BEADED ADVENTURES: USING TANGIBLE GAME ARTIFACTS TO ASSIST STEM LEARNING

Using Tangible Game Artifacts to Assist STEM Learning

EMILY K. JOHNSON AND ANNE SULLIVAN

Abstract

This paper describes the design principles guiding the creation of a versatile STEM education digital game, *BeadED Adventures*. Introducing the tangible aspect of tabletop games into a video game, *BeadED Adventures* is an interactive narrative where players solve STEM-based puzzles and make choices affecting the narrative plot by creating a tangible learning artifact: a string of beads that can be worn as a bracelet or used as a keychain, bookmark, etc.

The game's treatment of STEM subjects is intended to appeal to underrepresented youth who may be uninterested in these fields due to the way they are traditionally presented and represented. Following constructivist philosophies of learning and emphasizing player autonomy, the design of *BeadED Adventures* followed four main goals: to be engaging, to generate tangible learning artifacts, to encourage creativity, and to foster autonomy. A variety of future studies are planned to investigate the impact of this tangible learning artifact.

Background

Board games customarily require the player to physically interact with tangible elements in order to play the game. The *Chess* player moves the pieces by hand, the card game requires physical shuffling and dealing of the deck, and even tic-tac-toe requires a tangible writing implement. The digital versions of these respective games prevent the player from handling the game objects, placing them all on the digital screen as if under glass, removing the tactile element from the game experience altogether. In response, video games with non-standard and tangible interfaces are becoming more popular, especially among game design researchers (Carlsson, Choi, Pearce, & Smith, 2017; Lohmeyer, 2016; Sullivan & Smith, 2016) and specialized conference showcases such as alt.ctrl.GDC (alt.ctrl.GDC, 2018). By creating games with these types of interfaces, these designers are re-introducing touch and materiality back into video games.

As technology becomes more integrated with learning spaces, previously tactile education-oriented projects are also experiencing digitization and placement under glass. As more students gain access to mobile devices, traditionally hands-on learning activities from manipulatives to chemistry experiments are being recreated in digital spaces as simulations and games (e.g., Reimer & Moyer, 2005; Brinson, 2015; Squire et al., 2004). The loss of the tactile elements previously embedded within these educational activities, and the increasing popularity of digital games with tangible interfaces inspired the authors to design *BeadED Adventures*, an educational game with a child-friendly physical interface. We designed this game with the intent to leverage the affordances of digital games and tangible objects in an exploration game where players create tangible learning artifacts as they interact with STEM concepts.

BeadED Adventures

Inspired by the tangible artifact-creating game, *Loominary* (Sullivan, et. al 2018), *BeadED Adventures* operates using a Makey-Makey and a PC to display a choose-your-own-adventure story created in Twine. The game is set in an abandoned castle, which the player explores freely, learning and engaging with computational thinking content. We use pseudo-code rather than a specific coding language, so that the students are not required to learn syntax for a particular language. Throughout the castle, players interact with a variety of items and beings as they progress through the game. Each choice available to the player is presented as a series of options worded as second-person statements, like the popular *Choose Your Own Adventure* novels (Hendrix, 2011).

Beside the door in the dim light from the skylight down the hall, you discover a long, narrow ledge next to the door. Above it, on the wall is faded writing. The writing contains some words you can recognize, but in a strange order:

```
[IF marbles are aligned THEN
door IS unlocked
ELSE
door IS locked
ENDIF]
```

You try the handle. Locked.

You take a step forward to inspect this cryptic message, and you feel something bump your foot. Looking down, you discover seven marbles made of translucent blue glass scattered around on the floor.

You pick up the marbles and put them in your pocket—they could come in handy later. Then you retrace your steps back toward the skylight.

You look more closely at the ledge.

You turn around, retracing your steps back toward the skylight.

Image 1. An example puzzle teaching conditionals in BeadED Adventures.

The player makes a selection by lifting the dispenser containing the bead color corresponding to the story choice, removing a bead, and adding it to their bracelet (Figure 2). The sensor connected to the dispenser then records the player's selection as a button push when the dispenser is replaced, and advances to the next scene accordingly. At the end of the game, players will be able to take the tangible learning artifact they created as a record of their educational journey through the game. The string of beads can then be worn as a bracelet or used as a bookmark, keychain, etc.

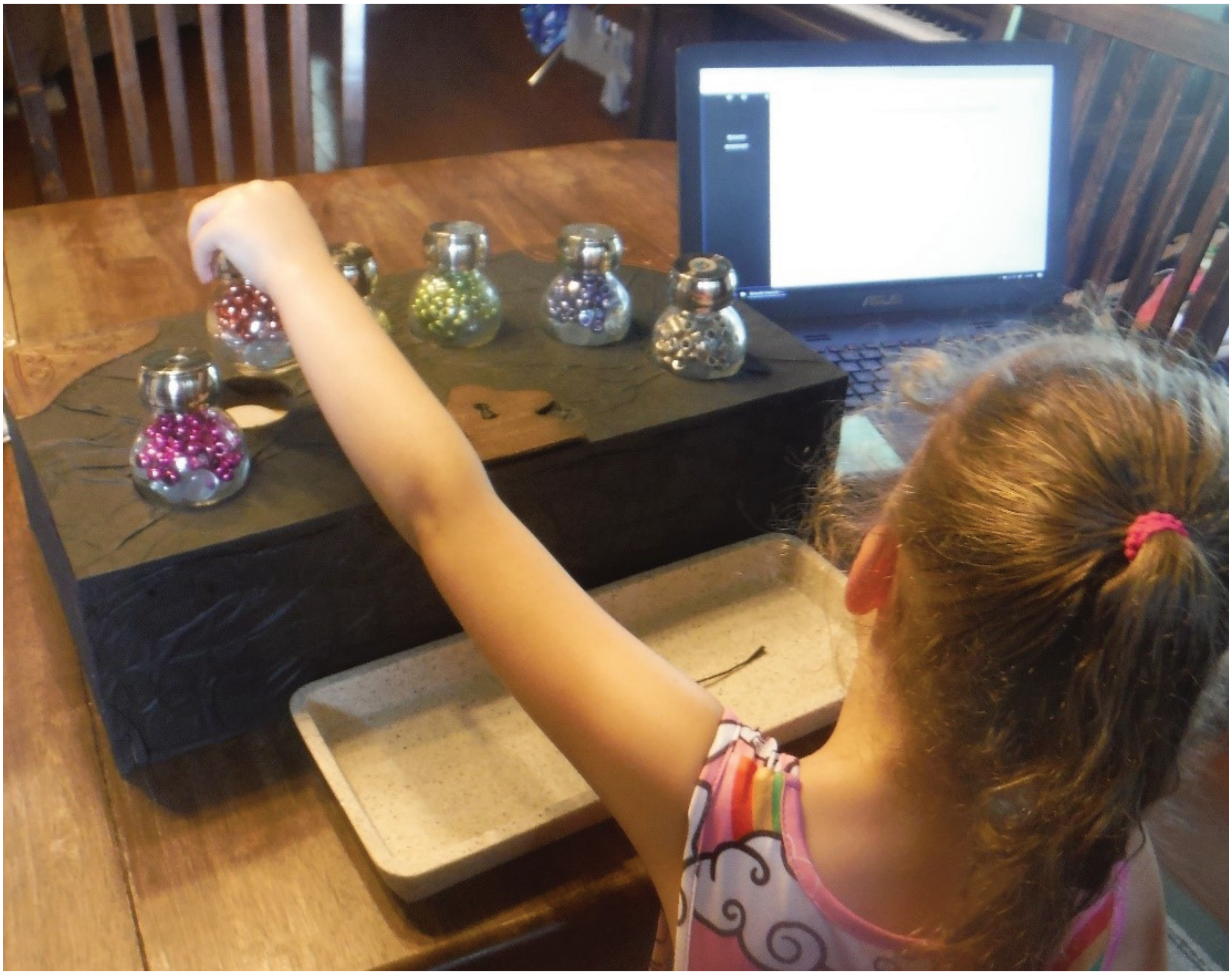

Image 2: Player selecting bronze beads to indicate her choice.

Like game artifacts developed to augment the player's retelling of gameplay for entertainment purposes (Sullivan & Smith, 2016), the bracelet a player creates in *BeadED Adventures* can later be referred to when recalling information learned in the game, compared with peer-created artifacts, and more. Additionally, we predict that the creation of the learning artifact will be a motivating factor for players—even those initially uninterested in STEM subjects—to approach and complete the game. The game is not intended to thoroughly teach the player how to code in any specific language, but rather to pique their interest and spur them to further their knowledge on their own.

Through exploration and narrative, the player interacts with educational content. The system is created in such a way that different games can address various STEM topics, and our first prototype focuses on computational thinking. The player chooses which areas in the castle to explore, and at various locations throughout the castle, there are puzzles they must leverage their newly constructed knowledge to solve. The castle in this early prototype has three areas, with player interactions within each area focusing on distinct aspects of computational thinking: variables, conditionals, and loops. Within each area, knowledge is gained through exploration, and a puzzle must be solved in order to move on to a different area. The final puzzle, which allows the player to leave the castle and ends the game, requires cumulative knowledge of all three areas.

Design and Educational Goals

Prior to the design of *BeadED Adventures*, we established a set of core principles to guide the game's design. We wanted to ensure that the game would:

1. Be engaging to the player
2. Generate a tangible, player-created, personalized learning artifact
3. Encourage creativity
4. Foster player autonomy

Before a game can teach, it must motivate learners to play—therefore, it must be engaging. We predict that the novelty of the tangible artifact will entice learners to begin the game, but we must ensure that the entire game is engaging and enjoyable so that players are motivated to continue playing and learning after the novelty factor wears off (Henderson & Yeow, 2012).

Next, the decision to have the player create the tactile learning artifact was both of necessity and purposeful. On one hand, we were not interested in engineering an automated beading system. On the other, we wanted the player to be involved in the physical creation of the artifact, predicting that this will increase learning retention, given that physical and even imagined manipulation of objects in relation to a text have been shown to increase reading comprehension (Glenberg et al., 2004). If players were simply handed an artifact at the conclusion of their gameplay session, we expect it would hold less meaning than the one they created during gameplay, and we hypothesize it would not be as useful as a knowledge recollection aid.

Additionally, we wanted the game to explore the coupling of creativity and learning. Creativity is a fundamental aspect of the nature of science (Peters & Kitsantas, 2010; Abd-El-Khalick, Bell, & Lederman, 1998). Research suggests that creative thinking practice can improve computational thinking skills (Miller et al., 2013), and that even students in middle school can create their own knowledge when the environment "sparks and then rewards creative ideas" (Sternberg & Lubart, 1991, p. 613).

Finally, autonomy is closely linked with intrinsic motivation in learners (Ryan & Deci, 2000). Player agency also plays a vital role in game enjoyment (Ryan, Rigby, & Przbylski, 2006). When players feel empowered to make their own choices in a game, they are more likely to enjoy the game and therefore keep playing. Providing learners with choices rather than a scripted instructional path is an established educational technique that empowers students and increases their motivation (Patall, Cooper, & Wynn, 2010; McCombs & Whisler, 1997; Passe, 1996).

For the informal settings where we envision this iteration of the game being played, we felt it was appropriate to remove direct instruction from the game and allow the learner to explore and acquire knowledge autonomously in an exploratory learning environment (ELE) (Guitierrez-Santos, Mavrikis, Geraniou, & Poulovassilis, 2015). Thus, unlike the scripted 'story bracelet' (*Thanksgiving Story Bracelet*, n.d.) or 'story retell' bracelet and bookmark (*Story Retell and Sequencing,* n.d.) activities sometimes seen in elementary classrooms, we designed *BeadED Adventures* to be less rigidly structured, which necessitated a setting that would naturally induce exploration.

These four principles work together to align with a constructivist philosophy of learning, which follows Piaget's (1970) theory of cognitive development. Constructivism (Bruning et al., 2004; Geary, 1995) and discovery learning theories assert that learners retain knowledge better if they construct it themselves (Bruner, 1961; Schunk, 2006). In this game, players will be physically constructing a tangible artifact while they mentally construct new STEM knowledge.

Additionally, because the game focuses on STEM content, a set of fields that can be perceived as intimidating or inaccessible to youth, especially underrepresented populations, we decided on a fantasy setting that we anticipated would be somewhat broadly enticing: an abandoned castle. Each possible interaction within the castle allows the player to experience some aspect of computational thinking, such as variables and conditionals. Some interactions in the game are more passive, presenting knowledge within the narrative structure and asking players to make choices focused on the plot of the story, while others are more interactive, requiring players to solve puzzles. The goal of these varied interactions is to provide players with a positive, informal introduction to computational thinking with the intent to increase their interest in the field.

By creating a game environment that does not appear to be stereotypically STEM or masculine, like a laboratory or industrial space might—the setting is intended to foster an environment where underrepresented populations can feel a sense of belonging (Dasgupta & Stout, 2014). We predict that having an approachable, widely-appealing game environment will also increase positive student experiences with STEM subjects. This is important because research suggests that learning experience prior to entering college can heavily influence the likelihood that a student will pursue a major in that field (Wang, 2013).

Conclusion

BeadED Adventures is a STEM learning game that allows for player agency, allowing players to construct their own learning artifact that reflects their unique path through the game environment and the knowledge they gained in their journey. The design of this educational game reintroduces the tangible element into the digital video game experience. Intended for informal learning environments, this game will expose new or hesitant audiences to STEM subjects in an approachable, appealing way.

The game design followed four goals: to be engaging, to generate tangible learning artifacts, to encourage creativity, and to foster autonomy. *BeadED Adventures* follows constructivist philosophies of learning and emphasizes player autonomy as they create learning artifacts that can aid in learning comprehension and recall of STEM concepts. Future studies are planned to assess the game's efficacy in teaching STEM concepts, player perceptions of the gameplay and the STEM content, and any player attitudes toward STEM subjects that may be influenced by the game.

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