflection and revision. The technologies enhance the in-person work of learning about space and place, but clearly and necessarily mediated by the teachers. Documentation allowed children to create narratives of their experiences collaboratively and reflectively (Bereiter & Scardamalia, 2014). The digital tools mobilized the children, extending the possibilities to structure and generalize their learning while recording and discussing in groups.

Acknowledgments

We would like to express our sincere gratitude to Leah Rosenbaum for the revision; Paulo Freire Initiative (Columbia University), Lemann Center for Brazilian Studies (Columbia University), and Escola Vera Cruz for the support.

References

- Brasil. (2018). Ministério da Educação. *Base Nacional Comum Curricular*. Brasília: Author.
- Bereiter C. & Scardamalia, M. (2014). Knowledge building and knowledge creation: one concept, two hills to climb. In B. J. Zimmerman & D. H. Schunk (Eds.), *Handbook of Self-Regulation of Learning and Performance* (pp. 85-97). Routledge.
- Lai, E. R. (2011). *Metacognition: A literature review*. Always learning: Pearson research report, 24, 1-40.

Martinez, S. L. & Stager, G. (2013). *Invent to learn: Making, tinkering, and engineering in the classroom*. Constructing Modern Knowledge Press.

Papert, S. (1980). *Mindstorms: computers, children, and powerful ideas*. Basic Books.

Papert, S. (1993). *The children's machine: Rethinking school in the age of the computer*. Basic Books.

Resnick, M. (2007). All I really need to know (about creative thinking) I learned (by studying how children learn) in kindergarten. In *Proceedings of the 6th ACM SIGCHI conference on Creativity & Cognition* (pp. 1-6). ACM.

Rinaldi, C. (2021). *In dialogue with Reggio Emilia: Listening, researching and learning*. Routledge.

Zimmerman, B. J. (2000). Attaining self-regulation: A social cognitive perspective. In M. Boekaerts, P. R. Pintrich, & M. Zeidner (Eds.), *Handbook of self-regulation* (pp. 13-39). Academic Press.

Balancing hands-on scaffolding and play-based activities for young children's programming

Affordances for learning from instruction and guided play

Robin Samuelsson, Uppsala University, robin.o.samuelsson@nordiska.uu.se

Abstract

There is a long-lasting debate on the relative merits of instructional vs. Constructionist learning approaches. This study examines the relative merits of instructional and guided play activities for 1-2-year-old nursery children using an educational design featuring a programmable floor robot. The study shows how hands-on instructional methods did not lead to an increase in successful programming actions but did increase children's use of longer programming sequences. Moreover, the study shows the longer time on task associated with guided play and discusses the relative merits and the complex educational choices early childhood educators face.

Introduction

Today, there is a broad educational uptake concerning children's learning related to computational thinking. It is now being implemented in early education settings to start children's programming education early [1]. As part of this, educational researchers have implemented educational robotics at ever younger ages [2]. However, an educational challenge remains on how pedagogical approaches promote conceptual development while still maintaining the exploratory and playful approaches needed for the youngest nursery-aged children [3].

The entry of educational tools such as the educational robots examined in this study also unearths debates about learning. In the learning sciences, the relative merits of constructionism versus the role of direct instructional approaches have been a critical discussion point that has often divided the field [4]. Later, however, researchers have examined the precise types and amounts of scaffolding children receive in different activities [5, 6].

In programming education, constructionist learning approaches have a long history, where children's construction through direct engagement with educational tools has been vital in educational and technological design [7, 8]. Lately, playful approaches to robot programming have experimentally been shown to foster children's learning of programming knowledge and skills [9]. This type of tool is well-adopted into play-based education building on constructionist thinking, as programmable floor robots, such as the Blue-Bot used in this study, very much are 'tools-to-think-with' [8, 10] that may engage young children's learning through hands-on engagement.

The Current Study

For the relatively long period defined as early childhood, some computational thinking concepts may also be relevant at different stages of young children's lives and learning trajectories [2]. However, as programmable robots are something

children can interact with from a very young age, it is crucial to examine how children of various ages can relate to them and the practices that can support young children's programming. Unfortunately, few studies have examined children younger than 3, an exception being Critten et al. [11] study of two-year-olds, showing how children learned sequencing from play-based learning activities.

To further extend the reach and meet the challenges of an approach to early programming for the very youngest children in the educational system, this study follows pedagogical development during a six-month design-based project featuring a programmable floor robot, the Blue-Bot and assesses both instructional and guided play activities that were implemented during two of the project's phases.

Methods

The study uses a design-based methodology [12] for educational development and tracks activities during a six-month project introducing programming to young children through the educational floor robot, the Blue-Bot, at a preschool in Stockholm, Sweden. The study is set in a department featuring sixteen 1-2-year-old children. Video ethnographical methods were employed during weekly visits, combining child-observational video collection methods [13] of project activities with traditional ethnographic field notes.

For the project design, formative focus-group sessions with teachers were held where pedagogical problems and design of new activities and phases were developed iteratively throughout the six month project. This paper focuses on the project's first hands-on instructional activities and the guided play activities [14] that were developed as a play-based approach to children's programming developed as a co-design between the preschool department and the researcher.

Analytical Procedure

The video of project-related activities using the Blue-Bot in programming activities was recorded during the project. For this study, 12,9 hours of handheld video has been the main object for quantitative embodied interaction analysis. Thirty-six sessions representative of the two phases: Instruction (23), and Guided Play (13) were selected for further coding. Actions ($n=2268$) of children and teachers during the 36 sessions were coded in MAXQDA and grouped into two main categories of behavior: *Children's successful programming actions*, i.e. actions that led to a completed programming move of the robot. Moreover, it was coded whether these were single presses, double or multiple presses. Secondly, *Teachers scaffolding actions* were coded. This included both verbal scaffolding actions, such as telling or hinting a suggested path for children, and also physical scaffolding cues (e.g., pointing or gesturing to the robot).

The length of children's engagement during a session was also noted in Excel, allowing the a calculation of the average time-on-task for each phase activity type. Using the total time of sessions and the codes for each phase, a per-minute average for teacher scaffolding actions and children's programming actions were calculated for each activity type (Instruction and Guided Play).

Results

Figure 1 displays the frequency of teachers scaffolding actions as a per-minute average and the frequency of children's

successful programming actions. The teachers made an average of 8,3 scaffolding actions per minute during the Instructional phase and an average of 2,9 during the Guided Play phase.

During the Instructional phase, children performed an average of 2,5 successful programming actions per minute, of which 23% were multiple-press actions. Children performed 2,8 actions per minute during guided play, and 16% were multiple-press actions. Thus, the more intense frequency of scaffolding actions in the Instructional phase, did not lead to an increased programming actions compared to the less-scaffolded guided play phase. However, the instruction resulted in more complex programming moves.

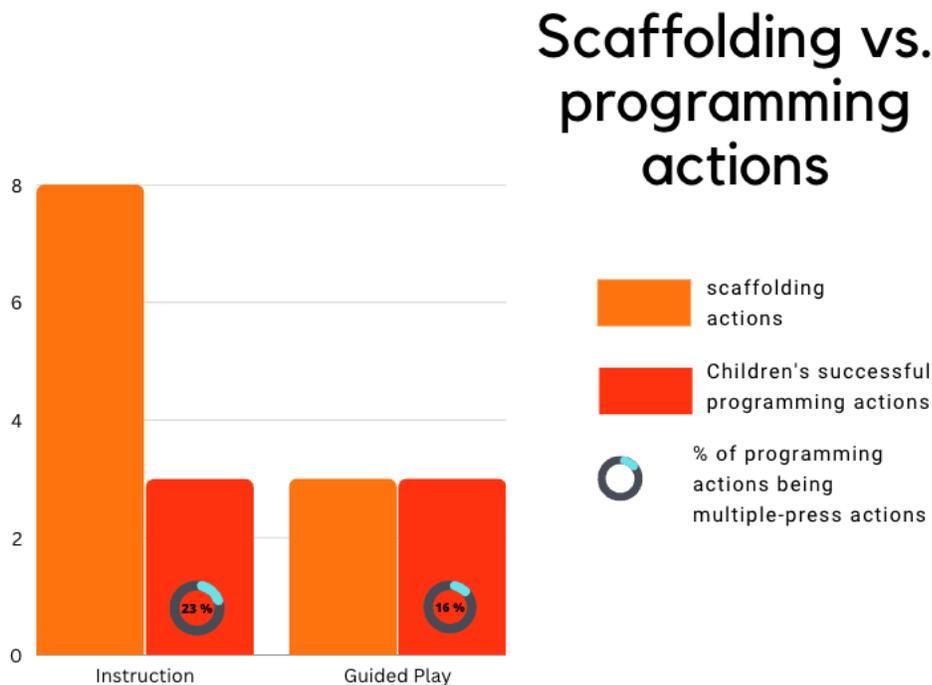


Figure 1: Chart displaying teacher scaffolding actions and children's programming actions for the Instruction and Guided Play phases, calculated as per-minute averages. The percentage of children's programming actions with two or multiple presses is displayed in the in-bar tag.

Children's Time-On-Task

There were significant differences in the results when examining the average session length. During the instructional activities, children's time-on-task averaged 3,1 minutes, but during the guided play activities, the average time-on-task were 11,7 minutes.

Discussion

Much debate has raged regarding the relative merits of direct instruction and constructionism [4-7]. These debates resurface as new educational technologies and subjects are emerging in educational environments. For the youngest children, where play is a fundamental part of learning, this is increasingly important, as instruction must be balanced

with child-initiated playful activity. This paper has shown some of the relevant features of different approaches to programming with very young children.

The study indicates that the increased scaffolding during the hands-on instructional activities did not increase the frequency of children's successful programming actions. However, during the instructional phase, the children performed more advanced programming actions, suggesting a value to teachers' instructional effort. Regarding children's time-on-task during the phases, instructional activities made children lose interest quicker, compared to the play-based guided play activities, where time-on-task greatly exceeded the instructional sessions. This shows potential trade-offs between instructionally-oriented and play-based activities with young preschool children.

The results point to some relative affordances for learning using different approaches. This gives guidance to how teachers can implement forms of activities with very young children's programming, showing how guided play techniques boost children's engagement with programming activities, but how additional scaffolding attempts for teaching complex concepts and actions can be valuable, however potentially at the cost of children's time on task engagement. This is an important educational balance for early childhood educators to manage.

Conclusion

The study has pointed out some of the relative advantages of hands-on instruction and guided play for early programming using a robotics kit. In addition, the study illustrates the often complex pedagogical choices that arise when new curricula become part of ever-younger children's education. As more advanced curricula are entering preschool children's educational settings, it is valuable how to consider pedagogical approaches for this very age-group.

References

1. Wing, J.M. 2008. Computational thinking and thinking about computing. *Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences*. 366, 1881 (Oct. 2008), 3717–3725. DOI:<https://doi.org/10.1098/rsta.2008.0118>.
2. Bers, M.U. et al. 2014. Computational thinking and tinkering: Exploration of an early childhood robotics curriculum. *Computers & Education*. 72, (Mar. 2014), 145–157. DOI:<https://doi.org/10.1016/j.compedu.2013.10.020>.
3. Samuelsson, R. 2020. Guiding Preschool Play for Cultural Learning: Preschool Design as Cultural Niche Construction. *Frontiers in Psychology*. 11. <https://doi.org/10.3389/fpsyg.2020.545846>
4. Tobias, S. and Duffy, T.M. 2009. *Constructivist Instruction: Success or Failure?*. Taylor & Francis Group.
5. Hmelo-Silver, C.E. et al. 2007. Scaffolding and Achievement in Problem-Based and Inquiry Learning: A Response to Kirschner, Sweller, and Clark (2006). *Educational Psychologist*. 42, 2 (Apr. 2007), 99–107. DOI:<https://doi.org/10.1080/00461520701263368>.
6. O'Neill, D.K. 2012. Designs that fly: what the history of aeronautics tells us about the future of design-based research in education. *International Journal of Research & Method in Education*. 35, 2 (Jul. 2012), 119–140. DOI:<https://doi.org/10.1080/1743727X.2012.683573>.
7. Resnick, M. 2017. *Lifelong Kindergarten: Cultivating Creativity through Projects, Passion, Peers, and Play*. Cambridge, Massachusetts: The MIT Press.
8. Papert, S. (1993). *Mindstorms: children, computers, and powerful ideas*. (2nd ed.) New York: Basic Books.
9. Bers, M.U. et al. 2019. Coding as a playground: Promoting positive learning experiences in childhood classrooms. *Computers & Education*. 138, (Sep. 2019), 130–145. DOI:<https://doi.org/10.1016/j.compedu.2019.04.013>.
10. Holbert, N. and Wilensky, U. 2019. Designing Educational Video Games to Be Objects-to-Think-With. *Journal of the*

Learning Sciences. 28, 1 (Jan. 2019), 32–72. DOI:<https://doi.org/10.1080/10508406.2018.1487302>.

11. Critten, V. et al. 2022. Can Pre-School Children Learn Programming and Coding through Guided Play Activities? A Case Study in Computational Thinking. *Early Childhood Education Journal*. 50, 6 (Aug. 2022), 969–981.
12. Bakker, A. 2018. *Design research in education: a practical guide for early career researchers*. Routledge.
13. Pellegrini, A.D. et al. 2013. *Observing children in their natural worlds: a methodological primer*. Psychology press.
14. Weisberg, D.S. et al. 2016. Guided Play: Principles and Practices. *Current Directions in Psychological Science*. 25, 3 (Jun. 2016), 177–182. DOI:<https://doi.org/10.1177/0963721416645512>.

SYMPOSIA

Constructionist Approaches to Learning Artificial Intelligence/Machine Learning

Past, Present, and Future

Luis Morales-Navarro & Yasmin B. Kafai (Chairs), University of Pennsylvania, luismn@upenn.edu, kafai@upenn.edu

Ken Kahn, University of Oxford, toontalk@gmail.com

Ralf Romeike, Freie Universität Berlin, ralf.romeike@fu-berlin.de

Tilman Michaeli, Technische Universität München, tilman.michaeli@tum.de

Daniella DiPaola, Massachusetts Institute of Technology, dipaola@mit.edu

Safinah Ali, Massachusetts Institute of Technology, safinah@mit.edu

Randi Williams, Massachusetts Institute of Technology, randiw12@mit.edu

Cynthia Breazeal, Massachusetts Institute of Technology, cynthiab@media.mit.edu

Francisco Castro, New York University, francisco.castro@nyu.edu

Kayla DesPortes, New York University, kayla.desportes@nyu.edu

Gary Stager, Constructing Modern Knowledge, gary@stager.org

Vishesh Kumar, Northwestern University, vishesh.kumar@northwestern.edu

Herminio Bodon, Northwestern University, bodon@u.northwestern.edu

Marcelo Worsley, Northwestern University, marcelo.worsley@northwestern.edu

Victor R. Lee, Stanford University, vrlee@stanford.edu

Parth Sarin, Stanford University, psarin@stanford.edu

Benjamin Xie, Stanford University, benjixie@stanford.edu

Jacob Wolf, Stanford University, jwolf@stanford.edu

Isabel Sieh, Stanford University, isabelrs@stanford.edu

Deepak Varuvel Dennison, Stanford University, deepakvd@stanford.edu

Raycelle Garcia, Stanford University, raycellegarcia@stanford.edu

Brian Smith (Discussant), Boston College, b.smith@bc.edu

Abstract

Although constructionism originated embedded within early artificial intelligence research, it is only recently that researchers have returned to designing and researching constructionist tools and activities for learning Artificial Intelligence/Machine Learning (or: AI/ML). The pervasiveness of AI/ML in the everyday lives of young people—impacting how they connect with friends, listen to music, play games, or attend school—coupled with the accessibility of applications powered by large language models, discussions about algorithmic justice, and growing efforts to incorporate computing into K-12 education increase the urgency of AI/ML education. Yet, within education, most AI/ML efforts have centered on learning analytics and providing scaffolds to learners, focusing on what Papert called “the computer being used to program the child.” In contrast, constructionist AI/ML efforts center on designing learning environments and researching how young people can create personally relevant AI/ML powered applications. In this symposium, we bring together historical perspectives on constructionism and AI/ML, examine current efforts that build on learner’s interests, and develop possible directions for future research and design. We discuss how when creating AI/ML powered projects, teachers and learners can collaboratively develop and integrate conceptual and critical understandings that are increasingly important to participate in the world.

Symposium Overview

Children and youth interact everyday with complex and distributed Artificial Intelligence/Machine Learning (AI/ML)-powered applications when they socialize with friends, go school, play games, listen to music, order food or watch videos. Yet, there are little opportunities for young people to learn about how the AI/ML technologies they use daily are designed. In this context, it is important to revisit Seymour Papert's (1980) vision of shifting from a paradigm where "the computer is being used to program the child" to one in which "the child programs the computer" by creating personally relevant AI/ML powered applications. Constructionism, the theory and learning strategy, formulated by Papert and his colleagues, was born in the context of early artificial intelligence research (Solomon et al., 2020), however it is in the last decade that constructionist researchers have turned their attention to the design of learning environments for children to learn and create with AI/ML (Kahn & Winter, 2021). While in the early days of constructionism several studies by Kahn (1977) and Goldstein and Papert (1977) addressed the interactions between early AI research and learning, more recent efforts have incorporated AI/ML in constructionist tools and activities within block programming (e.g., Kahn et al., 2020) and physical computing environments (e.g., Tseng et al., 2021) providing opportunities for young people to create and think with AI/ML. At the same time, whereas today's AI/ML technologies differ from those of constructionist early AI research and education, by drawing on ML and large data sets instead of symbolic AI, early questions about how children think about their own thinking with computing and AI/ML remain relevant. Moreover, supporting young people in creating AI/ML-powered applications is imperative so that they can be empowered to participate in computing fully and critically (DiPaola et al., 2022; Kafai & Proctor, 2022). In this symposium, we bring together historical perspectives on constructionism and AI/ML, current efforts that build on learner's interests, and possible directions for future research and design. We discuss how when creating AI/ML powered projects, teachers and learners can collaboratively develop and integrate conceptual and critical understandings that are increasingly important to participate in the world.

The symposium includes presentations on how youth can learn about AI/ML in personally relevant ways, AI/ML teaching concepts and curricular efforts, and research related to generative AI/ML. Castro and DesPortes investigate how youth can learn about AI/ML while creating personalized dance and computing projects that use pose detection models. Morales-Navarro and Kafai research how youth learn from failure cases when creating and auditing personally relevant ML-powered physical computing projects. Kumar and colleagues study how youth can learn about AI/ML ideas and engage with ethical issues in the context of sports. Michaeli and Romeike present teaching concepts for constructionist AI/ML that center on analyzing data, implementing algorithms and creating personalized assistants. DiPaola and colleagues discuss three curricular efforts that center socio-technical learning trajectories for children to engage with AI/ML creatively and ethically. Khan investigates how tools like ChatGPT can serve as navigators and support the creation of AI/ML projects on Snap! Stager discusses the use of LOGO for "playing with language" within contemporary GPT AI-hype. Lee and colleagues present work on the collaborative design of generative AI/ML learning activities with teachers. The symposium is organized in four sections: (1) the chairs will introduce the topic and then each presenter will give an one-minute teaser about their work (~10 min); (2) the first half of the presenters will have 15 minutes to share their work using posters placed around the room, followed by the second half of presenters (15 minutes) an arrangement which will give both audience and presenters time to see each other's posters; (3) our discussant Cynthia Solomon, a pioneer in the constructionism community and the design of computing learning environments for children, will synthesize and reflect on findings (10 minutes); and followed by (4) a Q&A with audience and presenters (~10 min).

Presented Posters

AI/ML Building blocks or ChatGPT? (Kahn)

Nearly 50 years ago Kahn (1977) I became interested in providing programming tools to enable children to create AI-powered apps. This entails creating libraries of AI/ML components in Lisp, Prolog, and most recently in Snap! (Kahn et al., 2020). The Snap! AI/ML libraries for speech, vision, language, and neural network programming have been widely used (<https://ecraft2learn.github.io/ai/>). However, very soon after GPT-4 became available I explored what it would be like to create AI/ML apps via a conversation with a chatbot. I chose five sample Snap! AI/ML projects that can repeat what was said in funny voices and in different languages, draw by tracking user gestures, predict confidence from text, simulate conversations between famous people, and generate illustrated stories. At first, I asked for simple versions of the desired app. Often I needed to tell ChatGPT how the program was failing or copy and paste an error message for it to respond to. After a few exchanges the app was functioning fine and then I asked for an additional feature and the process was repeated. Sometimes I asked ChatGPT to explain how something worked or to add comments to some generated code. On occasion I needed to copy and paste some documentation created after GPT's training cutoff (September 2021) in order to proceed. The experience is very close to playing the role of a navigator in pair programming. Except that I also needed to copy and paste the generated code into HTML, CSS, and JavaScript files and run the result. Using ChatGPT in this manner is very empowering. And the learner still needs to come up with the concept of the application, plan a series of steps in its creation, and evaluate and test the interim results. The learner must still address the high-level aspects of their projects and, if so motivated, can engage with the low-level technical details.

Learning from failure and edge cases: Creating, testing, debugging and auditing ML-powered e-textile projects (Morales-Navarro & Kafai)

Current efforts to promote AI/ML literacy emphasize the importance of ensuring that learners have opportunities to engage with AI/ML ethically and critically by considering how it can impact people in positive and negative ways (Touretzky & Gardner-McCune, 2021; DiPaola et al., 2021). However, conversations about ML, society and ethics are often disconnected from technical issues (Fiesler, 2020; Petrozzino, 2021). Yet the consequences and implications of ML applications are closely intertwined with functionality failures (Raji et al., 2022). As such, we argue that criticality must be embedded in the process of creating personally relevant ML projects instead of just being an add-on or conversation topic. Building on constructionist approaches to computing education that emphasize the importance of creating personally relevant applications that can be shared with others (Harel and Papert, 1990; Kafai & Burke, 2014) and recent work on the role of failure in constructionist learning (Fields et al., 2021; Klopfer et al., 2022), we investigate how students engage with failure and edge cases when creating, testing, debugging and auditing ML-powered e-textile projects. We build on current research on the design process of ML applications (Tedre et al., 2021) and algorithm audits (Metaxa et al., 2021; Devos et al., 2022) to analyze how youth learn from failure cases when designing their own projects and auditing their peers' projects. We analyzed video recordings, youth reflections, and interviews from a workshop conducted in 2023 with 15 youths (ages 14-16) identifying themes that emerged when youth found, addressed, and reflected on failure cases while designing and auditing AI/ML-powered e-textiles. Our findings show that failure and edge cases provided rich opportunities for youths to revise their understandings of how their applications worked, consider the context for which they designed their projects, and make connections between technical and ethical aspects of their designs.

Building minds with AI/ML: Exploring a constructionist approach to k-12 AI/ML education (Michaeli & Romeike)

To participate in an increasingly digital world and make informed decisions about AI/ML and its impact on our society, everyone needs to learn about the core ideas and principles of AI/ML (Michaeli et al., 2023), starting in K-12 education. Often, unplugged approaches are used to introduce students to AI/ML in a fun and engaging way. This allows students to focus on the underlying concepts behind AI/ML rather than on technical details, while making the general functionality of AI/ML-related phenomena accessible. However, it is important not only to explain the relevant phenomena, but also to empower everyone to actively shape this world and use AI/ML as a creative tool. Teaching must therefore go beyond unplugged approaches and enable students to create and construct. To this end, we have developed a variety of teaching concepts that allow for collaborative and creative design in different dimensions, such as: (1) analyzing data using ML methods, as well as the social impact of the resulting ML models without necessarily requiring low-level technological details such as programming pitfalls (Michaeli et al., 2023); (2) implementing the actual algorithm that makes the computer “learn” in a block-based programming language. Unlike many other approaches, students do not simply apply pre-trained models or use existing libraries to classify their data. In this way, students design AI/ML systems themselves, and by looking behind the scenes, the supposed “magic” of such processes is demystified (Jatzlau et al., 2019; Michaeli et al., 2020). (3) Turning your smartphone into your AI/ML-powered personal assistant by designing the interaction with language processing techniques, programming the behavior according to your ideas in a block-based language, and giving the assistant its own identity. These approaches can serve as examples of how to enable a constructionist approach to AI/ML and are being used in professional development for CS and non-CS teachers, as well as in mandatory K-12 CS education.

Constructionism, ethics & creativity: Developing k-12 AI/ML education for classrooms (DiPaola, Ali, Williams, & Breazeal)

As the use of AI-enabled technologies by children becomes increasingly common, there arises the need to help K-12 students learn about how these algorithms work. In our work, we approach AI/ML learning with three goals: 1. helping students understand how AI/ML algorithms work, 2. having students responsibly use their AI/ML knowledge to reach their goals, and 3. empowering students to reflect on the societal implications of AI/ML and how it might affect their rights. Our pedagogical approach is one that encourages exploration in technical, ethical, and real-world applications before culminating in a constructionist project (Ali et al., 2019). Ali et al. (2021a) propose a “socio-technical learning trajectory”, in which students build up their knowledge of the technical, ethical, and real-world implications of particular topics in AI/ML before culminating in a constructionist project. In this poster session, we will share work from three curricula that follow a socio-technical learning trajectory: (1) How to Train Your Robot where students construct supervised machine learning models to control robots and develop AI/ML projects that assist or entertain others (Williams, Kaputsos, & Breazeal 2021), (2) Creative AI/ML for learning about generative algorithms (Ali et al., 2021a; Ali et al., 2021b; Lee, et al., 2021), and (3) Social Robotics & Societal Impact which enables children to learn about the ethical issues surrounding social robots before creating conversational skills for them (DiPaola 2021). We have deployed these curricula with over 3500 teachers nationally and internationally. Our curricula demonstrate that technical and ethical scaffolding leads to projects that are both personally meaningful and have real-world implications in mind.

“Hey! This is just like AI!” (Stager)

The ferocity of hype and hysteria accompanying the public release of ChatGPT feels unprecedented. Predictably, the claims of education being revolutionized over Christmas vacation are being advanced by people demonstrating little to no understanding of AI/ML or computing. I have been alarmed by the realization that many of those exaggerating the promise or perils of generative AI/ML have been obstacles to teaching all children to program computers. In a simulacrum of the instructionism vs. constructionism debate, the response to ChatGPT are calls to teach children *about* AI/ML. Discussions of ethics, risks, cheating, and banning ChatGPT are examples of what Alan Kay called, “Computer Appreciation.” It is certainly a departure from the Papertian image of the child programming the computer rather than the computer programming the child. (Papert, 1996) Whether technology such as ChatGPT realizes its promise or precipitates catastrophe, it seems imperative that children develop sufficient computational fluency to understand the technology and potentially shape its development. Papert wrote, “Piaget said that to understand is to invent. He was thinking of children. But the principle applies to all of us.” (Papert, 1993). In a desire to help children construct an understanding of “generative AI,” like ChatGPT, I began teaching kids (and their teachers) to write Logo programs for “playing with language” in the spirit of Paul Goldenberg and Wally Feurzig’s timeless projects. (Goldenberg and Feurzig, 1987) Students engaged in writing computer programs to generate random insults or produce the plural form of a word learn a great deal about reporters, list processing, conditionals, variables, concatenation, symbolic programming, linguistics, probabilistic thinking, debugging, grammar, pattern recognition, and linguistics. Even at a rudimentary level, such programming experiences remain elusive to most students. Aside from sharing a desire to help the computer “work for us,” I did not mention “artificial intelligence” during our programming sessions. However, it was during one such programming session that a fifth grader exclaimed, “Hey! This is just like AI!”

Leveraging learners’ knowledge and practices as a language for understanding AI/ML within dance and computing (Castro & DesPortes)

Computing systems that enable connections between dance and AI/ML models provide spaces to explore their opportunities, constraints, and failures and reason about how AI/ML is influenced by human design decisions, which are often shaped by biases and inequities (Noble, 2018). By centering dance, which is situated within various cultures and communities through music, movement, and social experiences (DesPortes et al., 2022), learners with dance experience have a language that they can use to examine the sociotechnical aspects of AI/ML and computing, while learning about and within these systems (Castro et al., 2022). Our work explores how six learners from STEM From Dance engaged with AI/ML concepts as they created dances with a creative computing system, danceON. danceON enables learners to use their own and existing pose detection models as they code movement-responsive virtual animations over live or pre-recorded dance videos (Payne et al., 2021). The design of danceON, which provides learners access to 33 body key points for each frame of video data using an off-the-shelf ML algorithm trained on inaccessible datasets, invited learners to speculate on possible causes when danceON performed poorly or when its behavior misaligned with a learner’s envisioned performance. Pose detection algorithms also make assumptions about the human body that may not capture the diversity of human bodies in the real-world; this had implications on how learners navigated the coding of animations over their bodies for their dances when certain body points were not directly accessible to them. Learners also reasoned about these limitations and behaviors of AI/ML by connecting to their experiences with AI/ML systems within their communities. The work demonstrates the power of tools to highlight the flaws and opportunities of AI/ML systems and empower learners to think about how to address these within similar systems, while also engaging in personally meaningful creation of dance.

Craft-ing classroom activities through co-design that interrogate artifact creation with generative AI/ML (Lee, Sarin, Xie, Wolf, Sieh, Dennison, & Garcia)

Co-design with teachers is generating more interest in the learning sciences and adjacent fields that value core ideas of Constructionism and maker pedagogies. Through co-design, where researchers and educators meet repeatedly to ideate, critique, and test new learning experiences, tensions emerge related to what can be made feasible given classroom constraints and pressures. Through the Stanford CRAFT (*Classroom-ready Resources about AI For Teaching*) project (Lee et al., 2023), we embrace the opportunity to lean into these tensions and co-create curricular resources about AI/ML with practicing high school teachers. Beyond co-design, CRAFT intentionally pursues an “across-the-disciplines” approach (Jiang et al., 2022) to exploring AI/ML and emphasizes modularity and adaptation of co-created resources. A design tension, however, is to balance tendencies in schools to rely on instructionist pedagogies (Papert & Harel, 1991) when we wish to strongly encourage Constructionist ones. In this poster, we describe some of the collaboration processes and resulting resources that navigate that tension. The specific resources discussed include ones to help high school English and Art classrooms examine how the use of generative AI/ML tools, such as ChatGPT and DALL-E 2, complicate questions about who is constructing a new public artifact. The main data source which informs our design work is the corpus of video recorded co-design sessions and interviews with teachers. Of note our art teacher co-designer was instrumental in steering CRAFT toward provide resources to help students consider major concerns among artists about who is being credited and compensated for the creative work that trains generative AI/ML systems. Similarly, one of our English teacher co-designers shaped the design of a scaffolded generative AI/ML prompting environment where students, with support from teachers, can examine qualities of novel text creations. In this respect, given the ease by which new artifacts are being created, pedagogies of construction also add interrogation of construction in the age of Generative AI/ML.

Sports Through an AI/ML Lens: Opportunities for AI/ML Exposure and Education in Athletic Spaces for Student-Athlete Identity Expansion (Kumar, Bodon, Worsley)

Sports and athletic play are highly relevant venues to think about AI/ML tools and education. While AI/ML tools are prominently used in professional sports, learning about the computing concepts is relegated to classroom experiences often missing the rich potential of embodied movement, as well as cultural and personal identity involvement that sports engender (Madkins et al. 2019). We have developed a suite of activities that introduces AI/ML driven proprietary technologies leveraging concepts like object, pose and gesture detection in youth athletic spaces (Jones et al. 2020; Kumar & Worsley, 2023). We then provide them opportunities to develop and extend variations of similar ideated sports technologies. This blend of playing and testing followed by tinkering and making centers our goals of culturally sustaining identity *expansion* for youth – orienting AI/ML as tools in service of youth interests and values, in contrast to technocentric approaches to computing often fostered in traditional computing classes and spaces (Kayumova & Sengupta, 2022). In this poster, we present our curricula, and highlight select cases of different learning and participation trajectories that emerge in introducing these activities in sports camps (Bodon et al. 2022). We show examples of how such constructionist AI/ML experiences can enable newer representations and structurations (Wilensky & Papert, 2010) to reflect on and deepen sports understandings – for thinking of posture and accuracy through the lens of computational feedback in addition to more familiar interpersonal judgment. We also highlight how even these highly contextualized use cases can surface deep conversations around much broader ethical impacts of these technologies – for instance, discussing the surveillance impacts of face and gesture recognition technologies in professional sports (Karkazis & Fishman, 2017) as well as urban and personal security (Vakil, 2018).

References

- Ali, S., Payne, B. H., Williams, R., Park, H. W., & Breazeal, C. (2019, June). Constructionism, ethics, and creativity: Developing primary and middle school artificial intelligence education. In *International workshop on education in artificial intelligence k-12 (eduai'19)* (Vol. 2, pp. 1-4).
- Ali, S., DiPaola, D., Lee, I., Hong, J., & Breazeal, C. (2021, May). Exploring Generative Models with Middle School Students. In *Proceedings of the 2021 CHI Conference on Human Factors in Computing Systems* (pp. 1-13).
- Ali, S., DiPaola, D., Lee, I., Sindato, V., Kim, G., Blumofe, R., & Breazeal, C. (2021). Children as creators, thinkers and citizens in an AI-driven future. *Computers and Education: Artificial Intelligence*, 2, 100040-100051.
- Bodon, H., Worsley, M., & Kumar, V. (2022, June). Youth Experiences with Authentically Embedded Computer Science in Sport. In *Interaction Design and Children* (pp. 504-509). Braga, Portugal.
- Castro, F. E. V., DesPortes, K., Payne, W., Bergner, Y., & McDermott, K. (2022). AI + Dance: Co-Designing Culturally Sustaining Curricular Resources for AI and Ethics Education Through Artistic Computing. *Proceedings of the 2022 ACM Conference on International Computing Education Research - Volume 2*, 26-27. <https://doi.org/10.1145/3501709.3544275>
- DesPortes, K., McDermott, K., Bergner, Y., & Payne, W. (2022). "Go[ing] hard...as a woman of color": A case study examining identity work within a performative dance and computing learning environment. *ACM Transactions on Computing Education*. <https://doi.org/10.1145/3531000>
- DeVos, A., Dhabalia, A., Shen, H., Holstein, K., & Eslami, M. (2022, April). Toward User-Driven Algorithm Auditing: Investigating users' strategies for uncovering harmful algorithmic behavior. In *Proceedings of the 2022 CHI Conference on Human Factors in Computing Systems* (pp. 1-19).
- DiPaola, D., Ali, S., & Breazeal, C. (2021). What are GANs?: Introducing Generative Adversarial Networks to Middle School Students. *Proceedings of the 11th Symposium on Education Advances in Artificial Intelligence (EAAI '21)*.
- DiPaola, D. (2021). How does my robot know who I am?: Understanding the Impact of Education on Child-Robot Relationships (Doctoral dissertation, Massachusetts Institute of Technology).
- DiPaola, D., Payne, B. H., & Breazeal, C. (2020, June). Decoding design agendas: an ethical design activity for middle school students. In *Proceedings of the interaction design and children conference* (pp. 1-10).
- DiPaola, D., Payne, B. H., & Breazeal, C. (2022) Preparing Children To Be Conscientious Consumers And Designers Of Ai Technologies. In S. Kong, and H. Abelson, (Eds.), *Computational Thinking Education in K-12: Artificial Intelligence Literacy and Physical Computing*. MIT Press.
- Fields, D. A., Kafai, Y. B., Morales-Navarro, L., & Walker, J. T. (2021). Debugging by design: A constructionist approach to high school students' crafting and coding of electronic textiles as failure artefacts. *British Journal of Educational Technology*, 52(3), 1078-1092.
- Fiesler, C., & Garrett, N. (2020). Ethical Tech Starts With Addressing Ethical Debt. *Wired*.
- Goldenberg, E. P., & Feurzeig, W. (1987). *Exploring language with Logo*. Mit Press.
- Goldstein, I., & Papert, S. (1977). Artificial intelligence, language, and the study of knowledge. *Cognitive science*, 1(1), 84-123.
- Green, L. (2020). Let The Student Program The Computer, Not The Computer Program The Student. *BootUp*

Professional Development. <https://bootuppd.org/blog/let-the-student-program-the-computer-not-the-computer-program-the/>

Harel, I. E., & Papert, S. E. (1991). *Constructionism*. Ablex Publishing.

Jatzlau, S., Michaeli, T., Seegerer, S., & Romeike, R. (2019). It's not magic after all—machine learning in snap! using reinforcement learning. In *2019 IEEE blocks and beyond workshop (B&B)* (pp. 37-41). IEEE.

Jiang, S., Lee, V. R., & Rosenberg, J. M. (2022). Data science education across the disciplines: Underexamined opportunities for K-12 innovation. *British Journal of Educational Technology*, 53(2), 1073-1079. doi:10.1111/bjet.13258

Jones, S. T., Thompson, J., & Worsley, M. (2020). Data in Motion: Sports as a site for expansive learning. *Computer Science Education*, 30(3), 279-312.

Jordan, B., Devasia, N., Hong, J., Williams, R., & Breazeal, C. (2021, May). PoseBlocks: A toolkit for creating (and dancing) with AI. In *Proceedings of the AAAI Conference on Artificial Intelligence* (Vol. 35, No. 17, pp. 15551-15559).

Kafai, Y. B., & Burke, Q. (2014). *Connected code: Why children need to learn programming*. MIT Press.

Kafai, Y. B., & Proctor, C. (2022). A Revaluation of Computational Thinking in K-12 Education: Moving Toward Computational Literacies. *Educational Researcher*, 51(2), 146-151.

Kahn, K. (1977). Three interactions between AI and education. *Machine intelligence*, 8, 422-429.

Kahn, K., & Winters, N. (2021). Constructionism and AI: A history and possible futures. *British Journal of Educational Technology*, 52(3), 1130-1142.

Karkazis, K., & Fishman, J. R. (2017). Tracking US professional athletes: The ethics of biometric technologies. *The American Journal of Bioethics*, 17(1), 45-60.

Kayumova, S., & Sengupta, P. (2022). Beyond representationalism: Heterogeneity as an ethical turn in STEM and computing education. In *The learning sciences in conversation* (pp. 218-234). Routledge.

Klopfer, E., Anderson, E., & Perry, J. (2020). Constructionist Learning Games in School. In N. Holbert, M. Berland, & Y. B. Kafai (Eds.), *Designing Constructionist Futures: The Art, Theory, and Practice of Learning Designs* (p. 0). MIT Press.

Kumar, V., & Worsley, M. (2023, Feb). Scratch For Sports: Athletic Drills as a Platform for Experiencing, Understanding, and Developing AI-driven Apps. In *Proceedings of the AAAI Conference on Artificial Intelligence*. Washington, D.C.

Lee, I., Ali, S., Zhang, H., DiPaola, D., & Breazeal, C. (2021). Developing Middle School Students' AI Literacy. *Proceedings of the 52nd ACM Technical Symposium on Computer Science Education*, 191-197.

Lee, V. R., Sarin, P., Xie, B. & Wolf, J. (2023) CRAFT-work: An Integrative Co-Design Approach for Designing High School AI Literacy Resources. Paper presented at the ACM SIGCHI 2023 AI Literacy Workshop, Hamburg, Germany.

Madkins, T. C., Martin, A., Ryoo, J., Scott, K. A., Goode, J., Scott, A., & McAlear, F. (2019, February). Culturally relevant computer science pedagogy: From theory to practice. In *2019 research on equity and sustained participation in engineering, computing, and technology* (pp. 1-4). IEEE.

Metaxa, D., Park, J. S., Robertson, R. E., Karahalios, K., Wilson, C., Hancock, J., & Sandvig, C. (2021). Auditing algorithms: Understanding algorithmic systems from the outside in. *Foundations and Trends® in Human-Computer Interaction*, 14(4), 272-344.

- Michaeli, T., Seegerer, S., Jatzlau, S., & Romeike, R. (2020). Looking beyond supervised classification and image recognition—unsupervised learning with snap!. *CONSTRUCTIONISM 2020*, 395.
- Michaeli, T., Romeike, R., & Seegerer, S. (2023). What students can learn about artificial intelligence—recommendations for K12 computing education. In *Proceedings of World Conference on Computers in Education, WCCE 2022*.
- Michaeli, T., Seegerer, S., Kerber, L., & Romeike, R. (2023). Data, Trees, and Forests—Decision Tree Learning in K-12 Education. In *Proceedings of the 3rd Teaching Machine Learning and Artificial Intelligence Workshop*, PMLR.
- Noble, S. U. (2018). *Algorithms of Oppression: How Search Engines Reinforce Racism* (Illustrated edition). NYU Press.
- Papert, S (1980). *Mindstorms*. Basic Books.
- Papert, S. (1996). *The connected family: bridging the digital generation gap*. Longstreet.
- Papert, S., & Harel, I. (1991). Situating Constructionism. In S. Papert & I. Harel (Eds.), *Constructionism* (pp. 1-11). Norwood, NJ: Ablex.
- Payne, W. C., Bergner, Y., West, M. E., Charp, C., Shapiro, R. B. B., Szafir, D. A., Taylor, E. V., & DesPortes, K. (2021). danceON: Culturally Responsive Creative Computing. *Proceedings of the 2021 CHI Conference on Human Factors in Computing Systems*, 1–16.
- Petrozzino, C. (2021). Who pays for ethical debt in AI?. *AI and Ethics*, 1(3), 205–208.
- Raji, I. D., Kumar, I. E., Horowitz, A., & Selbst, A. (2022, June). The Fallacy of AI Functionality. In *2022 ACM Conference on Fairness, Accountability, and Transparency* (pp. 959–972).
- Solomon, C., Harvey, B., Kahn, K., Lieberman, H., Miller, M. L., Minsky, M., ... & Silverman, B. (2020). History of logo. *Proceedings of the ACM on Programming Languages*, 4(HOPL), 1-66.
- Stager, G. (2021). The Future is Computational. In G. Stager (Ed.), *Twenty things to do with a computer forward 50: Future visions of education inspired by Seymour Papert and Cynthia Solomon's seminal work*. Constructing Modern Knowledge Press.
- Tseng, T., Murai, Y., Freed, N., Gelosi, D., Ta, T. D., & Kawahara, Y. (2021, June). PlushPal: Storytelling with interactive plush toys and machine learning. In *Interaction design and children* (pp. 236-245).
- Tedre, M., Denning, P., & Toivonen, T. (2021, November). CT 2.0. In *Proceedings of the 21st Koli Calling International Conference on Computing Education Research* (pp. 1-8).
- Touretzky, D., & Gardner-McCune, C. (2022) Artificial Intelligence Thinking in K-12. In S. Kong, and H. Abelson, (Eds.), *Computational Thinking Education in K-12: Artificial Intelligence Literacy and Physical Computing*. MIT Press.
- Vakil, S. (2018). Ethics, identity, and political vision: Toward a justice-centered approach to equity in computer science education. *Harvard Educational Review*, 88(1), 26–52.
- Wilensky, U., & Papert, S. (2010). Restructurations: Reformulations of knowledge disciplines through new representational forms. *Constructionism*, 17, 1-15.
- Williams, R., Kaputsos, S., & Breazeal, C. (2021). Teacher Perspectives on How To Train Your Robot: A Middle School AI and Ethics Curriculum. *Proceedings of the 11th Symposium on Education Advances in Artificial Intelligence (EAAI '21)*.
- Williams, R., Ali, S., Devasia, N., DiPaola, D., Hong, J., Kaputsos, S.P., Jordan, B., & Breazeal, C. (2022). AI + Ethics

Curricula for Middle School Youth: Lessons Learned from Three Project-Based Curricula. *International Journal of Artificial Intelligence in Education*, 1-59.

Williams, R. (2021, March). How to train your robot: project-based ai and ethics education for middle school classrooms. In *Proceedings of the 52nd ACM Technical Symposium on Computer Science Education* (pp. 1382-1382).

Williams, R., Ali, S., Devasia, N., DiPaola, D., Hong, J., Kaputsos, S. P., ... & Breazeal, C. (2022). AI+ ethics curricula for middle school youth: Lessons learned from three project-based curricula. *International Journal of Artificial Intelligence in Education*, 1-59.

Productive Designs for Successful Failure

Constructionist Perspectives on Supporting Personally Meaningful and Culturally Empowered Learning and Teaching

Luis Morales-Navarro & Yasmin B. Kafai (Chairs), University of Pennsylvania, luismn@upenn.edu, kafai@upenn.edu

Karen Brennan, Harvard University, karen_brennan@gse.harvard.edu

Paulina Haduong, Harvard University, haduong@g.harvard.edu

Varsha Venkatasubramanian, Harvard University, varsha_venkatasubramanian@gse.harvard.edu

Heike Hennig, Technische Universität München, heike.hennig@tum.de

Tilman Michaeli, Technische Universität München, tilman.michaeli@tum.de

David Weintrop, University of Maryland, weintrop@umd.edu

Jennifer Tsan, WestEd, jennifertsan@uchicago.edu

Diana Franklin, University of Chicago, dmfranklin@uchicago.edu

Yerika Jimenez, University of Florida, jimenezyerika@gmail.com

Christina Gardner-Mccune, University of Florida, gmccune@ufl.edu

Colin Hennessy Elliott, Drexel University, ch3457@drexel.edu

Michael Schneider, University of Colorado, Michael.J.Schneider@colorado.edu

Jeffrey B. Bush, University of Colorado, , Jeffrey.Bush@colorado.edu

Deborah A. Fields, Utah State University, deborah.fields@usu.edu

Mimi Recker, Utah State University, mimi.recker@usu.edu

Jessie Nixon, Utah State University, jessie.nixon@usu.edu

Francisco Castro, New York University, francisco.castro@nyu.edu

Kayla DesPortes, New York University, kayla.desportes@nyu.edu

Mike Tissenbaum, University of Illinois, miketiss@illinois.edu

Casey Smith, University of Illinois, cjsmith0@illinois.edu

Ashita Bawankule, University of Illinois, anb8@illinois.edu

David Hopping, University of Illinois, davidah3@illinois.edu

Nathan Holbert, Teachers College, holbert@tc.columbia.edu

Isabel Correa, Teachers College, mic2130@tc.columbia.edu

Blake Danzig, Teachers College, bpd2119@tc.columbia.edu

David Zikovitz, Teachers College, dmz2117@tc.columbia.edu

Paulo Blikstein, Teachers College, paulob@tc.columbia.edu

Matthew Berland (Discussant), University of Wisconsin-Madison, mberland@wisc.edu

Abstract

In education, we cherish success and fear failure. But not every learning experience is a success right away, in fact failing and making mistakes and then learning from them is the norm rather than the exception. In this symposium, we present different perspectives on how failure can contribute to constructionist learning and teaching, examining how learners identify and address failures in their designs and how distinct approaches to failure can support learners in collaboratively creating personally meaningful projects. Taking a holistic approach to failure—that incorporates cognitive, social, and affective factors—we argue that failure should play a key role in constructionism and present

different perspectives for finding a more productive stance that turns failures into rich opportunities for constructionist learning and teaching.

Symposium Overview

While traditional instructionist approaches to learning frame failure and errors as undesirable, when making constructionist projects encountering failure is nearly inevitable. As Papert (1980) remarks, “errors benefit us because they lead us to study what happened, to understand what went wrong, and, through understanding, to fix it.” Recent scholarship has shifted our perspectives on how errors, mistakes, and failure can be beneficial for learning in open ended activities when designers holistically attend to the learner’s emotional, motivational, social and cognitive aspects of encountering failure (Zhang & Fiorella, 2023; DeLiema et al., 2022). These perspectives complement earlier work that shows that early failure in well-defined learning activities can be beneficial for later student success (Kapur, 2016). Within constructionism, recent efforts on situating failure have taken on a more agentic role highlighting the importance of failure from promoting different strategies for getting unstuck (Haduong & Brennan, 2018) to having students design failure artifacts for learning (Fields et al., 2021). We build on contemporary research on failure and learning—that sees learning from failure as a holistic process that involves cognitive, social, and affective factors—by presenting a range of perspectives on failure in constructionist learning.

Participants will examine how to scaffold students in debugging Scratch projects, how teachers can support students debugging of open-ended projects, how learners encounter failure and design failure artifacts, and how tools can support debugging. Brennan and colleagues examine the implementation of a curriculum designed to support students when they encounter failure in self-directed programming projects. Franklin and colleagues present a mnemonic strategy designed to help novices identify and resolve bugs they encounter while creating projects on Scratch. Jiménez and Gardner-McCune examine students’ productive and unproductive debugging behaviors on Scratch. Hennig & Michaeli investigate different types of feedback provided by teachers when students request help with debugging. Hennessy Elliott and colleagues examine how teachers support students in debugging physical computing systems. Morales-Navarro and colleagues analyze student reflections and the different types of bugs they engaged when creating personally relevant buggy physical computing projects for their peers to solve. Castro and DesPortes examine how youth use their bodies, practices, and observations to address failure in dance and computing projects. Fields and colleagues explore the role of failure outside the classroom in a remote Thai village’s development of a sustainable water management system. Tissenbaum and colleagues present a collaborative debugging at a distance tool for physical computing projects. Schneider presents a tool for students to safely explore and test physical computing projects while debugging. The symposium is organized in four sections: (1) the chairs will introduce the topic and then each presenter will give a teaser about their work (~10 min); (2) the first half of the presenters will have 15 minutes to share their work using posters placed around the room, followed by the second half of presenters (15 minutes)—this arrangement will give the audience and presenters time to see each other’s posters; (3) our discussant Matthew Berland will synthesize and reflect on findings (10 minutes) followed by (4) a Q&A with audience and presenters (~10 min).

Presented Posters

Self-directed programming projects in the elementary classroom: Learning and “unlearning” (Brennan, Haduong, & Venkatasubramanian)

Though elementary schools are increasingly offering introductory computer science learning experiences, it remains challenging to structure opportunities that enable young learners to develop and implement self-directed projects. Part of the challenge resides in helping students manage the inevitable moments of getting stuck and encountering failure. These experiences of failure in self-directed programming projects invite students and teachers to learn new strategies and “unlearn” aspects of traditional school culture (Cochran-Smith, 2003). To help students engage in self-directed programming projects involving encounters with failure, our research group developed *Getting Unstuck*, a 10-module intermediate Scratch curriculum. The curriculum reimagines the classroom as a design studio: a learning environment in which students are invited to *explore*, *create*, *share*, and *reflect* through self-directed programming projects. In a pilot study of the curriculum conducted with six 3rd, 4th, and 5th grade teachers and their students, we sought to understand what was challenging for students and teachers as students pursued self-directed projects. Through thematic analysis of pilot teachers’ reflective journals, students’ design journals, interviews with the teachers, and classroom observations, we identified dimensions of learning and “unlearning” in which the students engaged across the design studio activities of exploring, creating, sharing, and reflecting. As students *explored*, students and teachers reimagined their relationship to examples and explicit instruction. As students *created*, students and teachers developed new ways of thinking about remixing and the role of tenacity. As students *shared*, teachers and students learned how to trade perfectionism for the benefits of sharing works-in-progress and how to be supportive digital citizens. As students *reflected*, teachers and students explored the benefits of contemplative practice as more than external accountability. We hope this work underscores the power and potential of supporting self-direction in the classroom. Although this shift in learning culture is replete with challenges, viewing moments of failure as opportunities for development underscores the possibilities of this approach.

Investigating teacher feedback in debugging using a video vignette approach (Hennig & Michaeli)

Debugging is a core issue in K-12 computing education, challenging students and teachers alike. For students, finding and fixing programming errors is a significant challenge, especially when working in open-ended, constructionist learning environments. For novice programmers, the naturally high number of errors and lack of strategies for dealing with them can lead to frustration. Typically, the students ask the teacher to help them individually with their programming problems (Michaeli & Romeike, 2019). The teacher’s goal is to empower students to find and fix the current and similar future bugs themselves while fostering a positive error culture in the classroom. To do this, they need to understand the problem, diagnose why the student is stuck, and choose an appropriate intervention in a very short time. However, there is a lack of research on effective teacher feedback for debugging situations in the classroom (Hennig & Michaeli, 2022). As a first step in addressing this issue, we conducted a study investigating teachers’ diagnostic and intervention skills. Using a video vignette approach, we confronted experienced computer science teachers with scripted videos of typical classroom debugging situations: Two students are pair programming and seek help from the teacher. We asked the teachers for their diagnosis of the student’s problem and their reaction using an open-ended questionnaire. This allows a realistic simulation of typical classroom situations, as situational features such as student questions, discussion within the programming pair, and the students’ code are available to the teacher. Initial results

show that the aspects considered in the teachers' diagnosis are diverse. The proposed interventions are primarily aimed at guiding students to solve the specific problem and only rarely address larger issues, such as how failure can be used for learning.

Buggy projects as Objects-to-think-with (Morales-Navarro, Fields & Kafai)

Supporting students in learning debugging often involves instructionist approaches such as teaching them techniques, following checklists, or having them fix teacher—or researcher—designed programs. Instead, our approach to debugging in Debugging by Design (DbD) builds on constructionism by having learners create personally relevant, buggy applications for their peers. Prior studies on DbD show that creating buggy e-textile projects may support students in identifying and solving bugs while attending to the emotional and motivational toll that debugging often takes (e.g., Fields et al., 2021). Beyond these attitudinal gains, in this study we sought to understand what students *learned* in designing bugs: What kind of bugs did students create and what does this reflect about their learning and understanding of computing? We investigate the role of buggy projects as objects-to-think-with, “in which there is an intersection of cultural presence, embedded knowledge, and the possibility for personal identification” (Papert, 1980, p. 24) by analyzing the different types of bugs that students designed for each other to solve and their reflections on the design process. In Spring 2019, an experienced teacher at a metropolitan U.S. high school implemented DbD in a classroom with 11 girls and 14 boys. Drawing on observations, photographs, code, and students' initial designs and plans, we systematically analyzed students' buggy designs, identifying, and classifying each bug. Overall, 12 groups of students designed a total of 185 bugs, which we classified into 30 categories, from basic syntax (capitalization, punctuation, spelling) to sophisticated logic and design errors. Our analysis demonstrates how students explored the intricacies and interrelatedness of the physical computing system (PCS), from the organization of code structure to multiple types of variables, logic statements, function calls, and conflicts between the physical and coded aspects of projects. In the poster, we consider how this bug-motivated exploration of PCS fulfilled the goals of Papert's objects-to-think-with.

WHAT A MESS: Scaffolding debugging in Scratch (Franklin, Tsan, & Weintrop)

Debugging is an essential skill for building and creating with technology. Fixing errors and resolving challenges that emerge while programming is necessary to create functioning software and can also serve as a powerful opportunity for learning (McCauley et al., 2008). Despite the critical role it plays in programming, the practice of debugging is rarely the focus of instruction or explicitly scaffolded in learning environments, instead, learners are often left to their own devices to discover and develop productive debugging strategies. Research on novices learning to debug has identified the conceptual underpinnings and generative practices related to learning to debug (Rich et al., 2019). Informed by this research, we sought to understand how to support novice Scratch programmers in learning productive and effective debugging strategies. Towards this end, we developed the mnemonic: WHAT A MESS! to help novices identify and resolve bugs they encounter. It first helps learners identify the issue: What is the program trying to do? How did it go wrong? Analyze what happened, and Three before me (a common peer-first help-seeking strategy), and then directs learners' attention to common sources of bugs: Arguments, Missing blocks, Extra blocks, Scrambled blocks, and Substituted blocks. In this poster, we present the WHAT A MESS! debugging approach and show how it has been incorporated into Scratch Encore (Franklin et al., 2020), a culturally responsive middle school computer science curriculum. This includes the specifics of each element of the mnemonic along with scaffolds developed to help learners employ the various concepts/practices as they work to author personalized and personally meaningful Scratch programs.

Towards understanding students' debugging behaviors in scratch (Jiménez & Gardner-McCune)

Debugging is a complex cognitive process that requires students to learn how to apply different programming skills, such as program comprehension, reading, writing, tracing, predicting, and modifying programs (McCauley et al., 2008). Learning these skills can be challenging for novice students and demotivate them if they are not carefully supported throughout the process. Motivated by a lack of studies focused on in-depth analysis of elementary students' debugging in block-based programming environments, we designed a 4-week online debugging intervention that explicitly taught elementary students the debugging process, as well as how to read, write, trace, predict, modify, and debug in Scratch 3.0 using reciprocal teaching. At the end of the summer camp, students participated in a debugging study where they solved tasks focused on common bugs, they encountered during the summer camp. Through video and constant comparative analysis with ten elementary students, we found that they exhibited both productive and unproductive debugging behaviors while debugging buggy code in Scratch. The productive behaviors students exhibited were found to be directly correlated with the debugging skills that were taught during the four-week debugging intervention. These debugging skills included: 1) code reading before starting the debugging process, 2) testing the code before debugging, 3) iterative testing, 4) tracing through the code while debugging, and 5) talking out loud while debugging. In contrast, unproductive debugging behaviors are defined as actions taken by students that do not lead to successful debugging of code. We found that elementary students experienced attitudinal (e.g., self-doubt, hesitation) and procedural (reducing code complexity) debugging behaviors while debugging in Scratch. Our findings suggest that explicitly teaching debugging skills to elementary students can be effective in improving their ability to debug code, but continued reinforcement and support may be necessary to ensure the skills are retained and utilized effectively.

Facilitating failure: How teachers support learning through debugging with physical computing (Hennessy Elliott, Nixon, Bush, & Recker)

Engaging in debugging tasks with physical computing systems (PCS) illuminates secondary students' emerging understandings about computing, and creates important moments for their teachers to support them encountering instances of failure (DeLeima, et al., 2022). When deciding how to provide guidance, teachers wrestle with uncertainty about what issues students need to resolve and how to best resolve them (Hennessy Elliott, et al., 2022). This paper presents analyses of middle school teachers' interactional work as they support students assembling and programming a sensor-based PCS. The PCS becomes an "object to think with" (Papert, 1980), in the context of instructional activities designed to help students develop understanding of physical phenomena. Using video data of seven teachers over three years, we analyzed debugging moments where teachers worked directly with students encountering issues. Analyses visualized the variety of approaches teachers took on two dimensions capturing debugging pedagogy: an **understanding dimension**—which captures whether a teacher's approach privileges of their own or the student's understanding—and the **process/product dimension**—which captures whether a teacher's approach is oriented to supporting students in debugging or in just getting their PCS to work. Teachers' orientation on the two dimensions were not always consistent nor correlated across debugging episodes. Teachers used a large variety of orientations in relation to the kinds of questions and problems students articulated. We posit that these decisions were influenced by teachers' read of students' emotional, cognitive, and social states, as well as other contextual factors. The teacher's role in facilitating student engagement with failure in the context of physical computing was situated and improvisational, relying on their ability to not only figure out bugs in the PCS but also the students' orientations to its failure. This has implications for how professional learning is designed to help teachers support students as emerging debuggers of PCS.

Exploring with the body: Situating failure and iteration while learning dance and computing (Castro & DesPortes)

Dance and computing learning experiences bridge the digital and physical world to create ways for learners to engage in a variety of practices for thinking, exploration, and learning in which the body and its context are integral. Learners engage with their own dance cultures and identities as they use body positioning and movement to learn and communicate (Castro et al., 2022; Leonard et al., 2021). We explore how goal setting, failure, and iterations towards successes are navigated as learners build dance videos with coded animations using danceON. danceON is an open-access, web-based, creative coding environment that embeds pose detection models and enables learners to upload dance videos over which they can code movement-responsive virtual animations and engage authentically with dance (Payne et al., 2021). In a 15-week remote study, six learners from STEM From Dance used danceON to create dance computing artifacts within individual and group activities, while documenting their design processes through blogs. We analyzed learners' blogs and recording transcripts from the sessions by identifying instances of how learners used their bodies, practices, and observations of danceON behavior to think through misalignments between code and animation behaviors, the limitations of pose detection algorithms in representing their bodies and movements, and the impacts of these misalignments and limitations on the dance computing performances they created. We found that learners iteratively redefined goals throughout the development of their dance computing artifacts (e.g., "happy mistakes") as they negotiated and navigated where "failures" exist, such as in learner's actions or within the limitations of danceON. We demonstrate how learners transformed "failures" into meaningful and productive learning experiences within open ended creative computing environments.

The dams blew out: A Thai village's collective and constructionist response to failure (Fields, Morales-Navarro, Blikstein)

In this poster we share a provocative story about a village's collective response to the failure of months of manual labor in creating a sustainable water management system. Ban Samkha is a rural village of about 600 people, set amongst the hills and forests of Northern Thailand. The area faced annual water shortages due to a lengthy dry season and the lack of any water infrastructure to contain precipitation from the wet season. In March 2546 (2003 in Gregorian years), inspired by a constructionism that validated their collective learner agency and emphasized learning by doing (Fields et al., 2022), the village began to create a system of "check dams", using trees, rocks, and leaves to create small drainage blockages on the mountain near the village to drive water into the ground. Within three months they had built 20 check dams. However, because villagers had built dams at the bottom of the mountain, all the dams blew out from the force of the water during the rainy season. Part of a larger study on the village and constructionism in Thailand (Fields et al., 2022), for this analysis we applied an iterative case study approach to the village's 25-year learning journey, encompassing 37 hours of interviews and 350+ pages of scanned project documentation (mostly from village records and writings) collected across four site visits. We share how in the face of utter failure, the village engaged in collective reflection and iteration, sought expertise and resources (from satellite maps to identify natural water drainage to used chainsaws and donations of cement for stronger dams higher up the mountain), and over 10 years created a system of 20,000+ check dams. This case expands our understanding of constructionist approaches to failure, with both every day and sophisticated technology, for deeply consequential learning.

Connected Spaces: Technological infrastructure for collaborative debugging at a distance (Tissenbaum, Smith, Bawankule, Hopping, Holbert, Correa, Danzig, & Zikovitz)

Connected Spaces (C/S) is a technology framework and suite of tools that supports collaborative debugging for geographically distributed middle and high school makers. The goal of Connected Spaces is to benefit learners who are traditionally underrepresented in STEM+C career pathways by connecting them to like-minded peers and offering new opportunities for them to develop their maker identities and sense of belonging within a larger maker community. Three technologies—the dashboard, help button, and REACH projector—work in tandem to support students in help-seeking, finding collaborators, and getting “unstuck”. The dashboard is an ambient display across makerspaces where learners showcase their skills and their availability to help. Help seekers use the dashboard to find peer support or collaborators. The design aims to support makers’ identity building and sense of community by enabling learners to customize their individual representations (e.g., affinities, works-in-progress, etc.) on the dashboard. The HELP button is designed to ease the initial request for help, providing a simple physical interface for selecting a need and broadcasting the request across the connected makerspaces. The REACH projector supports collaborative debugging as a two-way communicator that combines a projector and a camera in an overhead display. Makers put a work-in-progress they need help with under REACH and it is projected into their collaborator’s REACH space. Anything the collaborator puts under their REACH is simultaneously projected at the help seeker’s REACH, allowing real-time non-located debugging around physical objects. In this poster session, we demonstrate these technologies and share our initial findings from multiple implementations across makerspaces in Illinois and New York that led to the current design. Including an approach that combined coding students’ week-by-week of their dashboard personas with one-on-one interviews to understand its impact on their computational identities and applying the Divergent Collaboration Learning Methods (Tissenbaum et al., 2017) framework to understand students’ boundary spanning collaborative practices.

Circuit check: Enabling students to safely explore while debugging e-textiles (Schneider)

E-textiles weave computational and electronic components into fabric materials, enabling students to create projects that can sense and interact with the physical world. While this combination of hardware and software can provide an engaging medium for creative learning, it also forms a more challenging space for debugging. Debugging is a known challenge in software engineering (McCauley et al., 2008), but it can be even more challenging in physical computing systems, like e-textiles, where students not only have to contend with errors in their software, but also in their circuit’s hardware and even the connections between the two (Booth et al., 2016). Early student attempts at debugging often follow a trial-and-error approach that consists of guessing at a potential cause, making a quick change to the system, and then hoping everything now works. Unfortunately, this approach is not very forgiving of mistakes where hasty changes can create new bugs instead of solving the original one. While making mistakes is a natural part of debugging, they shouldn’t be so costly for students to make. I designed an interactive debugging tool, Circuit Check, to provide a safer environment for debugging. Unlike traditional debugging techniques, like print statements and commenting out code chunks, which require students to add or remove specific lines of code, Circuit Check enables students to observe sensors and test actuators without any code modifications. This enables students to make incorrect guesses and safely explore their hardware while debugging. I have evaluated Circuit Check’s debugging features through classroom observations of high school teachers and their students who used Circuit Check to debug e-textile projects. Through analysis of video recordings of classroom interactions and teacher interviews, I have found that Circuit Check’s unique design and debugging features support not only students in debugging on their own, but also in collaboratively debugging with their teacher and peers.

References

- Booth, T., Stumpf, S., Bird, J., & Jones, S. (2016, May). Crossed wires: Investigating the problems of end-user developers in a physical computing task. In *Proceedings of the 2016 CHI conference on human factors in computing systems* (pp. 3485-3497).
- Castro, F. E. V., DesPortes, K., Payne, W., Bergner, Y., & McDermott, K. (2022). AI + Dance: Co-Designing Culturally Sustaining Curricular Resources for AI and Ethics Education Through Artistic Computing. *Proceedings of the 2022 ACM Conference on International Computing Education Research – Volume 2*, 26–27. <https://doi.org/10.1145/3501709.3544275>
- Cochran-Smith, M. (2003). Learning and unlearning: The education of teacher educators. *Teaching and Teacher Education*, 19(1), 5-28. [https://doi.org/https://doi.org/10.1016/S0742-051X\(02\)00091-4](https://doi.org/https://doi.org/10.1016/S0742-051X(02)00091-4)
- McCauley, R., Fitzgerald, S., Lewandowski, G., Murphy, L., Simon, B., Thomas, L., & Zander, C. (2008). Debugging: A review of the literature from an educational perspective. In *Computer Science Education* (Vol. 18, Issue 2, pp. 67–92). <https://doi.org/10.1080/08993400802114581>
- DeLiema, D., Kwon, Y. A., Chisholm, A., Williams, I., Dahn, M., Flood, V. J., ... & Steen, F. F. (2022). A Multi-dimensional Framework for Documenting Students' Heterogeneous Experiences with Programming Bugs. *Cognition and Instruction*, 1-43.
- Fields, D. A., Kafai, Y. B., Morales-Navarro, L., & Walker, J. T. (2021). Debugging by design: A constructionist approach to high school students' crafting and coding of electronic textiles as failure artefacts. *British Journal of Educational Technology*, 52(3), 1078-1092.
- Fields, D. A., Morales-Navarro, L., & Blikstein, P. (2022). "The village that learns": a learning journey across intraventions and domains over two decades in a rural Thai community. *Mind, Culture, and Activity*, 29(3), 191-214.
- Franklin, D., Weintrop, D., Palmer, J., Coenraad, M., Cobian, M., Beck, K., ... & Crenshaw, Z. (2020). Scratch Encore: The design and pilot of a culturally-relevant intermediate Scratch curriculum. In *Proceedings of the 51st ACM technical symposium on computer science education* (pp. 794-800).
- Haduong, P., & Brennan, K. (2019, February). Helping K-12 Teachers Get Unstuck with Scratch: The Design of an Online Professional Learning Experience. In *Proceedings of the 50th ACM technical symposium on computer science education* (pp. 1095-1101).
- Hennig, H., & Michaeli, T. (2022). Investigating Teachers' Diagnostic and Intervention Skills in Debugging. In *Proceedings of the 17th Workshop in Primary and Secondary Computing Education* (pp. 1-2).
- Kapur, M. (2008). Productive failure. *Cognition and instruction*, 26(3), 379-424.
- Leonard, A. E., Daily, S. B., Jörg, S., & Babu, S. V. (2021). Coding moves: Design and research of teaching computational thinking through dance choreography and virtual interactions. *Journal of Research on Technology in Education*, 53(2), 159-177.
- Michaeli, T., & Romeike, R. (2019). Current status and perspectives of debugging in the k12 classroom: A qualitative study. In *2019 IEEE Global Engineering Education Conference (Educon)* (pp. 1030-1038). IEEE.
- Papert, S (1980). *Mindstorms*. Basic Books.
- Payne, W. C., Bergner, Y., West, M. E., Charp, C., Shapiro, R. B. B., Szafir, D. A., Taylor, E. V., & DesPortes, K. (2021).

danceON: Culturally Responsive Creative Computing. Proceedings of the 2021 CHI Conference on Human Factors in Computing Systems, 1–16.

Rich, K. M., Strickland, C., Binkowski, T. A., & Franklin, D. (2019, February). A K-8 Debugging Learning Trajectory Derived from Research Literature. In Proceedings of the 50th ACM Technical Symposium on Computer Science Education (pp. 745-751). ACM.

Tissenbaum, M., Berland, M., & Lyons, L. (2017). DCLM framework: Understanding collaboration in open-ended tabletop learning environments. *International Journal of Computer-Supported Collaborative Learning*, 12(1), 35–64.

Zhang, Q., & Fiorella, L. (2023). An integrated model of learning from errors. *Educational Psychologist*, 1-17.

Facilitating Computational Tinkering

Exploratory and Expansive Collaborative Design Work with Informal Learning Educators

Ricarose Roque (chair), University of Colorado Boulder, ricarose@colorado.edu

Ronni Hayden, University of Colorado Boulder, ronni.hayden@colorado.edu

Ryoko Matsumoto, Tinkering Studio Exploratorium, rmatsumoto@exploratorium.edu

Sebastian Martin, Tinkering Studio Exploratorium, sebastianm@exploratorium.edu

Rupal Jain, MIT Media Lab, rupal@media.mit.edu

Natalie Rusk, MIT Media Lab, nrusk@media.mit.edu

Caitlin Martin, ckMartin Consulting, ckmartin.consulting@gmail.com

Abstract

We will share insights, resources, and tools from collaborative efforts between researchers and educators in a multi-institutional and design-based research practice partnership that we have called *Facilitating Computational Tinkering*. These partners include the Tinkering Studio at the Exploratorium, the ideaLAB makerspace network at Denver Public Library, the Lifelong Kindergarten research group at MIT, and the Creative Communities research group at University of Colorado Boulder, along with a network of community-based organizations around the world. Our shared work aims to make visible the complexity of engaging in a community-based research practice partnership work across multiple levels including analysis of existing infrastructural supports and constraints, the iterative and collaborative design of activities, and the development of equity-oriented professional development for educators.

Introduction

In this collaborative initiative, we seek to actively engage learners in computational thinking through *computational tinkering*. Resnick and Rosenbaum (2013) argue, “the tinkering approach is characterized by playful, experimental, iterative style of engagement, in which makers are continually assessing their goals, exploring new paths, and imagining new possibilities.” Our approach to computational tinkering aims to broaden the styles of engaging with computing, providing a more social, physical, and cross-disciplinary alternative to more dominant ways of teaching computing that focus on planning and optimization of a single solution (Turkle & Papert, 1991; Resnick & Rusk, 2019).

We locate our collaborative work within making and tinkering spaces, which have spread widely across informal learning organizations such as museums, libraries, and community centers. Researchers have documented the potential of these spaces to support expansive and equitable learning experiences that build on family and community knowledge (Barton & Tan, 2018; Barton, Tan, & Greenberg, 2017). Facilitators play important roles in enabling such learning experiences. While there has been extensive research on making and tinkering spaces, much of this research focuses on participant experiences or program design with very limited research and design attention paid to facilitators and their practices. Their work practices not only include supporting participant learning, but also logistics, partnership building, and design work to adapt or develop new experiences for participants that respond to the changing social, cultural, and political dynamics of their communities (Hladik, 2022).

Presenters in this symposium represent different efforts across *the Facilitating Computational Tinkering (FCT)* project,

specifically highlighting our collaborative design work across time between educators and researchers. These partners include the Tinkering Studio at the Exploratorium, Denver Public Library, the Lifelong Kindergarten research group at MIT, and the Creative Communities research group at University of Colorado Boulder, along with a network of community-based organizations around the world. Our shared work recognizes the important role and work of informal learning educators, or facilitators, in supporting creative and equitable learning experiences for youth and families – as well as the importance of providing facilitators with needed professional development, resources, and time to challenge and deepen their facilitation practices to continue their equity-oriented work (Vossoughi et. al, 2016).

Papers 1, 2, and 3 share stories from our “R&D threads,” or our iterative, collaborative, and nonlinear design process that interweave materials and ideas that converge and diverge into new threads. Papers 1, 2, and 3 present the development of an activity, a resource for facilitators, and a new creative coding app, respectively, in collaboration with educators around the world, while Papers 4 and 5 share our research that documents our design process. Paper 4 expands on theories of infrastructuring related to educators implementing educational innovations and Paper 5 highlights the process of negotiating values and goals that emerged within our multi-organization design-based research-practice partnership. Across these papers we will share design principles and frameworks that have emerged and have broader implications for the FabLearn/constructionism community.

This symposium contains implications for initiatives intending to support collaborations across academic and community-based organizations. Papers 1 and 2 makes visible the work of educators that includes design work and critical reflections on practice, critical process work that is often left out of academic publications. Paper 3 is an example of engaging with community partners in a design process and recognizes the important and situated knowledge of educators that can inform the design of new technologies and learning experiences. While Papers 2 and 5 share academic research, they also demonstrate the ways that academic research can translate into actionable resources and tools for educators within and beyond a collaborative design project. Paper 4 advances the conversation around infrastructuring by proposing a new theory for understanding the interplay of design work and infrastructures in informal learning environments.

Presented Papers

Tinkering studio R&D process: Guided by learners, materials, and facilitators (Matsumoto, Martin)

At the Tinkering Studio, we practice a collaborative activity development and idea generation process that involves our team, community educators, and workshop participants. This approach unfolds over the course of multiple workshop sessions, during which facilitators take roles as thinking partners, learners, and activity designers to co-create a computational tinkering experience. By engaging in a continuous cycle of planning, facilitating, and reflecting together, we co-develop open-ended experiences that support facilitators in their role as designers and empower them to adapt the activity to their specific contexts.

In our presentation, we will share case studies that illustrate our collaborative activity development process. Specifically, we will focus on the theme of creating animated stories on hand-held devices in a cardboard environment and demonstrate how ideas develop among a distributed group of educators and designers.



Figure 1: Examples of computational tinkering projects bridging digital coding with physical materials. At an internal R&D session, cardboard phone cases and overlays are created to expand and support digital storytelling.

The Tinkering Studio shares a strong interest in exploring the intersection of physical and digital elements. In line with this vision, we have been experimenting with embedding a device with the OctoStudio coding app (Paper 3) into a book's page, giving a physical nature to a coding platform. Additionally, we used layered cardboard overlays as physical materials to enrich and support the narrative. This idea evolved into a more interactive and collaborative project when we shared our half-baked idea with a group of educators. Instead of just using cardboard on a digital screen, we designed a large-scale house installation featuring multiple windows with embedded digital screens. In this new concept, learners are invited to participate by designing their own unique views for each window.



Figure 2: The concept of the cardboard overlay is further explored on the museum floor with visitors by integrating the phone into a large-scale cardboard installation.

In this presentation, we will demonstrate how these prototyping sessions with visitors and educators serve as valuable tools for refining and developing the next iteration of the learning experience. We will share case studies documenting learner's and facilitator's experiences in the environment to illustrate core principles of our R&D process.

- Iterating on the activity in response to our observations of visitor facilitator interaction (e.g. from cardboard frames to immersive cardboard environments)
- Providing multiple entry points with open-ended prompts for learners with different backgrounds and interests (by, for example, using a familiar physical material, like cardboard, or a familiar concept, like creating objects for an environment, combined with computational materials)

Central to this approach is providing learning designers/facilitators with the agency to remix the activity based on their specific contexts, while still ensuring the core pedagogical values remain intact. This means that the learning experience can be adapted to different settings while still maintaining its core principles. This reciprocal nature in co-constructing computational tinkering activities fosters a more inclusive and adaptable learning environment.

What equity means to me: Supporting facilitators to critically reflect on their conceptions of equity (Roque, Hayden, Moreno)

Facilitators in informal STEM environments make key decisions at the micro (moment to moment interactions) to meso (how space is designed, how they recruit people, how they curate activities) (e.g. Vossoughi et al., 2021) that can influence who and how people can participate. Without careful and consistent effort towards equity, these decisions can risk the reproduction of existing inequalities. Through research interviews and “shareback” discussions with educators (Roque, Haldik, Hayden, & Moreno, 2023), our team designed and developed a zine for educators to scaffold their reflections and conversations with colleagues to critically reflect and deepen their understanding and equity-oriented work.

We interviewed 16 facilitators from three informal learning organizations that included a science museum, makerspaces in a library system, and community-based technology centers for youth. All facilitators were based in the United States and represented 5 states. During 90-minute virtual interviews, we asked participants to share a computing-based activity that they had implemented in their space. We also asked questions about their background, goals, and how they considered equity in their practice. In the first round of thematic analysis, we noticed the ways that equity was emerging implicitly and explicitly in how they designed activities. To focus our analysis, we used a framework of questions inspired by Shirin Vossoughi (2017), where she argues that out-of-school spaces committed to addressing issues of equity must ask: “Access to what? For whom? Toward what ends? And based on whose values?”

After preliminary analysis, our research team conducted 60-90 minute, virtual “share-backs” where we shared and discussed what we learned with interviewees and their colleagues. From our analysis, we found that spaces had different stances on their equity work. For example, the network of library makerspaces focused on providing free and open access to their resources. Facilitators at the community-based tech centers focused on being culturally responsive to the communities they serve. In share-backs with educators, we highlighted different tensions within their stances. For example, when considering “for whom,” library facilitators had commitments to serve whoever came into their spaces, whereas facilitators in the community technology centers focused on developing relationships specifically with teens in their communities — such differences enabled different possibilities and challenges for equity-oriented work.

These share-backs led to the design of an interactive zine to scaffold these conversations about equity. We shared this zine with facilitators across these organizations and beyond to engage in and provide feedback. From our conversations, facilitators reported more concrete and explicit conversations with their peers about their equity-oriented work. As facilitators continue to incorporate computing/STEM in innovative ways into their spaces, there is an opportunity to interrupt dominant scripts of what “counts” as computing, who participates, and how someone engages with computing to more meaningfully support groups who have been marginalized from traditional computing spaces. We also see this work as contributing to ways that academics might make their research more actionable for practitioners and shows a model of professional development for facilitators wanting to expand their conceptions of what equity looks like in their spaces.

Octostudio: Developing a new tool for computational tinkering with community-based educators around the world (Rusk, Jain)

Community-based educators who work with youth have developed a variety of practices to support youth agency and

learning to express their interests and ideas (Kafai et al., 2009; Martin et al., 2016). These facilitation practices often involve working around limitations in existing technological tools, which typically are not designed for use by young people in marginalized communities (Roque et al., 2021).

OctoStudio is a new mobile app designed to support young people creating projects that they find personally and culturally meaningful (see Figure 3). The OctoStudio project was sparked by requests from educators working within Brazil, India, South Africa, Uganda, and other regions to provide opportunities for youth in their communities to make use of the increasing availability of mobile phones for creative expression and computational participation. In this presentation, we will share how the iterative design of the OctoStudio app is responding to practices community-based educators have developed around the needs and interests of youth in their communities, as well as constraints and affordances in locally available devices and networking infrastructure.

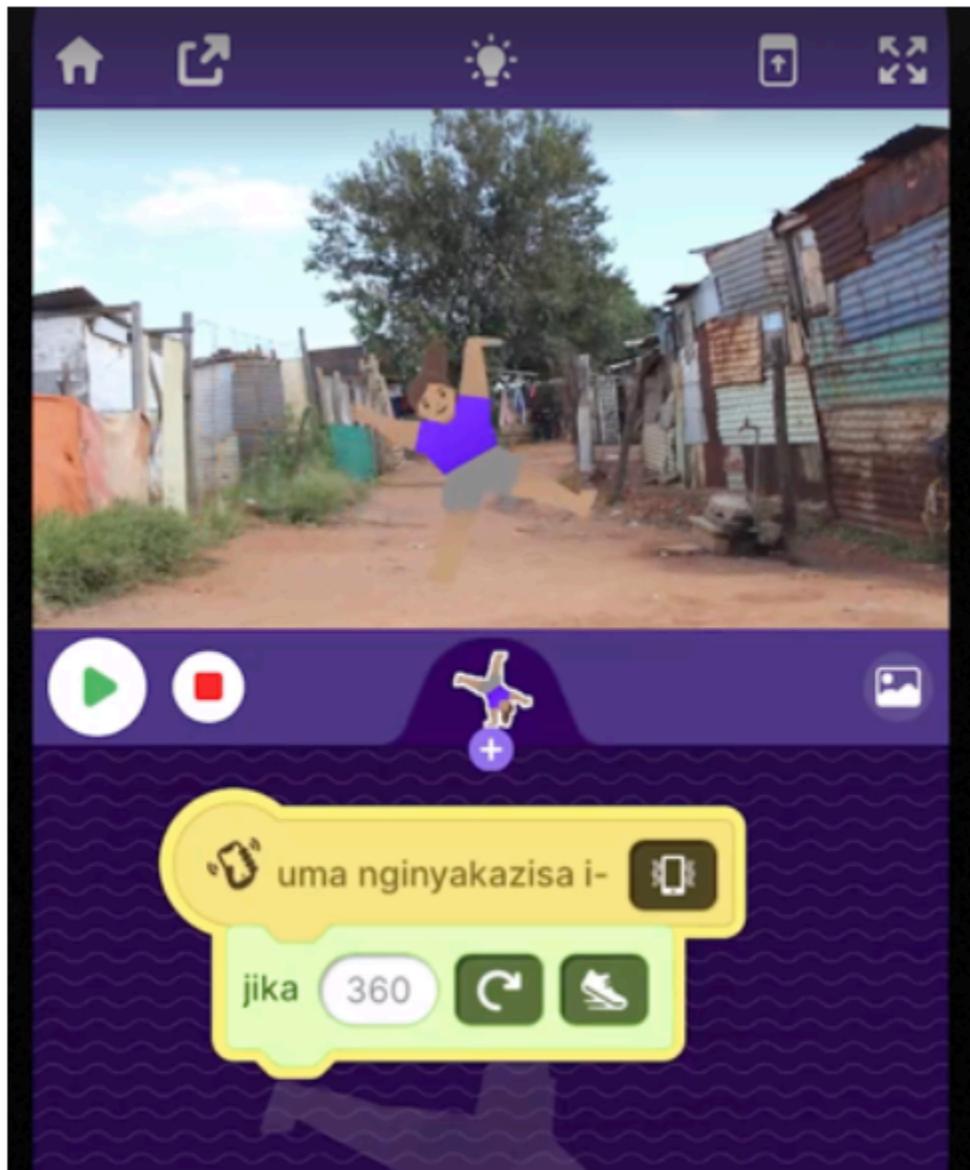


Figure 3: Example of an OctoStudio project with a backdrop contributed by an educational partner in South Africa

Community-based partners have shaped the iterative design of the app by exchanging ideas relevant to their local context, trying out the app in their communities, and participating in reflection and design discussions with each other and our university-based development team. Partners have been sharing values, practices, knowledge, experiences, and resources that influence the design (Bang & Vossoughi, 2016). Data collection to understand this dynamic process includes thematic analysis of virtual sessions with partners to understand observations and experiences, documentation of iterative versions of the app, and intermediary representations tracing the ways that partner feedback has shaped design decisions.

Although OctoStudio builds on previous work developing block-based coding environments, there are important differences. For example, the set of coding blocks and user interface have been designed to make it easier for beginners to learn through tinkering. Each coding block has both text and an icon to support learners of different language and literacy abilities to recognize and understand the function of each block. The coding blocks offer a variety of physical sensors and outputs that are widely available on a broad variety of phones – enabling learners to create novel projects that they can interact with (e.g. by shaking or tilting their mobile phone). The app is designed so that all creating and saving of projects takes place offline, without requiring any internet connectivity. Based on partner feedback, we have also prioritized making projects easy to share with family and friends, supporting screen recording videos of their creations without use of data.

In the symposium, we will share insights and examples from global partners that illustrate how they have been using OctoStudio to support computational tinkering in their communities. The app is currently in alpha testing by partners, and is planned for public release internationally in October 2023, the same month as the conference. This work illustrates how developing collaboration with community-based educators through iterative design cycles can provide important insights into local infrastructuring practices and shape the development of creative tools that support more equitable engagement and culturally-sustaining participation by youth, families, and educators across marginalized communities.

Lines of infrastructure: Revealing educators' infrastructuring practices across design implementations (Hayden, Moreno, Ruppert, Roque)

In efforts to build transformative informal STEM learning environments, we must consider how innovative educational practices and tools are adaptable, sustainable, and equitable. Studying infrastructure allows us to attend to the invisibilized and relational work at play within local systems, practices, and environments (Star, 1999), which has implications for how we can effectively design educational practices and tools. Our work continues to build on these theoretical conceptions of infrastructure in design work by emphasizing the dynamic process of infrastructure work that takes place to make innovations sustainable in informal STEM environments.

In this paper, we propose “lines of infrastructure.” Based, in part, on Azevedo’s “lines of practice” (2011), lines of infrastructure highlights the dynamic, distinctive, recurrent pattern of infrastructuring that emerges across related design implementations. A line of infrastructure reveals an infrastructuring cycle across implementations, and how previous implementations inform each other– even if the activity, tools and materials, or participants change. This paper extends our prior work which introduced a framework of six types of infrastructure that support the design and implementation of computational tinkering activities in informal STEM environments: institutional routines and resources, social and facilitation practices, institutional and facilitator values, facilitator expertise, tools and materials and physical space (Hayden, Hladik, & Roque, 2023). Based on collaborative design work with our partners, observations and field notes in their spaces and a grounded theory approach to analyzing our data, the theory of “lines of infrastructure” emerged.

We share one example of a line of infrastructure that emerged over a three-year period collaborating with a facilitator named Katie (pseudonym) that we are calling “material conscientiousness.” This line makes visible how during Katie’s initial interview (described in paper 2.2) as well as throughout the R&D of two separate workshops around computational tinkering activities, Katie is designing around a preference for environmentally friendly, accessible, and economic materials. This preference is both impacted by and impacts the infrastructure in the learning environment she works in and thus contributes to the sustainability of computational tinkering activities in her space. For example, Katie mentioned that upcycling is appreciated in her makerspace community. In co-designing a workshop for an activity called “scribbling machines,” this preference was surfaced as Katie expressed a desire to use more sustainable materials in the workshop, leveraging her network at the library branch to collect recycled food containers for the scribbling machine bodies and opting to replace the tape in the activity design with reusable velcro loops and rubbed bands as connectors. Katie’s value around material accessibility resulted in prioritizing activities that exemplify the potential for everyday materials to become objects to make with, and her economic concerns play into the decisions she makes around the use of consumable materials or expensive technology in activity design. Through this line we can make visible how Katie is infrastructuring across distinct types of infrastructure including facilitator and community values, tools and materials, and institutional resources.

The theory of “lines of infrastructure” points to the complexity in decision making and behind-the-scenes facilitator work that can play out across multiple collaborations, highlighting the important perspectives and design work of educators (Hladik et al., 2022). This work aims to expand our capacity to build equitable informal STEM learning environments by understanding how infrastructure can be considered and leveraged in the design and implementation of educational innovations. Our work builds on previous scholarship about infrastructures in formal learning environments (e.g. Penuel, 2019; Bielaczyc, 2013) to highlight that informal learning spaces have their own affordances and constraints that must be considered by researchers, designers, and practitioners in these spaces.

Setting values and intentions “in sponge”: Iterative value negotiation in multi-organization design collaborations (Martin, Hladik, Roque)

The negotiation of values and intentions is a key part of the design process (Ferrell et al., 2021) and this is especially true and complex in diverse teams, where tensions between various community discourses, goals, and values may emerge (Tabak, 2022). However, few studies deeply explore the process and tools of negotiation, especially in ways that embrace messiness, multiple directions, and creative exploration. In this symposium, we articulate the process of negotiating values and intentions that emerged within a multi-organizational, design-centered RPP to advance equity in informal computing education—a process that encourages ways to set things “in sponge” before they are set “in stone.” Our investigation uses Iversen et al’s (2012) framework to dive into the value negotiation process in an RPP. They suggest rough stages of emergence (values being brought to light), development (iterating and refining these values), and grounding (linking these values with the design artifact), though the process is by no means linear (Iversen et al., 2012).

Project team members include university researchers and designers, directors of informal learning spaces, informal learning facilitators, graduate students, and an external evaluator. Monthly all-team meetings involve discussion and activities to advance the goals of the project; monthly leadership team meetings address higher-level project planning needs; and smaller meetings happen as needed around project efforts and interests within and across sites. All meetings are virtual. Alongside these meetings, our team engages in ongoing research and development related to computational tinkering, both within and across sites. Documentation of our process includes running meeting notes with links to external documents and representations used or created in the meetings, a dedicated Slack channel with asynchronous conversation threads and pointers to related organizational efforts, and evaluation synthesis briefs.

Throughout the project process and documentation of artifacts, repetition has been key to moving forward and integrating values (overarching ideas considered integral to the project), principles (key ideas that guide design and facilitation), and intentions (specific outcomes and deliverables connected to those values). Namely, circling back to and through big ideas and developing multiple representations were ways to keep ideas flexible and expand them together over time. Our experience of Iversen et al's (2012) phases of emergence, development, and grounding has been highly iterative.

For example, when considering emergence through the project span, we have found it important to integrate proposed, organizational, and current sociopolitical values. Although project goals and intentions were articulated as part of the funded grant proposal (one form of emergence), we have continuously returned to them throughout various discussions, activities, and artifacts. Our values and intentions also emerged from each institution's previous research and design work, including facilitation frameworks, as well as existing computational tools that could be repurposed or expanded for this project. Finally, the sociopolitical context (i.e., George Floyd protests, anti-Asian violence, and growing nationalism in the US), as well as readings and activities related to equity and justice in education, influenced an emerging commitment to equity in our work. We continue to circle back to this idea of equity throughout the project, raising questions including "How can our values of equity and belonging inform our facilitation and design principles?" We believe that this repetition, rather than something to be done quickly (e.g., move fast and break things, a sentiment common in design industries), allowed us to (re)attend to the values and intentions that would ground the project.

This work to investigate process provides insights for others working on complex RPPs and encourages more detailed documentation of negotiating shared values and intentions. How can we plan for and fund these complex projects in ways that allow for the messiness and tensions within design collaborations, creating space for deep discussions and continuous iteration on the values that drive our work? How can we "set things in sponge" so that we can move forward with shared purpose and understanding, without "smoothing out" all the disagreements or tensions within the first few weeks or months of a project? And how can we document this process in ways that highlight multiple perspectives and change over time?

Symposium Format

We will have an interactive symposium that includes hands-on demos and posters. The chair (Roque) will introduce the symposium and presenters will give short presentations (10 mins). Next, participants can engage in demonstrations and posters highlighting our research and design process (35 mins). We hope this material, social, and intellectual engagement will spark discussions for both researchers, practitioners, and those that identify as both. Finally, we will conclude with a facilitated discussion by the chair and the panelists and invite questions and comments from participants (15 mins).

Acknowledgments

This material is based upon work supported by the National Science Foundation under Grant No. 2005764.

References

Bang, M., Faber, L., Gurneau, J., Marin, A., & Soto, C. (2016). Community-based design research: Learning across

generations and strategic transformations of institutional relations toward axiological innovations. *Mind, Culture, and Activity*, 23(1), 28–41.

Barton, A. C., Tan, E., & Greenberg, D. (2017). The makerspace movement: Sites of possibilities for equitable opportunities to engage underrepresented youth in STEM. *Teachers College Record*, 119(6), 1–44.

Calabrese Barton, A., & Tan, E. (2018). A longitudinal study of equity-oriented STEM-rich making among youth from historically marginalized communities. *American Educational Research Journal*, 55(4), 761–800.

Farrell, C. C., Penuel, W. R., Coburn, C. E., Daniel, J., & Steup, L. (2021). Research-Practice Partnerships in education: The state of the field.

Hayden, R; Hladik, S; Roque, R (2023). Expanding and Focusing Infrastructuring Analysis for Informal STEM Education. *Proceedings of the International Conference of the Learning Sciences (ICLS)*.

Hladik, S., Sengupta, P., & Shanahan, M. C. (2023). Museum facilitator practice as infrastructure design work for public computing. *Cognition and Instruction*, 41(2), 248–289.

Iversen, O. S., Halskov, K., & Leong, T. W. (2012). Values-led participatory design. *CoDesign*, 8(2-3), 87–103.

Kafai, Y., Peppler, K., & Chapman, R. (2009). The computer clubhouse: A place for youth.

Martin, C. K., Sandherr, J., Boytor, E., Nacu, D., Pinkard, N. D., & Erete, S. (2016). Brokering learning between on-and offline environments: Social and technical practices. DML Learning Hub.

Penuel, W. R. (2019). Infrastructuring as a practice of design-based research for supporting and studying equitable implementation and sustainability of innovations. *Journal of the Learning Sciences*, 28(4-5), 659–677.

Resnick, M., & Rosenbaum, E. (2013). Designing for tinkerability. In *Design, make, play* (pp. 163–181). Routledge.

Roque, R., Hladik, S., Moreno, C., & Hayden, R. (2023) Surfacing the complex conceptions of equity across making and tinkering spaces. *Information and Learning Sciences*.

Roque, R., Tamashiro, M. A., McConnell, K., & Granados, J. (2021). Opportunities and limitations of construction kits in culturally responsive computing contexts: lessons from ScratchJr and family creative learning. In *Proceedings of ACM Interaction Design and Children* (pp. 246–256).

Star, S. L. (1999). The ethnography of infrastructure. *American Behavioral Scientist*, 43(3), 377–391.

Tabak, I. (2022). Productive tension in research practice partnerships: Where substance and politics intersect. *Cognition and Instruction*, 40(1), 171–177.

Turkle, S., & Papert, S. (1990). Epistemological pluralism: Styles and voices within the computer culture. *Signs: Journal of women in culture and society*, 16(1), 128–157.

Vossoughi, S. (2017). Access and equity in out-of-school learning. *SAGE encyclopedia of out-of-school learning*, 1–5.

Vossoughi, S., Davis, N. R., Jackson, A., Echevarria, R., Muñoz, A., & Escudé, M. (2021). Beyond the binary of adult versus child centered learning: Pedagogies of joint activity in the context of making. *Cognition and Instruction*, 39(3), 211–241.

Vossoughi, S., Hooper, P. K., & Escudé, M. (2016). Making through the lens of culture and power: Toward transformative visions for educational equity. *Harvard Educational Review*, 86(2), 206–232.

POSTERS

A novel generic app for mobile devices that utilizes Augmented Reality (AR) technology to create, share and deliver constructionist multimedia learning scenarios

CARLA – introducing a novel constructionist AR learning app

Harald Burgsteiner, University for Teacher Education Styria, harald.burgsteiner@phst.at

Abstract

CARLA is a novel app that utilizes Augmented Reality (AR) technology to create, share and deliver constructionistic multimedia learning scenarios (images, videos, sounds, podcasts, 3D models with and without animations, and 360° pictures). The app allows users to experiment and learn in an interactive and immersive manner using AR scenes (grouped in scenarios) that can be accessed through a smartphone or tablet and shared with other users and to publish them to a wider audience through various social media platforms. Overall, the CARLA app represents an advance in the field of AR-based learning, providing users with a powerful tool for creating and sharing AR scenes and scenarios that facilitate learning in a fun and engaging manner. First preliminary results demonstrate that the use of AR technology enhances the learning experience by providing an engaging and immersive environment for learning and that the ability to create their own AR learning material and share it among colleagues motivates teachers to use AR in school more frequently.

Introduction

Augmented Reality (AR) enables users to interact with virtual multimedia objects in the real world, providing an immersive and engaging learning environment. Previous research has shown that AR can enhance students' engagement and understanding of complex concepts [1]. The use of AR in education can increase motivation, engagement and learner responses when the learning scenarios and the included multimedia material are carefully designed [2, 3]. Both, the necessity of special purpose hardware and not free of charge teaching material hinders the wide use of AR in education. Mobile devices with its sensors, displays and connectivity promise to be an affordable alternative. Most of the apps that are available in the school context lack the ability to create and use your own created content (e.g., has to be bought together with schoolbooks or as separate bundles). Apart from the important financial aspect, there are several other reasons why it is crucial for students, teachers or educators to be able to create their own AR content, like customization and flexibility of the material to the specific needs and interests of their students, creating interactive and engaging AR experiences, creativity to come up with new and creative ways to use AR to enhance the learning experience, and involvement and inclusion, so students can create their own content to present and enhance their understanding of specific topics thereby additionally gaining digital skills and competencies.

Basic Concepts of the Application CARLA

The new and free app called CARLA which has recently be developed uses AR technology for learning purposes. The app provides an interactive and engaging learning experience that allows users to create and share AR scenes that can be accessed e.g., through a smartphone or tablet. The main technology behind CARLA is image-based scene recognition. It uses so called trigger images to initiate certain responses on the device being used. Currently these responses can include static images, videos, YouTube videos, short audio data, podcasts, and 3D objects. CARLA uses the concept of 'AR scenes' and 'AR scenarios' to distinguish between single AR experiences and a series of AR interactions that are logically or semantically connected. Packing scenes into scenarios enables educators to rapidly spread content to students by publishing a specific QR code generated by the app. Examples of a trigger image, a QR code and a possible self-created AV media (3D object built through photogrammetry from images taken by the students) can be seen in Figure 1 respectively.



Figure 1: Example of a trigger image together with its corresponding QR code which can be used to share AR scenes and scenarios between people. By scanning the QR with the CARLA app users get access to all media contained in the scene. The image to the left triggers in this case a short audio message, the screenshot on the right shows a scene with a photogrammetry created 3D model.

When creating a new AR scene, educators first define a trigger image and an audio-visual experience (another image, a video, a 3D model or even a podcast) by selecting and entering all necessary data. Once the scene is created it can be uploaded to the users' own web server after which a QR code is displayed that can in turn directly be shared. Due to this simplicity, it is also possible to re-use arbitrary published scenes in different (learning) scenarios.

Discussion and Outlook

CARLA enables teachers and students to easily create AR scenes, thus helping them to express their ideas and concepts of certain learning content: simply describe the content, take a picture for the trigger image (or select an existing one from the file browser), select a suitable AV media and automatically upload the data. The app generates a QR code to share the scene or scenario with other schools worldwide. Additionally, by abiding Creative Commons licenses the content can also be remixed and uploaded again. CARLA is currently only available for iOS and iPadOS devices (an Android version will follow). The availability of AR glasses will enable CARLA to be used hands-free, which allows more interactions with content. Future features include gamification elements of AR scenarios and connections to learning management systems.

References

1. Dunleavy, M., Dede, C., & Mitchell, R. (2009). Affordances and limitations of immersive participatory augmented reality simulations for teaching and learning. *Journal of Science Education and Technology*, 18(1), 7-22.
2. Garzón, Juan & Acevedo, Juan (2019). Meta-analysis of the impact of Augmented Reality on students' learning gains. *Educational Research Review*, Volume 27, pp. 244-260, ISSN 1747-938X, <https://doi.org/10.1016/j.edurev.2019.04.001>.
3. Chang, Hsin-Yi, Binali, Theerapong, Liang, Jyh-Chong, Chiou, Guo-Li, Cheng, Kun-Hung, Lee, Silvia Wen-Yu & Tsai, Chin-Chung (2022). Ten years of augmented reality in education: A meta-analysis of (quasi-) experimental studies to investigate the impact. *Computers & Education*, Volume 191, ISSN 0360-1315, <https://doi.org/10.1016/j.compedu.2022.104641>.

Leveraging app making as a constructionist tool for developing Indigenous Hawaiian youth's rightful presence Integrating geology, geography, and rightful presence

Colby Tofel-Grehl, Utah State University, Colby.tg@usu.edu

Tyler Hansen, Utah State University, Tyler.Hansen@usu.edu

Abstract

On the big island of Hawaii, youth experience many curricular materials that lack localized and culturally relevant meaning. Young people on the island find themselves disconnected from STEM due to community discontent at the tension between local community and science on the land. This paper focuses on a summer school experience for rural Hawaiian youth as they engaged in app making as a tool for advocating for local land rights and Hawaii focused learning. This poster showcases the ways that youth made sense of their own agency within their community while learning about the wahi pana, or sacred spaces on the island. Findings indicate engagement with local geology and geography education paired with culturally responsive computing fostered youth's sense of rightful presence [1] within a previously perceived hostile STEM learning.

Introduction

Between Hawaiians and tourists there exists a dynamic tension of disdain and need. The island's economy, brutalized by the COVID-19 pandemic, is built around tourism. However, more and more, rather than a mutually beneficial relationship, there exists growing tension between Hawaiians and the people that visit. For example, landowners and stewards of the public lands near the Waipio valley report highly contentious interactions with tourists in which tourist demands conflict with local land rights [2].

Within this context of rising tourist vandalism and disrespecting of the wahi pana, this poster shares an effort to foster student agency through the development of a culturally and geographically responsive curriculum. Specifically, this paper focuses on student experiences designing and building "Advocacy Apps," app-based programs intended to inform and guide tourists in the appropriate ways to engage and behave within Hawaii's sacred spaces.

Background and Theoretical Framing

This paper is framed by rightful presence [1]. Calabrese Barton & Tan define rightful presence as "legitimate membership in a classroom community because of who one is (not who one should be), in which the practices of that community work toward and support restructuring power dynamics toward more just ends through making injustice and social change visible" (p. 618). It is not merely the tolerance of non-dominant identities that is the goal of rightful presence;

rightfulness of presence requires youth to occupy the disciplinary space completely within the classroom space so that they are able to restructure, reimagine, and redesign the learning experience such that it is compatible with the complexity of their own multifaceted identities across communities and spaces. As we explored the ways students engaged their identities to advocate for their spaces, we asked the following question:

How do youth tackle the localized injustices of tourist behavior on Hawaii through engagement with app making?

Methods

This work engaged a grounded theory [3] approach to data analysis. Data were analyzed through open coding done in two rounds. During the first round of coding both of the coders explored the data for trends in student engagement. In the second round of coding, coders collaboratively developed themes generated from earlier codes. Data for this analysis included observational fieldnotes, students' artifacts, and interview transcripts.

Summer School and Teacher. During the summer of 2021, 10 students at the Hau'oli Middle School (HMS) engaged in a STEM, Culture and Community class. The class was co-designed between the lead author and one of the school's teachers. The teacher, Mrs. Awesomesauce, is national board certified and has been teaching at the school for 8 years. Previously, she taught for 15 years on the mainland. The class spanned two weeks during the summer of 2021. Class met for four hours per day and included two place-based field trips to sacred sites on the island.

The Project. Advocacy apps builds off two place-based learning fieldtrips. While on fieldtrips, youth interviewed land caretakers to understand the needs of the community related to tourist behavior. Youth then reflected on the importance of advocating for Hawaii when tourists were such a large group. Youth designed, constructed, and coded apps to guide visitors in their behavior.

Students. A total of ten students took the summer school class. Class size was limited due to the COVID-19 pandemic.

Findings

Findings indicate that students engaged eagerly with advocating for their local spaces. Collecting data from the local land stewards scaffolded a meaningful appreciation for the lived reality of what dealing with difficult tourists looked and felt like. As seen in Figure 1, youth were concerned with what they perceived as abusive and mean behavior on the part of the tourists. Understanding the conflict contextualized and made meaningful the news reports students had observed. Furthermore, students felt empowered and rightfully present within their school space to engage through the construction of apps to engage in the protection of their lands and their community. As one student noted "this is cool. Maybe I can help fix things." By engaging youth in owning and protecting the spaces in which they live, the advocacy apps project offered great potential for improving youth rightful presence and engagement in classroom learning.

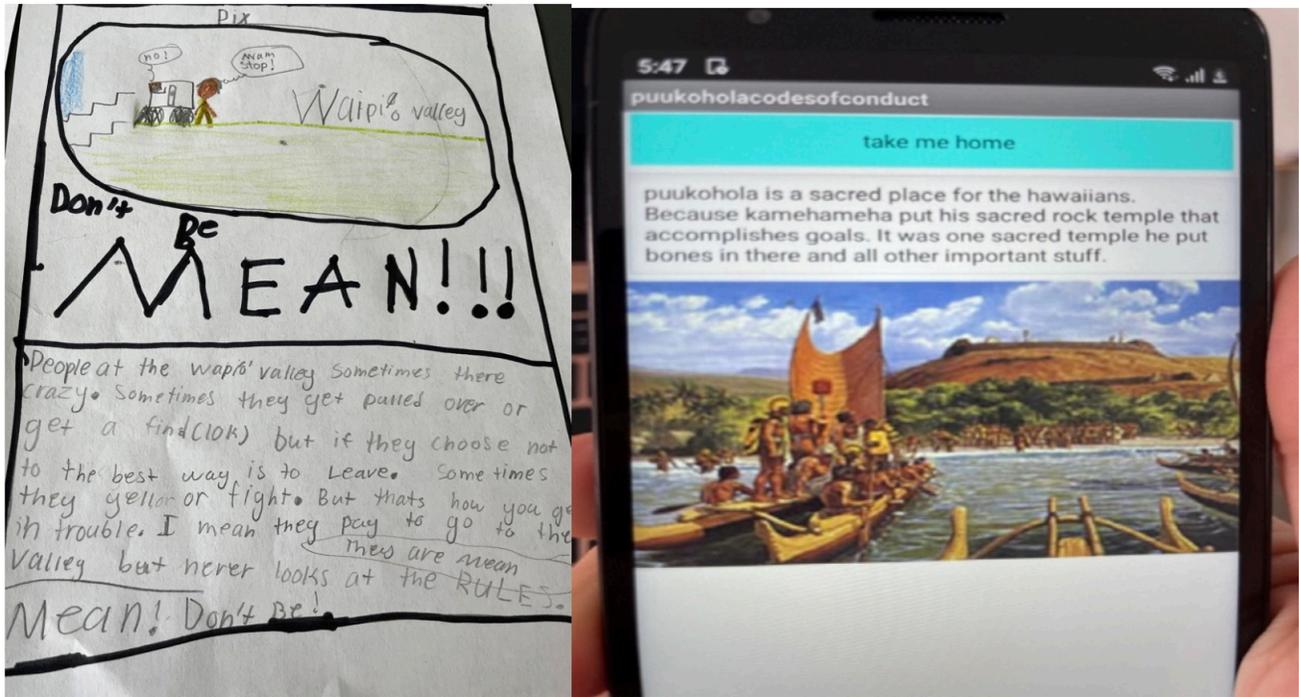


Figure 1. Examples of youth design and built advocacy app pages.

By engaging in app making youth were both educated and inspired to address the rising conflict across the island. Further exploration of data can inform more broadly about the mechanisms and systems that inform the development of rightful presence in youth and particularly indigenous youth. While this poster's sharing is brief, it indicates the potential value of app making as an important tool for constructionist educators in improving youth interest and engagement within and across curricular content.

Acknowledgments

We gratefully acknowledge the support of the National Science Foundation through award # 1942500. Any opinions, findings, and conclusions expressed in these materials are those of the authors and do not reflect the views of the NSF.

References

1. Calabrese Barton, A., & Tan, E. (2019). Designing for rightful presence in STEM: The role of making present practices. *Journal of the Learning Sciences*, 28(4-5), 616-658.
2. Tofel-Grehl, C. (2023). If science doesn't care about me why should I care about it?: An Indigenous Hawaiian student's experience of community science in building science belonging. *Journal of Research in Science Teaching*.
3. Charmaz, K. (2006). *Constructing grounded theory: A practical guide through qualitative analysis*. sage.

Scaffolding School-Based Maker Education

Investigating Expert Teachers' Designs and Student Learning using a Multiple Case Study Approach

Yuval Segev, University of Haifa, yuval.segev@edtech.haifa.ac.il

Dr. Yotam Hod, University of Haifa, yotamhod24@gmail.com

Abstract

This paper presents initial research examining the way expert maker educators in Israel's formal education system scaffold student learning. Using a multiple case study approach, we are currently investigating (a) the main capacities that expert maker educators scaffold in learning designs implemented in classroom settings; and (b) the way these scaffolds support students' learning. Our preliminary findings suggest that expert school-based maker educators are often driven by high-level goals related to the competencies they aim for their students to develop. They embed and organize a wide variety of scaffolds, some of which are innovative, around these goals. We are currently working to provide an in-depth mapping of these scaffolds and elucidate how they support students' growth. Understanding these dynamics between scaffolding practices and learning can enrich current conceptual understandings about maker education pedagogies as well as practical understandings about how maker education can be better implemented in schools.

Challenges and Approaches to School-Based Maker Education

While scholarship about maker education has described its potentially positive impact on students and schooling, relatively little has been researched and written about how maker education is or should be practically conducted in formal educational settings. Notably, there is a significant lack of knowledge about maker education as a pedagogy [1]. It is arguably common practice to neglect pedagogical design by assuming a techno-centric and hands-off approach to pedagogy and instruction in maker education [2]. This lack of knowledge or attention to the pedagogical design of maker education has often resulted in either neglect of pedagogical design or over-scripting maker activities [2], falling short of the celebrated promises about learning by making. Facing this gap in both conceptual and practical facets of maker education, recent scholarship is showing a rise in interest in how learning happens in maker education programs and how to best support it [3, 4]. The aim of this research is to advance knowledge and understanding about the ways maker learning can be supported, specifically in formal school settings.

We contend that advancing knowledge on how to support students' learning in maker education requires clarifying what capacities are the goals of instruction and what scaffolds can be applied to advance them. We draw on Reiser and Tabak's [2014] definition of scaffolding as the support provided to learners in complex learning tasks in which novices often participate in developmentally-appropriate versions of activities usually performed by experts in the field. Scaffolding both (a) enables participation in a practice currently beyond learners' capacities, and (b) fosters learners' growth in their current capacity. We build on this notion of scaffolding to inquire specifically into the actions and designs created by expert maker educators in support of student's growth in specific capacities.

This research focuses on expert maker educators within Israel's formal educational system. The Israeli maker education

ecology shares similarities with the global ecology, making it a good exemplar for research. In Israel, as is common in the world, maker education has developed and has spread in a 'bottom up' way by educators and entrepreneurs with no overarching entity responsible for its design and implementation [6]. Thus, the Israeli maker education ecology hosts a large variety of independently developed maker education programs showcasing a variety of learning designs that include various approaches to scaffolding. Acknowledging that maker educators are the knowledge experts on maker learning designs [7], this research will investigate maker educators' views and practices of maker learning scaffolds. We focus on expert maker educators – those with many years of experience, who have demonstrated mastery in their own settings, and who have taken mentoring positions – so that we can learn from the best practices in this unique ecology.

Methods

We are carrying out a multiple case study research design [8] of five expert maker educator's programs in Israeli schools. We will build on Sandoval's [2014] conjecture mapping as a grammar for articulating core scaffolds in the educators learning designs and their role as mediators of learning. Educator's intended designs will be gathered using semi-structured interviews. Evidence of the embodied designs, the use of scaffolds by educators and their use by students will be gathered using ethnographic methods, and will be documented using researcher's field notes, photographs of student's projects, digital learning artifacts and student interviews.

Findings and Discussion

Thus far, we have collected partial data from three (out of five) of the maker education programs we intend to study. Initial findings show that expert educators have elaborated learning designs including numerous scaffoldings to support their students' advancements in the capacities that educators view as central to maker learning. These scaffolds are usually developed independently by the educators and have been improved iteratively over the educator's years of practice. Moreover, our preliminary findings suggest that expert school-based maker educators are often driven by high-level goals related to the competencies they aim for their students to develop. They embed and organize a wide variety of scaffolds, some of which are innovative, around these goals.

We hope this research can make a contribution to both practical and conceptual understanding of scaffolding for maker learning building on Bereiter's [2014] concept of principled practical knowledge as a means to enable innovation focused on practical implementation in educational fields. Understanding the dynamics between scaffolding practices and learning can enrich current conceptual understandings about maker education pedagogies as well as practical understandings about how maker education can be better implemented in schools.

References

1. Anna-Lena Godhe, Patrik Lilja, and Neil Selwyn. 2019. Making sense of making: critical issues in the integration of maker education into schools. *Technology, Pedagogy and Education*, 28, 3 (2019), 317-328.
2. Fabio Campos, Tatiana Soster, and Paulo Blikstein. 2019. Sorry, I Was in Teacher Mode Today. *Proceedings of FabLearn 2019* (2019), 96-103.
3. Shirin Vossoughi, Natalie R. Davis, Ava Jackson, Ruben Echevarria, Arturo Muñoz, and Meg Escudé. 2021. Beyond the Binary of Adult Versus Child Centered Learning: Pedagogies of Joint Activity in the Context of Making. *Cognition and Instruction* 39, 3 (2021), 211-241.

4. José Armando Valente and Paulo Blikstein. 2019. Maker education: Where is the knowledge construction? *Constructivist Foundations* 14,3 (2019), 252-262.
5. Brian J. Reiser and Iris Tabak. 2014. Scaffolding. *The Cambridge Handbook of the Learning Sciences* (2014), 44-62.
6. Paulo Blikstein. 2018. Maker Movement in Education: History and Prospects. *Springer International Handbooks of Education* (2018), 419-437.
7. Bronwyn Bevan, Jean J. Ryoo, Aaron Vanderwerff, Karen Wilkinson, and Mike Petrich. 2020. "I See Students Differently": Following the Lead of Maker Educators in Defining What Counts as Learning. *Frontiers in Education*, 5, (2020). <https://doi.org/10.3389/educ.2020.00121>
8. Robert K. Yin. 2009. *Case Study Research*. SAGE.
9. William Sandoval. 2014. Conjecture Mapping: An Approach to Systematic Educational Design Research. *Journal of the Learning Sciences* 23, 1, 18-36.
10. Carl Bereiter. 2014. Principled Practical Knowledge: Not a Bridge but a Ladder. *Journal of the Learning Sciences* 23, 1 (2014), 4-17

Teachers' facilitation of maker-centered activities

A framework for video analysis

Mariam O. Al Jabaly, University of Helsinki, mariam.aljabaly@helsinki.fi

Hanna E. Aarnio, Aalto University, hanna.aarnio@aalto.fi

Video analysis as a methodological approach has the potential to clarify the complex classroom interaction between teachers and students during maker-centered activities. However, the development of a systematic approach for analyzing teachers' actions in such context is still in its early phases. This poster presents a framework for analyzing teachers' facilitation of design activities. To explore longitudinal video data from a maker-centered project of two teachers and two groups of students (n=6), we adapted the Making-Process-Rug method, originally intended to capture students' design actions. We further developed the method to involve both students' design actions and teachers' verbal and embodied facilitation actions. The qualitative video analysis revealed differences in types and intensity of teachers' facilitation in the different stages of the making process.

In maker-centered activities, students learn by collaborative designing and making of products and artifacts, facilitated by teachers [5]. Facilitation is a joint activity between teachers and students: besides direct support for learning, it includes pedagogical talk, listening, and embodied assistance [7]. To clarify this kind of complex classroom interaction, video research has been suggested as an effective methodological approach [1, 6]. Video data has been applied to study the making process [2, 4, 7], but there are not many systematic ways of exploring related teachers' facilitation in the context of formal education. The Making-Process-Rug method enables visualizing the entire making process, but its current applications have focused on analyzing students' design actions [3, 4]. The aim of this poster is to present a framework for analyzing teacher's facilitation of maker-centered activities. Particularly, this study explores what kind of facilitation is included in a maker-centered board game design project. The poster presents a visualization of the students' and teachers' actions in the beginning, middle, and end stages of the making process.

This study applies longitudinal video data from a maker-centered project of two teachers and two groups of students (n=6). The data were collected in Spring 2021 in a primary school in Southern Finland. The recordings covered 10 learning sessions (~40-45 hours). For this poster, we chose three learning sessions (~8 hours) from the beginning, middle, and end stages of the making process to give an overview about the whole project. In the project, the students' task was to create their own board game that included three types of materials (textile, wood, and 3D printed objects). The project was implemented by experienced craft teachers during the sixth graders' (12-13 years old) weekly craft lessons.

To analyze the data, we adapted the Making-Process-Rug method, which was originally developed to capture students' verbal and embodied design actions [4]. For the current study, we further developed the method to also involve teachers' verbal and embodied facilitation actions. Developing the framework was collaborative and iterative, and it included adding, combining, and refining codes. After reaching a mutual understanding about the codes, the final framework was utilized to recode the three sessions. The resulted coding is visualized with the Making-Process-Rug presented in the poster.

The preliminary results show that the teachers' facilitation of the two student groups was diverse and included both verbal and embodied actions. In total, there were 15 types of facilitation actions included in the making process. The teachers' facilitation differed both in terms of its types and intensity between the three learning sessions. The facilitation actions for the student groups were personalized in all sessions. At the beginning of the making process, facilitation was emphasized more than in the middle or the end stages. The differences between the two groups in intensity of facilitation emerged mainly in the middle of the process.

At the beginning of the making process, the student groups ideated the board game and documented their ideas. Facilitation for the groups focused on organizing the students' working process and supporting the ideation of the game. In the middle of the process, the groups redefined their ideas and sketched the design of their games. For Group 1, the teachers' facilitation focused on organizing the working process and discussing the manufacturing. For Group 2, the teachers supported the analysis of the design situation. At this point, facilitation was more intensive for Group 1 than for Group 2. At the end of the process, the students were discussing about manufacturing and making the board game. The teachers primarily organized the working process for Group 1 and discussed the manufacturing with Group 2.

Finally, by developing the Making-Process-Rug method [3, 4], our framework presents a novel, systematic way for analyzing and visualizing the teachers' facilitation of the making process. Having such a comprehensive visualization enables researchers to make accurate decisions on what episodes to choose for further analysis. As for the teachers applying maker-centered activities, the Rugs provide detailed insight about the nature of the making process and its facilitation.

References

1. Derry, S. J., Pea, R. D., Barron, B., Engle, R. A., Erickson, F., Goldman, R., Hall, R., Koschmann, T., Lemke, J. L., Sherin, M. G., & Sherin, B. L. (2010). Conducting video research in the Learning Sciences: Guidance on selection, analysis, technology, and ethics. *Journal of the Learning Sciences*, 19(1), 3–53. <https://doi.org/10.1080/10508400903452884>
2. Gutwill, J. P., Hido, N., & Sindorf, L. (2015). Research to practice: Observing learning in tinkering activities. *Curator: The Museum Journal*, 58(2), 151–168. <https://doi.org/10.1111/cura.12105>
3. Paavola, T., Kangas, K., Kokko, S., Riikonen, S., Mehto, V., Hakkarainen, K., & Seitamaa-Hakkarainen, P. (2021). Video data analysis for tracing emotional aspects of collaborative design and making processes. *Techne Series: Research in Sloyd Education and Craft Science A*, 21(3), 1–14. <https://doi.org/10.7577/TechneA.4053>
4. Riikonen, S., Seitamaa-Hakkarainen, P., & Hakkarainen, K. (2020). Bringing maker practices to school: Tracing discursive and materially mediated aspects of student teams' collaborative making processes. *International Journal of Computer-Supported Collaborative Learning*, 15, 319–349. <https://doi.org/10.1007/s11412-020-09330-6>
5. Seitamaa-Hakkarainen, P., Viilo, M., & Hakkarainen, K. (2010). Learning by collaborative designing: Technology-enhanced knowledge practices. *International Journal of Technology and Design Education*, 20, 109–136. <https://doi.org/10.1007/s10798-008-9066-4>
6. Sheridan, K. M., Halverson, E. R., Litts, B. K., Brahms, L., Jacobs-Priebe, L., & Owens, T. (2014). Learning in the making: A comparative case study of three makerspaces. *Harvard Educational Review*, 84(4), 505–556. <https://doi.org/10.17763/haer.84.4.brr34733723j648u>
7. Vossoughi, S., Davis, N. R., Jackson, A., Echevarria, R., Muñoz, A., & Escudé, M. (2021). Beyond the binary of adult versus child centered learning: Pedagogies of joint activity in the context of making. *Cognition and Instruction*, 39(3), 211–241. <https://doi.org/10.1080/07370008.2020.1860052>

Cobogó

A tool to empower play and make imagination visible

Mariana Lederman Edelstein, Teachers College, Columbia University, ml4794@tc.columbia.edu

Marcelo Falciano, Teachers College, Columbia University, maf2318@tc.columbia.edu

Blake Danzig, Teachers College, Columbia University, bpd2119@tc.columbia.edu

Nathan Holbert, Teachers College, Columbia University, holbert@tc.columbia.edu

Abstract

This poster presents the ongoing design and initial testing of a work-in-progress play kit, Cobogó. The project focuses on creating a low-cost constructionist tool and context for play and imagination to emerge, bringing physical activity, socialization, creation of narratives, collaboration, problem-solving, and joy to Brazilian schools. To achieve this, the kit provides a set of loose parts that children can incorporate into the play environment and that opens up opportunities for various types of play (Houser et al., 2016). Such materials include large geometric shapes made from wood, plastic, rope, and fabric. It also aims to be accessible to low-income communities and represents the local culture using materials that are part of Brazilian daily life. The test was in a Brazilian primary school setting. The first observations showed that the toolkit was well-received by the children and teachers and promoted child-directed play, imagination, the creation of narratives, and collaboration.

Introduction

Engaging in free play is a valuable and meaningful activity for learning and development. It allows for self-directed exploration, experimentation, and imagination. A growing body of research underscores how the interplay between environment, available materials, and the presence of “loose parts” impact the possible free play opportunities (Houser et al., 2016). Loose parts are open-ended objects and materials that can be manipulated, combined and changed in different ways. Adding loose parts to a play environment allows children to build and reshape the existing space to fit their needs and feel more ownership and connection to the playspace (Pereira et al., 2023). From a Constructionist perspective, learning happens particularly well when learners engage in making (and tinkering with) personally or communally meaningful artifacts (Holbert et al., 2020). Despite the growing evidence supporting the importance and value of free play for learning and development, many children face dwindling free play opportunities and many play spaces offer predominantly (if not only) stagnant play structures. In this poster, we share the ongoing design and initial testing of a construction kit (Cobogó) for public schools in Brazil to use and reuse as part of maker literacy, reflecting their culture and supporting the development of children’s imagination, motor skills, teamwork, and joy. Cobogó aims to enable children to build a meaningful relationship with the components and aims to be a real example of the idea of “objects to think with,” supporting a concrete style of reasoning (Turkle & Papert, 1990).

Cobogó’s design was partially informed by the first author’s experience as an elementary school educator in Brazil. The country overall offers a limited amount of playgrounds, partially attributed to the lack of resources (Agência Senado, 2022). Cobogó aims to promote the significance of free and meaningful play for children’s growth and development while also reflecting Brazilian culture. We initially tested the kit in a Brazilian primary school. For future steps, the authors aim

to discuss this project with a broader community and collect feedback for design improvements, availability to expand its testing to public schools, and continuing to advocate for the importance of non-structured play.

Design Elements

Cobogó uses loose parts, which consist of 5 large shapes made from wood (70cm x 40cm) with 6 holes in each, 5 PVC pipes (60cm), 3 nylon ropes (60cm), 3 pieces of “chita” fabric (1m x 1m), 20 rubber bands. The kit permits children to assemble in different ways and to be reused by others at the end of the play, facilitating creativity once they extend their bodies and minds. The large, collective material on the playground aims to support collaboration (Jarusriboonchai et al., 2019). It requires gross and fine motor skills as children of different ages coordinate the exercise, working in teams to carry out their play. There is no right or wrong way to do things. Cobogó is considered accessible to low-income communities and is meant to represent the local culture through the use of materials that are part of Brazilian daily life.

Playtest

The playtest was recorded for 45 minutes throughout the break of regular classes. The kit was provided for 10 children in the playground area. Observations that emerged from the experiment based on a post-test interview with the teachers and the video recording were: (i) Connection with their local environment – e.g., the groups incorporated sand; (ii) Child-directed play, imagination, and creation of narratives – e.g., a group built a chocolate factory; (iii) Socialization and collaboration: children created narratives in small groups during the activity; (iv) Loose parts: the teachers observed that materials provided an appropriate combination of rigid and flexible elements to the children’s creations. They believe the simplicity of the materials made the learners comfortable playing with them.

Conclusion

Cobogó addresses schools’ challenge to find a balance between structure and freedom in play by providing a low-cost constructionist tool that enables children to explore their imagination, emotions, and connections with the world. The first playtest indicated that the target audience involved their imagination in the play. At this point, researchers aim to present Cobogó, discuss design improvements, the availability to expand its testing to public schools and continue to advocate for the importance of non-structured play. These efforts will help bring imagination to the forefront and positively impact children’s development.

References

- Agência Senado. (2022, October 17). Milhares de Alunos Estudam em Escolas precárias, Apontam Debatedores. Senado Federal. Retrieved November 10, 2022, from www.shorturl.at/dhKZ5
- Holbert, N., Berland, M., & Kafai, Y. B. (Eds.). (2020). *Designing Constructionist Futures: The Art, Theory, and Practice of Learning Designs*. The MIT Press.
- Houser, N. E., Cawley, J., Kolen, A., Rainham, D., Rehman, L., Turner, J., Kirk, S., & Stone, M. (2019). A Loose Parts

Randomized Controlled Trial to Promote Active Outdoor Play in Preschool-aged Children: Physical Literacy in the Early Years (PLEY) Project. *Methods and Protocols*, 2(2), 27. <https://doi.org/10.3390/mps2020027>

Jarusriboonchai, P., Meissner, J. L., Almeida, T., & Balaam, M. (2019). Understanding Children's Free Play in Primary Schools. *Proceedings of the 9th International Conference on Communities & Technologies – Transforming Communities*, 178–188. <https://doi.org/10.1145/3328320.3328384>

Pereira, J. V., Dionísio, J., Lopes, F., & Cordovil, R. (2023). Playing at the Schoolyard: “The Who’s, the What’s and the How Long’s” of Loose Parts. *Children*, 10(2), 240. <https://doi.org/10.3390/children10020240>

Turkle, S., & Papert, S. (1990). Epistemological Pluralism: Styles and Voices within the Computer Culture. *Signs*, 16(1), 128–157

WORK-IN-PROGRESS

It's as Easy as 123

Supporting Users via Multiple Programming Approaches on a Single Device

Yuhan Lin, University of Maryland, jimmylin@umd.edu

David Weintrop, University of Maryland, weintrop@umd.edu

Audra Selkowitz, VEX Robotics, audra@vex.com

Jason McKenna, VEX Robotics, jason@vex.com

This paper introduces ROBO 123, a robot that can be programmed via four distinct methods designed to support users at all levels of programming ability. The ROBO 123 can be programmed by: (1) directly pressing buttons on its exterior (Figure 1a); (2) using a tangible programming approach based on a physical Coder and Coder Cards (Figure 1b); (3) defining instructions with a block-based programming language (Figure 1c); and (4) using the Python programming language (Figure 1d). In providing a range of programming approaches, the ROBO 123 can meet the user at their current level of ability and comfort while also providing mechanisms to help them move from basic to more sophisticated and powerful programming approaches. In supporting four distinct programming approaches that span physical and virtual contexts, the ROBO 123 contributes a novel addition to the growing ecosystem of tools designed to introduce novices to the practice of programming.



Figure 1: The ROBO 123 robot and the four distinct programming approaches it supports: (a) Touch Button programming, (b) Coder and Coder Cards, (c) Block-based programming, and (d) Text-based programming in python.

Wireless Embedded Visual Programming for Novices “Unplugging” CS education on embedded platforms

Devin Jean, Vanderbilt University, devin.c.jean@vanderbilt.edu

Gordon Stein, Vanderbilt University, gordon.stein@vanderbilt.edu

Brian Broll, Vanderbilt University, brian.broll@vanderbilt.edu

Ákos Lédeczi, Vanderbilt University, akos.ledeczi@vanderbilt.edu

Embedded systems are cheap and plentiful and are ubiquitous throughout the maker community. This makes them an obvious platform for hands-on, creative projects for K-12 students to increase awareness and interest in computer science and engineering. However, embedded programming platforms for K-12 education are often somewhat limited in either features or debugging capabilities, and do not typically include intuitive support for networking features that are vital to distributed computing and the Internet of Things. To address these issues, we introduce NetsBloxVM, an open-source, entirely wireless embedded programming platform which can connect to a remote server called NetsBlox to facilitate curated web API queries, support distributed computing via message passing between projects over the internet, and other features such as in-browser real-time collaborative editing.

Writing as Making

Towards a Critical Constructionist Praxis with Pre-Service Educators

Veena Vasudevan, University of Pittsburgh, veenav@pitt.edu

To create classroom environments that position non-dominant youth as the agentive, creative, cultural producers that they are – particularly in relation to digital media and technology – their teachers need to have opportunities to make and play with a range of technologies within their own educational experiences. Drawing from a course taught with 9 pre-service educators, this poster analyzes how teachers engaged in writing-as-making, and in doing so revealed the ways thinking expansively and critically about literacies and engaging in a range of making (both on and off the screen) led to increased transparency into processes of students' own learning, deeper connections to theoretical ideas related to literacies and learning, and a culture of vulnerability, dialogue, and support.

AI-Enhanced Philosophy of Education Studies

Sharon Hardof-Jaffe, Levinsky-Wingate Academic Center, Sharon.Hardof@L-W.ac.il

Eran Gusacov, Levinsky-Wingate Academic Center, Eran.Gusacov@L-W.ac.il

Contemporary education, particularly the humanities, has long been in crisis. Humanities education has not adjusted to ongoing technological innovations, constantly changing local and global market demands, social challenges of multicultural societies, and consequently, the diminishing status of knowledge. Teachers are no longer the exclusive possessors of knowledge, which undermines their authority, giving rise to doubts about their centrality in the classroom and putting in question the very relevance of the humanities to the learners' future (Blaschke, 2018; Glassner & Back, 2020; Roberts, 2021). The proposed program aims to utilize technology to restore the glory of the humanities and respond to the new needs of learners and teachers. It proposes educational modes of action in these fields, suggesting that constructionist approach (Papert & Harel, 1991) and a self-determined learning approach – heutagogy (Glassner & Back, 2020) could leverage transforming the humanities into an innovative learning experience and a source of skills and competencies required to cope with the socio-educational challenges of the knowledge society with its frequent changes, complexities, crises, and uncertainty. Further to previous ideas on integrating the constructionist approach into humanities teaching (Baranova et al., 2018; Hwang, 2023), we propose a philosophy of education course based on constructionism and self-determined learning to represent the humanities. The program's implementation leans on learning-by-making comprising AI applications.

Co-Constructing Language Learning through Tinkering with Wearable Soft Controllers in Galician Creative Libraries for Elementary Schoolers

Paola Guimeráns, Vigo University, paola.guimerans@uvigo.es

Iva Li, Teachers College, Columbia University, isl2126@tc.columbia.edu

This pilot study is a part of an ongoing Creative Library Project (Proyecto Biblioteca Creativa), taking place in two school libraries in Galicia, Spain, which investigates the potential benefits of co-constructing knowledge in the realms of electricity, programming, and language learning within the context of 21st-century skills. Specifically, the researchers focus on exploring the effectiveness of a constructionist approach involving crafting and gaming. This approach employs a range of conductive and non-conductive materials, Scratch, and Makey Makey kits, with the intent of facilitating multilingual language education and fostering creativity among elementary school students. Preliminary findings suggest that integrating physical and digital making processes holds the capacity to significantly enhance non-formal language learning opportunities. This highlights the unique attributes of school libraries as ideal environments for fostering such maker and STEAM education experiences.

Constructionist booster

a quantitative bridge program for first year university students

András Margitay-Becht, Saint Mary's College of California, am17@stmarys-ca.edu

This paper introduces a bridge program designed to bolster the mathematics confidence of freshmen college students right before starting school. Using the toolset of constructionism, inspired by ScratchMaths, the bridge program will prepare students who do not aim to major in Mathematics or Computer Science to perform college-level work in both of those areas. Combining a pre-introductory programming experience with a quick introduction to computational thinking, and then re-discovering the basic principles of high-school level algebra through a constructionist, programming approach, the bridge program aims to reinforce the existing knowledge of the students and embolden them to complete college level mathematics courses.

Programmable Oven Toaster

A Powerful Tool for Learning Chemistry & Home Economics in a Constructionist Way

Kyohei Sasaki, Panasonic Corporation, sasaki.kyohei@jp.panasonic.com

Kazutoyo Takata, Panasonic Holdings Corporation, takata.kazutoyo@jp.panasonic.com

In this paper, we present our “programmable oven toaster” and how it can be used in a creative learning class. Our oven toaster can be manipulated via Scratch-based coding, enabling students to go through as many trial-and-errors as they want, in their process of cooking. We propose the process of baking cookies via programming, which embodies a powerful concept in developing creativity and relevant disciplinary knowledge in a constructionist way.

Microworlds, Powerful Ideas, and What do we do Monday?

An exploration of microworlds and powerful ideas with an eye to how they are used in practical activities and projects.

Michael Tempel, Logo Foundation, michael@logofoundation.org

Michelle Hughes, Learning Arts Coaching & Consulting-LARC Bloomington, michelle.hughes194@gmail.com

Bryan Sanders, Loyola Marymount University, bryansanders@me.com

This works-in-progress proposal focuses on learner engagement with microworlds and powerful ideas, concepts discussed by Seymour Papert in his seminal 1980 book, *Mindstorms*. Recounting two workshops held early this year, the authors offer a detailed look at practical application in student-centered classroom activities and projects, with particular attention to the emergence of interdisciplinary artifacts. The discussion encompasses more than computer-based environments and emphasizes the importance of and need for students' construction of knowledge. In addition, the analysis attempts to more clearly define powerful ideas and their role in constructionist teaching and learning. This work is ongoing. The authors are planning additional workshops and intend to continue documenting, analyzing, and sharing future learning experiments that follow.

Constructionism in the Light of Computational Creativity

Lana, Issa, Freie Universität Berlin, lana.issa@fu-berlin.de

Ralf, Romeike, Freie Universität Berlin, ralf.romeike@fu-berlin.de

Various Artificial intelligent methods were developed with inspiration from human practices to optimize existing solutions or propose new valuable ideas. Computational Creativity is one of the emerging young fields that utilizes AI techniques to build results that are creative, novel, and represents the most impressive form of AI today. It impacts almost all disciplines and leads to continuous reports in the media, e.g. about AI generated images, stories, and music. If constructionist learning constitutes (re)constructing meaningful products students' find in the world around them, wouldn't the future of constructionist learning involve enabling students to create their own computational creativity system? In the following paper, we propose such a constructionist learning approach where students learn about and draw their own conclusions on CC systems. Students do not only learn powerful ideas of CC systems, but also reflect and apply the building blocks of the subject domain they are dealing with. Hence, they may better understand the world around them.

Empowering Learners with a Low-Barrier Mobile Data Science Toolkit Using MIT App Inventor to build data science mobile applications

Hanya Elhashemy, Massachusetts Institute of Technology, Technical University Of Munich, hanya.elhashemy@tum.de

Robert Parks, Massachusetts Institute of Technology, rparks@mit.edu

David Y J Kim, Massachusetts Institute of Technology

Evan Patton, Massachusetts Institute of Technology

Harold Abelson, Massachusetts Institute of Technology

This paper introduces a novel data science toolkit designed specifically for children, enabling them to create mobile apps integrated with data science capabilities. The toolkit showcases new features that simplify the data science process for young users. Additionally, the paper presents a collection of example apps created using the toolkit, highlighting the versatility and potential of this innovative platform. By empowering children to explore data science through app development, this toolkit opens exciting opportunities for hands-on learning and creative expression in the field of citizen science.

Co-Constructing Expert Problem Solvers

The Power of Constructionism in the Digital Age

Monahan, North Carolina State University, rpmonaha@ncsu.edu

Vandenberg, North Carolina State University, jvanden2@ncsu.edu

Smith, North Carolina State University, pmsmith4@ncsu.edu

Minogue, North Carolina State University, jminogu@ncsu.edu

Oliver, North Carolina State University, kmoliver@ncsu.edu

Hubbard Cheuoua, WestEd, ahubbar@wested.org

Ringstaff, WestEd, cringst@wested.org

Mott, North Carolina State University, bwmott@ncsu.edu

Programs that situate learners at the intersection of digital literacy, collaborative problem-solving, and tangible fabrication can be potent drivers toward future success. This work examines one such initiative, called InfuseCS, that incorporates an immersive Virtual Learning Environment (VLE) utilizing problem-based learning (PBL) scenarios within a Computer-Supported Collaborative Learning (CSCL) context, catering to upper elementary school students. Conducted in a public, Title 1 STEAM-centric elementary school in the mid-Atlantic United States. This program has enriched the educational journey of 10 to 11-year-olds, predominantly Hispanic and African American. The program encouraged students to collectively build and fabricate their learning experience, essentially constructing their understanding, knowledge, and skills through active engagement with coding solutions and direct collaboration. Acting as both a physical and conceptual makerspace, it allowed learners to fuse their inner cognition with external realities, embodying the tenets of constructionism. This manuscript probes into the program's teaching methodologies, explores its unique features, and concludes with insights and wider implications for education. The paper elucidates the scaffolded journey from Self-Regulated Learning (SRL) to Socially Shared Regulation of Learning (SSRL) and then to Co-Regulation (CoRL) as students collaboratively navigate the learning environment.

Sock-It-To-Ya

A Call for Collaboration on an Affordable Knitting Machine

Jayne Everson, University of Washington, everjay@uw.edu

Megan Hofmann, Northeastern University, m.hofmann@northeastern.edu

Amy J. Ko, University of Washington, ajko@uw.edu

Sock-it-to-ya is a low-cost knitting machine that can be made in makerspaces. There is compelling evidence that e-textiles support student identity and draw from their funds of knowledge in computation. This machine brings the craft of knitting into the e-textile landscape. It combines 3D printer files and market circuit boards to allow students to explore electronic knitting.

K-12 Computer Science Ideals in Context Lessons Learned from Co-designing a Constructionist Computer Science Program in the Global South

Adelmo Eloy, Columbia University and Universidade de São Paulo, adelmo@fablearn.net

Jacob Wolf, Harvard University, jwolf@g.harvard.edu

Nathan Rabinovitch, Columbia University, nathanrab@gmail.com

Paulo Blikstein, Columbia University, paulob@tc.columbia.edu

This paper describes the initial design of a Constructionist computer science (CS) program for middle school. The program follows an interdisciplinary approach and involves collaboration with a municipality in, based on guiding principles from an introductory CS course for secondary school students in another country. As we reflect on how our Constructionist ideals play out when initiating the CS program, we highlight three significant changes made during the program's implementation: maintaining a commitment to co-design, navigating between different programming environments, and encouraging metacognitive reflection. Looking ahead, we anticipate further refinement of the program based on classroom implementation and co-design activities, while also pushing our constructionist ideals further.

Write Your First Song

An Interactive Interface for Music Novices to Express Music Ideas

Xichen Li, Teachers College, Columbia University, xl3197@tc.columbia.edu

Paulo Blikstein, Teachers College, Columbia University, paulob@tc.columbia.edu

Songwriting fosters personal and cultural connections while addressing the social and psychological needs of adolescents. However, the abstract and symbolic nature of music theory often intimidates novices seeking self-expression through music writing. To overcome these barriers, we introduce “Write Your First Song,” a web-based interactive platform that enables novices to learn music theory using experiential learning and keyboard-based tasks. By avoiding conventional notation, the platform integrates storytelling and ratio concepts to facilitate music composition for beginners. Ideal for educators and self-paced learning, our design underwent preliminary user studies with 12 music beginners, providing valuable insights into the effectiveness of interactive interfaces for creative practice.

CYBATHLON @school scale up inclusion

towards a new low cost, high scale STEM module approach

Tobias M. Schifferle, CYBATHLON of Swiss Federal Institute of Technology ETH Zurich, tschifferle@ethz.ch

This WIP Paper presents the CYBATHLON @school STEM initiative which aims to foster inclusion and accessibility topics among pupils of all age groups by combining them with Engineering and STEM topics. The project trains (predominantly female) Engineering students to conduct courses in schools while acting as role models to the pupils. Many modules build on the educational exoskeleton Flexo which allows for new experiences and is well accepted. However due to being a complex system, the workshops are expensive to conduct, maintain and do not scale well. This paper identifies important obstacles and presents ideas on how to complement the project with a new module which scales better and adapts to certain needs of schools while preserving the positive aspects of the project.

“Are you doing anything I can interrupt right now?”

Using Social Wearables to Support Communication in Remote Work Environments

James Fey, University of California Santa Cruz, jfey@ucsc.edu

Raquel Robinson, University of California Santa Cruz, rrobins@ucsc.edu

Sarah Frost, University of California Santa Cruz, rrobins@ucsc.edu

Katherine Isbister, University of California Santa Cruz, kisbiste@ucsc.edu

The recent shift to remote work and learning has people in the same household co-working and living, each with personal schedules, meetings, classes, and nuanced habits. These new social dynamics necessitate clear and effective communication between members of a household, which can be challenging. We designed and built a “supple” wearable using commercially available DIY hardware to aid in navigating the complexities of social interactions in a work-from-home environment. We conducted a modified autoethnographic study in which two couples used the device over a week. In this paper, we discuss our iterative co-design of the device and the supple design requirements we used, and present results of the preliminary autoethnographic study. Researchers used the proof-of-concept devices for communication, customized how they wore them and details of the device function, and made use of them for personal management and reflection as well as communication.

Conductive Chemistry Learning

Critical technological explorations for early childhood Work in progress toward the development of a conductive chemistry kit

Anna Keune, Technical University of Munich, anna.keune@tum.de

Naomi Thompson, University at Buffalo, naomitho@buffalo.edu

Jenna Koenen, Technical University of Munich, jenna.koenen@tum.de

Early exposure to creative contexts to develop critical technological skills is a major contributor to transforming participation in STEM. Yet, in early childhood settings, critical technological design and advanced science content is nearly missing. Here, we discuss an ongoing research and design that investigates intergenerational practices and materials related to electricity and circuits and leverages them toward the design of a novel age-appropriate Conductive Chemistry kit. This kit will support children (age 3-6) and caring adults to learn the underlying chemistry of circuits and to critically explore technology by asking what electronics are made of, how they are made, what circuits are for, and who can create them. We merge the constructionist idea that learning happens best when people design personally meaningful projects with socio-material approaches to learning that materials associated with underrepresented groups can transform participation. The project will advance a scalable kit and knowledge about critical technology practices and advanced science learning in early childhood with implications for transforming early childhood education and chemistry education at large.

ChatLogo

A Large Language Model-Driven Hybrid Natural-Programming Language Interface for Agent-based Modeling and Programming

John Chen, Northwestern University, civitas@u.northwestern.edu

Uri Wilensky, Northwestern University, uri@northwestern.edu

Building on Papert (1980)'s idea of children talking to computers, we propose ChatLogo, a hybrid natural-programming language interface for agent-based modeling and programming. We build upon previous efforts to scaffold ABM & P learning and recent development in leveraging large language models (LLMs) to support learning of computational programming. ChatLogo aims to support conversations with computers in a mix of natural and programming languages, provide a more user-friendly interface for novice learners, and keep the technical system from over-reliance on any single LLM. We introduced the main elements of our design: an intelligent command center, and a conversational interface to support creative expression. We discussed the presentation format and future work. Responding to the challenges of supporting open-ended constructionist learning of ABM & P and leveraging LLMs for educational purposes, we contribute to the field by proposing the first constructionist LLM-driven interface to support computational and complex systems thinking. References

Papert, Seymour. 1980. *Mindstorms: Children, computers, and powerful ideas*.

Enchanting Woods

Engaging Children in Creative Expression through Interactive Storytelling and Embodied Interaction

Yinmiao Li, Northwestern University, yinmiaoli@u.northwestern.edu

Fangqing He, Harvard University, quinnhezz@gmail.com

Yumih Chang, Harvard University, yumihchang@gsd.harvard.edu

Qianyi Chen, University of California, qianyi.chen@berkeley.edu

Mingnan Du, Harvard University, mingnandu@gsd.harvard.edu

Creative expression is a rising field in primary and secondary schools. Computational technology is a novel medium for creative expression that has received increasing attention in education. We propose a computational technology-supported experience, Enchanted Woods, that prioritizes students' creative expression for children aged between 9 and 11 years old. Enchanted Woods is a classroom-size two-phase narrative-based design with physical interactions and purposely designed plot holes. The first phase placed students in the role of a lead character to immerse in the story, and the second round positioned students as the creator of the story to express their creativity. This work proposed an approach to transforming the classroom into an environment that supports children's creativity.

A Constructionist Learning Environment for Accessible Agricultural Robotics in Rural Communities via Making and Remixing

Alexander K. Jones, University of Maine, alexander.k.jones@maine.edu

Greg L. Nelson, University of Maine, gregory.nelson@maine.edu

Robotics environments, such as the original LOGO turtle, have facilitated constructionist learning and even grown into widespread products such as Lego Mindstorms. Many of those environments have been highly successful by minimizing the cost of entry by focusing on smaller, indoor robots with cheaper parts, and building communities of learners such as in FIRST robotics competitions. In this work in progress, we have begun to design and build a physical robotics framework and virtual simulation/making environment, with the goal of enabling rural learners to make robots that might be used in their community in culturally relevant ways outside of the classroom.

Constructing Sustainability

Integrating Constructionist Learning in Education for Sustainable Development

Sawaros Thanapornsanguth, United Nations University Institute of Advanced Studies, sawaros@unu.edu

Junichi Takada, Tokyo Institute of Technology, takada.j.aa@m.titech.ac.jp

This paper explores example of how support constructionist learning environment can support Education for Sustainable Development (ESD) by designing and making innovation that addresses environmental and social problems. In this paper, we describe an “Education for Sustainable Development through Design and Technology” course where undergraduate and graduate students from Japan and Thailand, from various disciplines were tasked with constructing “social or environmental solutions”. Data collected from interviews, student-built projects and class final reports suggest that when making is framed as being a set of practices, skills, and technologies to connect with one’s interest, students can successfully engage in an act for sustainable development. The course is designed and implemented as a learning environment that uses human-centered design, the process of empathize, define, and ideate to help the students better understand their users and generate creative ideas for their projects. After coming up with the ideas the students learn through building prototypes and testing them for further iterations

Political Activism in a Youth Community Garden

How the making of a community garden supports youth's political activism in heterogeneous engineering

Yume Menghe Xu, Tufts University, Menghe.Xu@tufts.edu

Brian Gravel, Tufts University, brian.gravel@tufts.edu

Community gardens afford effective STEM learning because they provide contexts that are meaningful and relevant, so youth can draw their funds of knowledge when learning in these spaces. Analyzing data from youth in a public high school constructing their community garden, we present a case where constructing a community garden becomes an avenue for the youth to engage in heterogeneous engineering. This engineering project that was motivated by their deep care for their community supported their participation in political activism.

Turtle Geometry Today and Yesterday

Cynthia Solomon, Private educational consultant, cynthia@media.mit.edu

Artemis Papert, Artist, artemis@turtleart.org

In this paper we illustrate how the interplay between two artists can lead to a plethora of designs. Explorations were done in TurtleArt and TurtleStitch, two microworlds based on Turtle Geometry. It's 2023 and Turtle Geometry is alive and thriving. It was invented by Seymour Papert in 1969 as part of the Logo programming language. Logo with turtles was first used by children in the 1970/71 school year. The focus of this paper is on the artistic explorations in two distinct microworlds, both offshoots of Logo: TurtleArt and TurtleStitch. TurtleArt is an environment for programming two dimensional images using code as the medium. It allows you to explore color, shading, shapes and composition, amongst other things. TurtleStitch has opened up the makerspace world to embroidery design and creative stitchery using a computerized embroidery machine. Both environments embrace a visual world, enticing beginners as well as experts. Explorations can lead to intricate designs where the user will discover concepts from programming and mathematics. In this paper, we want to share with you a kind of collaboration we have experienced over the past years. We are each familiar with the other's work, but are also an expert in different traditions and practices. Artemis is an artist and uses TurtleArt as a creative medium. Cynthia is a teacher and researcher and has latched on to TurtleStitch as an expressive medium, and an enticing learning and teaching tool. What is described here links turtle geometry, TurtleArt and TurtleStitch. Both of us enjoy playing off one another's ideas and building on the other's designs. Because each of the two artistic mediums allows for things that are not possible in the other, adapting each other's design from TurtleStitch to TurtleArt or vice-versa can be challenging. However, it is always fun and stimulating.

Supporting Knowledge Construction in Making via Collective Process-Oriented Documentations

Collective Process-Oriented Documentation for Making

Yipu Zheng, Teachers College, Columbia University, yipu.zheng@tc.columbia.edu

Paulo Blikstein, Teachers College, Columbia University, paulob@tc.columbia.edu

This three-year design-based study aims to explore knowledge construction in making and to present effective design of using collective process-oriented documentation as a means to enable learners and facilitators to recognize and reflect on learning collectively. Built upon previous research on process-oriented documentation, this research adds a collective perspective to students' documenting process in making. In addition, this study presents how auto-generated knowledge maps using natural language processing and network analysis techniques could be potentially integrated in a collective documentation practice to help students see the connections among different projects and learn from each other. The contribution of this work is two-fold: First, it suggests design and practices on supporting knowledge construction in making. Second, it provides rich descriptions on the process of knowledge construction in making that might not be able to be captured without such an interface.

Multivocal Play an Interactive Exhibit

Lucius Von Joo, Teachers College, Columbia University, lav2111@tc.columbia.edu

Blake Danzig, Teachers College, Columbia University, bpd2119@tc.columbia.edu

This interactive exhibition centers the Multivocal Annotated Layers method to showcase and explore children's play across different cultures. The exhibit presents annotated posters from New York, Chiba, Tokyo, and California adventure playgrounds and invites visitors to contribute their own reflections, fostering an evolving dialogue. The result is an immersive experience that illuminates the universal aspects of play, builds international connections, and emphasizes the unique perspectives of young participants.

Kaleidolight

*An Interactive Device for Exploring Additive Color Theory Through Hands-on Creation
Kaleidolight: An Interactive Educational Device for Young Students to Explore Additive Color Theory and Create Visual Art Through Hands-on Learning Experience with the Integration of Light, Color, and Shapes*

Xiaoyan Qin, Teachers College, Columbia University, xq2206@tc.columbia.edu

Additive color serves as a vital component of both tangible and digital realms. However, comprehending and applying additive color theory can be challenging for learners in the absence of adequate visual demonstrations and scaffolds. Additive color theory employing light also offers immense potential for artistic creation, yet at school, it is often overshadowed by pigment and subtractive color theory, which are predominantly covered in school art curricula. In response to this gap, Kaleidolight is designed for learners aged 6 to 18 to facilitate an exploration of additive color theory and art creation utilizing light as a medium through hands-on playing and art creation combining RGB color and geometric shapes.

SPATIAL

An Embodied Learning Design To Support Geometry Learning Through Collaboration and Physical Movements

Zhanlan Wei, Teachers College, Columbia University, zw2754@tc.columbia.edu

Paulo Blikstein, Teachers College, Columbia University, paulob@tc.columbia.edu

This paper describes SPATIAL, a three-dimensional embodied learning space where geometry objects can be constructed, perceived, visualized, and expressed through collaboration and physical movement. As target objects appear on a computer screen, learners work collaboratively to create the object using the buttons distributed around them, comparing their creation with the target object by rotating it and viewing virtual representations from different angles. This paper reviews the theoretical frameworks and design elements that inform SPATIAL and briefly explains how learners can benefit from this design by visualizing, communicating, and experiencing mathematical concepts in a physically immersive way.

Creative Expression through Color and Sound

A NetLogo Model for the Sonification of Color and the Visualization of Sound

Yinmiao Li, Northwestern University, yinmiaoli@u.northwestern.edu

John Chen, Northwestern University, yuehanchen2023@u.northwestern.edu

This paper presents a Constructionist Model for students from age 8-10 to create multimedia abstract art that focus on the manipulation of color and sound. The design of the model is inspired by Wassily Kandinsky, an avant-garde artist of abstract drawings who experienced synesthesia in which he visualized music as colors and shapes and heard sounds while painting. Kandinsky explored and incorporated his senses of sounds and visuals into his artistic practices. The model referred to Kandinsky's famous drawing Concentric Circles and provided space for students to explore the relationship between color and sound.

Stories and STEM

Designing for Relationship Building and Meaningful Forms of Expression in a Family Computing Workshop

Ronni Hayden, University of Colorado, ronni.hayden@colorado.edu

Jose Hernandez, Denver Public Library ideaLAB, jmhernandez@denverlibrary.org

In this paper we share about the design and rationale of a computing activity aimed at centering storytelling and relationship building for families with children ages 7-12 engaging in a local library program. This activity was designed as an iteration of the Family Creative Learning workshop series and was collaboratively imagined and iterated on by the two authors, a graduate student researcher and a Library Program Assistant working within a makerspace in a metropolitan library branch. This activity, called Family Light Boxes, combines the Circuit Playground Express and Neopixels with everyday materials to allow families to explore how they might bring family stories to life using light, shadow and code. In this paper we share about the details of the activity, considerations behind the choices that were made in its design, and reflections about the affordances and constraints of designing for meaningful engagement with computing, storytelling, and everyday materials using these tools.

Civic Engagement in the Scratch Online Community as a Case for Civic Imagination in Creative Computing

Cecilé Sadler , Massachusetts Institute of Technology, csadler@mit.edu

Jaleesa Trapp, Massachusetts Institute of Technology, jaleesat@mit.edu

Paulina Haduong, Harvard University, haduong@g.harvard.edu

Learning to program can help young people see themselves as creators and scaffold their ability to participate in a technologically-mediated society. This paper proposes a framework for understanding the ways in which young people engage civically through computational making. We aim to represent the various ways that civic engagement is actualized in young people's media production practices via the Scratch online community to draw attention to the need for the incorporation and promotion of speculative pursuits that move toward civic action. We also consider opportunities for educators to design civic-focused experiences for young people learning to express themselves using digital tools. We define the four components of the framework—civic identity, civic awareness, civic imagination, and civic action—through discussion and analysis of example projects shared by young people on the Scratch online community.

Making at School

Experiences from the Design-Based Research Project

Bernadette Spieler, Zurich University of Teacher Education, bernadette.spieler@phzh.ch

Tobias M. Schifferle, Zurich University of Teacher Education, tobias.schifferle@phzh.ch

This paper explores the transformative potential of Making in fostering self-guided, hands-on learning among students in grades 5 to 9. It presents the two-year initiative, “Making at School”, wherein Zurich University of Teacher Education (PHZH) created and tested different Maker Education scenarios. A cohort of 13 educators received professional development, subsequently implementing the designed scenarios across approximately 60 classes, thereby engaging around 600 students. Applying the principles of design-based research, the training programs were iteratively enhanced, leveraging methods including teacher interviews, focus group discussions, and student questionnaires. Preliminary results indicate that while educators could introduce new concepts within their classrooms successfully, there emerged a need for additional support, particularly for advanced courses.

Transforming Teaching Science Education

Case Studies on Implementing a Constructionist Curriculum for Middle School Students

Giliane Filismino Sales, Escola de Tempo Integral Maria Dorilene Arruda Aragão, giliane.sales@edu.sobral.ce.gov.br

Antonia Renata de Araújo Azevedo, Escola Padre Oswaldo Carneiro Chaves Municipal, renata.aazevedo04@gmail.com

Mariana Lederman Edelstein, Transformative Learning Technologies Lab, Columbia University, ml4794@tc.columbia.edu

Paola Salmona Ricci, Transformative Learning Technologies Lab, Columbia University, paola.ricci@tltlab.org.br

Claudia Peria, Transformative Learning Technologies Lab, claudia@tltlab.org

This paper presents two case studies of the implementation of a constructionist curriculum unit tailored to middle school students based on the IDEIA Science Curriculum. The Pedagogical Redesign Teachers from a disadvantaged region in Latin America share their perspectives, experiences, and challenges in adopting a student-centered approach to teaching science. The first case study focuses on seasonal variations, emphasizing the connection between geographical location and seasonal patterns. The second case study explores air masses and climate, aiming to develop students' understanding of the relationship between air mass displacement and observed climatic conditions. Both case studies highlight the positive impact of student engagement and the transformation of the teacher's role from instructor into a facilitator of knowledge construction. Despite challenges, the implementation of these constructionist approaches fosters meaningful learning experiences and enhances student engagement, encouraging other science teachers to consider similar teaching practices.

Cultural Making and Scientific Education

Elements for an ethical-critical approach from the south

João Paulo Mannrich, Federal University of Santa Catarina State, jpmannrich@yahoo.com.br

Eduarda Boing Pinheiro, Federal University of Santa Catarina State, eduardaboingpinheiro@gmail.com

Elizandro Maurício Brick, Federal University of Santa Catarina State, elizandromb@gmail.com

Based on the notion of Cultural Making and Southern authors who draw from an ethical-critical view of education, we argue that maker education should not be limited to mere hands-on activities that address disciplinary knowledge without any connection to the educators' and learners' realities. To achieve this, we introduce the concept of three pedagogical moments that assist in designing activities that are relevant to the learners' realities. We provide examples of potential maker education approaches inspired by these three pedagogical moments, drawing from two cases developed in Brazil.

The Griot Dolls

Black Dolls to Think History

Inara Bezerra Ferreira de Souza, Teachers College, Columbia University, ib2510@tc.columbia.edu

Andréia Maria de Lima Assunção, University of São Paulo, Brazil, amlassuncao@gmail.com

Mariana Lederman Edelstein, Teachers College, Columbia University, ml4794@tc.columbia.edu

The Brazilian education system has struggled to provide an inclusive education that integrates Afro-Brazilian, African, and Indigenous History into daily teaching and learning. Law 10.639/03 was intended to promote inclusive schooling and guarantee the ethno-racial diversity rights of the Brazilian population. Despite this legislative progress, the implementation of Afro-Brazilian and African history in the education system faces continued challenges due to structural racism. This paper introduces the Griot Doll, a toolkit designed to help Brazilian schools provide a more inclusive education. The Griot Doll is a constructionist “object to think with” constituted by a set of black dolls without figurative human faces and bodies and featuring interchangeable hair possibilities. It provides a physical representation of Afro Culture that has historically been excluded from the Brazilian education system. Students can use the toolkit to reflect, represent, and create narratives from a black storytelling perspective. The Griot Dolls aim to go beyond a toy, providing a way for students to identify themselves as historical subjects.

ElectricCity

Electrical Block Circuits for Elementary Learners

Mariana Lederman Edelstein, Teachers College, Columbia University, ml4794@tc.columbia.edu

Sadia Ahmed, Teachers College, Columbia University, sa4161@tc.columbia.edu

ElectricCity is an ongoing project aimed at teaching electrical circuits to students in grades K-3 to K-5, aligning with the Next Generation Science Standards (NGSS). The project incorporates a constructionist approach, utilizing a city environment and mission cards to engage learners in creative problem-solving related to electrical circuits. The project consists of three pillars: blocks, mission cards, and implementation design. The blocks are designed to facilitate quick connections and provide a tangible representation of circuit components. Mission cards offer both creative and problem-solving challenges, allowing learners to explore and fix circuit errors. Comprehensive lesson plans support teachers in scaffolding student learning and facilitate group work. Design principles such as agency, group work, scaffolded learning, personalization, and storytelling are incorporated to enhance engagement and understanding. Future directions include expanding the curriculum, providing additional resources for teachers, and testing ElectricCity in K-3 to K-5 school environments. ElectricCity aims to create a structured and enjoyable learning environment for students to achieve their science learning goals in the context of electrical circuits.

Making Floats for the Brazilian Carnival Parade

The Emergence of the “Situated Maker Space”

José A. Valente, State University of Campinas, joseavalente4@gmail.com

Eliton M. Moura, Columbia University, tommeireles@gmail.com

Paulo Blikstein, Columbia University, paulob@tc.columbia.edu

This paper explores the production process of “allegorical floats” at a Brazilian samba school and asks whether the school’s production environment—which involves a combination of art, engineering, and science—can be considered a maker space. The samba schools, originally considered “dancing societies,” are now competitive communities with the annual Carnival parade as their endpoint. The data collection and analysis involved participant observations and semi-structured interviews conducted over a period of two years. We suggest that samba schools can be considered maker space situated between community and educational ones. The making process at the samba school is reflective, creative, and public, but education is not its main function. The paper concludes with reflections on different modalities of maker spaces and how they relate to diverse community needs and dynamics.

Fostering Literacy Development through Constructionist Pedagogy

A Case Study in Elementary Education

Luca Nucci Vernalha, Escola Estilo de Aprender, luca.vernalha@gmail.com

Mariana Lederman Edelstein, Teachers College, Columbia University, ml4794@tc.columbia.edu

Brett Schechter, Teachers College, Columbia University, bs3407@tc.columbia.edu

This paper explores the implementation of constructionist approaches to restore literacy skills among elementary school students in Brazil affected by the COVID-19 pandemic. By drawing on Piaget's constructivism and Papert's constructionism, the study explores the active role of learners and the supportive role of teachers in the literacy process. While constructionist approaches have been applied to various disciplines, their use in language literacy education is still limited. Through a case study, this research demonstrates the effectiveness of a constructionist approach using a poster as a thinking tool. The teacher models reading skills, collaboratively develops a poster with the class, and facilitates the creation and presentation of posters by student groups. This process fosters students' creativity, innovation, and communication skills, all crucial for literacy development. The findings highlight the positive impact of constructionism on students' reading abilities, comprehension, and sense of ownership in learning. The paper concludes by emphasizing the significance of constructionist literacy and encourages further discussions and contributions to broaden the scope of constructionist approaches in literacy education.

Designing a Middle School Curriculum to Critically Explore Socioscientific Issues with Machine Learning

Changzhao Wang, University of Miami, czwang530@gmail.com

This paper presents the design and research of a Machine Learning (ML) curriculum for middle school students to critically explore socioscientific issues. Ten middle school students from diverse backgrounds participated in the second iteration—a 4-week free online afterschool program. They were engaged in hands-on practices of solving real-world problems with AI/ML technology, such as collecting photos of themselves wearing and not wearing masks to train their own ML models that can automatically recognize if a person wears mask or not. The designed learning environment provided them the opportunity to learn through social interactions with ML tool, physical tool, peers, and instructors. As a result, students showed improved AI/ML knowledge and practices and good understanding of AI ethics.

Act Happy! Act Crazy!

Using Emotion-based Commands to Engage Young Learners in Robotics Programming

Yuhan Lin, University of Maryland, jimmylin@umd.edu

David Weintrop, University of Maryland, weintrop@umd.edu

Audra Selkowitz, VEX Robotics, audra@vex.com

Jason McKenna, VEX Robotics, jason@vex.com

This paper explores the use of emotion-based programming commands as a means to engage young learners (ages 4-6) in robotics programming activities. Using the VEX 123 robot and its Coder card programming approach, young learners are invited to program a robot to recreate well-known stories. To support storytelling, the VEX 123 includes emotion-based commands including act sad, act crazy and act happy, each of which produce a predefined robot behavior associated with the emotion. The paper reports on learners in two elementary classrooms showing how these emotion-based programming commands were productive scaffolds to help novices engage in the task of programming a robot.

Constructing various learning activities on the Semantic MediaWiki playground

Evgeny Patarakin, HSE University, epatarakin@hse.ru

The article showcases the successful integration of various forms of collaborative learning on a single platform, the Semantic MediaWiki. Drawing on the theoretical framework of constructionism and the work of Papert and Minsky, we utilized object classes in the Semantic MediaWiki environment as initial building blocks. The categories of programming languages, video games, data sets, multi-agent models, diagrams, scripting tutorials, and online communities yielded the largest number of objects. By leveraging MediaWiki extensions, we transformed wiki pages into executable articles, which included flowcharts in graphviz, mermaid, and plantUML languages, as well as visual blocks of programs in Scratch and Snap! languages. Furthermore, we were able to embed running projects in multi-agent modeling languages such as Scratch, Snap!, StarLogo Nowa, and NetLogo Web to executable wiki-pages. The article demonstrates how these learning activities on the wiki foster the creation and modification of datasets, the use and modification of simulations, and scripting tutorials. Extending MediaWiki capabilities through Semantic Mediawiki, EmbedScratch, ScratchBlocks4, Snap! Project Embed, graphviz, mermaid, Widgets:iframe, Widgets:YouTube, allows teachers to collect projects created in various online educational communities in one field. This helps students learn from simpler to more complex examples of how to solve similar problems in different multi-agent programming environments. Website address – <http://digida.mgpu.ru>

Introducing Digital Design Research (DDR)

Constructionist Principles at the Methodological Level

Brendan Jacobs, The University of New England

This paper recounts the evolution of Digital Design Research (DDR) as a research methodology designed to document the construction of digital artifacts. DDR is an extension of Design-Based Research where change and collaboration are embraced during interventions in educational settings. Constructionism has been described in various ways as a learning theory, epistemology, and theoretical framework, but constructionist principles can also be applied at the methodological level, particularly when working with digital artifacts which embody the learning.

Discover BBC micro:bit board as part of a dynamic and experimental AI learning process

Rodrigo Gonzalez, Ceibal , rogonzalez@ceibal.edu.uy

Carla Degregorio, Ceibal , cdegregorio@ceibal.edu.uy

Constant technological progress is a key challenge for Education and Society in the 21st century. This fact reflects the need of educational communities to stay updated in relation to technological tools and new pedagogies. This article describes experiences in the use of micro:bit programmable boards as part of a dynamic and experimental process of Artificial Intelligence (AI) educational projects. Micro:bit's design allows users without prior knowledge to develop their first programming skills, to use AI platforms while creating models that can respond intelligently to different stimuli and use data provided during training. The experiences presented rely on the TeachableMachine platform to create a machine learning model for classroom projects. These experiences are recorded in pedagogical sheets that ensure the applicability of these concepts and tools on different types of curricular content in diverse educational contexts.

Reconsidering a Picture Rewriting Rule-Based Programming Language for Preschool Children in Japan A Comprehensive Study Using Viscuit

Takeshi Watanabe, Nihon University, watanabe.takeshi@nihon-u.ac.jp
Yuriko Sekimizu, Kagawa-fujimigaoka Kindergarten

In Japan, in response to the mandatory implementation of programming education in elementary schools there is a growing trend in the private sector to offer programming education services for preschool children, and some kindergartens and nursery schools have started their own programming education programs. Furthermore, worldwide, the start of programming education is being accelerated at an early age. However, there has been little discussion about what kind of programming education should be provided to preschoolers and whether such education is possible. In this study, we draw a picture of how preschoolers can express themselves through programming as an ideal form of programming education for preschoolers using Viscuit that adapts picture rewriting rule.