# Designing for Productive Failure

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**Abstract:** Much of the appeal of educational games stems from the notion that players are persistent despite frequent failure and the possibility of re-producing that persistence in education. Our workshop brought together researchers in the humanities, cognitive science, and educational psychology as well as industry producers to discuss what makes failure appealing, why failure relates to learning, and how to design for productive failure. We explained why players seek out failure in video games when it makes them feel bad and what that means for learning. Confusion, in particular, facilitates learning when experimentally induced via the presentation of system breakdowns, contradictory information, and false feedback in learning tasks with computer agents. Individual differences in motivation, however, moderate learners' adaptive and non-adaptive responses to failure. The workshop generated discussions on how research can inform design and provided an example of a math program strategically developed to foster productive failure.

## Introduction

We could not learn without failure. In fact, trial and error may be the most fundamental learning mechanism in nature. It is how babies explore and get to know the world. What tastes good? What hurts? What makes us laugh? We try. We stumble. We revise. We try again. Sometimes we get it. Sometimes we abandon the task. If we only did things we already knew how to do, we would not learn anything. This kind of productive failure is prevalent in children's play and inherent in their games, particularly video games. Failure is the norm in most video games—success is the exception. How many replays does it take to complete a level of *Angry Birds* (Rovio Mobile, 2009) successfully? Players experiment with one strategy after another, making adjustments, trying again, keeping what works, and discarding what looks like unsuccessful ideas. It is a wonderful iterative learning process.

If only formal learning had such a positive relationship with failure.

Our workshop drew on the expertise of researchers in the humanities, cognitive science, and educational psychology as well as industry producers to discuss how to design for productive failure. Drawing from the book *The Art of Failure* (Juul, 2013), we discussed why video game players choose to engage in experiences that induce frequent failure. To explain the cognitive, emotional, and behavioral processes through which failure may promote learning, we presented research on the effect of confusion on learning as well as a study on how learners' motivation affects their responses to failure. Based on these presentations, about 50 workshop participants—including educators, researchers, and game designers—tackled three design challenges for promoting productive failure:

1. How can we keep the freedom to learn and experiment that we find in games, even when students are aware that they are playing in a context where they may be monitored?
2. How do we design games in a way that promotes mastery goal orientations?
3. How do we promote productive confusion, creating moments that are likely to involve failure in the short-term but can help students to understand concepts better in the long-term?

Wrapping up, we illustrated how research informed the design decisions made in *MATH 180* (Scholastic, 2013), a program strategically structured to promote productive failure.

## The Strange Appeal of Failure in Video Games

There is a paradox when it comes to failure in games. We generally avoid failure, a condition that is prevalent when we play games. Yet we seek out games even though that leads to experiencing something that we normally avoid. Juul (2013) argues that failure in a game is unique. The paradox of failure in games exists partly because games implicitly promise that when we are stuck, we can remedy the problem if we keep playing. Part of the success of video games depends on cultivating a situation of trust, where players genuinely believe that they have a fair chance of overcoming failure within the time that they have available. The feeling of escaping failure (often by improving skills) is central to the enjoyment of games.

Failure is crucial to learning because it makes us see new details and depth in the game that we are playing through experimentation. Part of the reason that deep knowledge is more likely to be developed through failures than successes is because we are more likely to search for causes for failure than causes for success (Weiner, 1985). Whereas success can make us complacent and believe that we have understood the system we are manipulating, failure gives the opportunity to consider why we failed.

Workshop participants were given the challenge of designing ways to keep the freedom to learn and experiment that is often characteristic of games, even when students are aware that they may be monitored. To reduce the negative effect of monitoring on promoting productive failure, participants suggested allowing students to flag the parts that others can view, offer help, and evaluate. This would preclude continuous monitoring. Others suggested creating a climate to redefine mistakes so that monitoring has a different effect, such as by framing mistakes as desirable feedback that are necessary for learning and progressing.

Another challenge for game designers is to push players to engage in situations in which failure is experienced because overcoming failure can lead to positive affect and learning, even though the experience of failure does not feel good. Designer Soren Johnson of the *Civilization* series describes it as a general problem that players seek out the optimal path to play a game and stick to it even when they find it fundamentally uninteresting. The strategy of lumberjacking in *Civilization III* (Firaxis Games, 2001) is one such example:

> Civilization III provides a simple example with “lumberjacking”—the practice of farming forests for infinite production. Chopping down a forest gives 10 hammers to the nearest city. However, forests can also be replanted once the appropriate tech is discovered. This set of rules encourages players to have a worker planting a forest and chopping it down on every tile within their empire in order to create an endless supply of hammers. However, the process itself is tedious and mind-numbing, killing the fun for players who wanted to play optimally. (Johnson, 2011, p. 32)

If players can reach their goal in an optimal way without challenge, they often do not seek a more challenging route for that same goal. Such examples introduces some doubt about the completeness of the *reversal theory*, which claims that we seek low arousal in normal goal-directed activities such as work, but high arousal (e.g., challenge, danger) in activities performed for their own sake, such as games (Kerr & Apter, 1991). Player psychology is more complex than that, with competing short-term goals of avoiding failure and long-term goals of overcoming failure in a challenging activity. Failure in itself is rarely fun, so environments that allow players to acquire new skills through overcoming failure need to be strategically designed.

## How Failure Impacts Learning: Cognitive, Emotional, and Behavioral Processes

It is appealing to recreate in educational environments the culture of how failure functions as a desirable feature in games given the potential adaptive effects of failure on learning. Drawing on two research strands, we discussed with workshop participants the cognitive, emotional, and behavioral processes during and after failure that promote learning. We first presented work on the effects of confusion on learning. Findings suggest that confusion can be successfully induced through different methods and that experiencing confusion during challenging learning tasks is crucial for learning. Second, we illustrated how learners’ motivation, as measured by achievement goals, influenced their reactions to failure while playing a collaborative game at a science museum.

### Effects of Confusion on Learning

Learning environments that challenge students and create failures can cause students to stop, think, and revise their current understanding. Confusion is one affective state that is likely to occur during this iterative revision process. There is considerable empirical evidence to support the claim that confusion is prevalent during complex learning and related to learning at deeper levels. Confusion occurs when students confront contradictions, anomalies, and discrepant events that create impasses and when students are uncertain about how to proceed (Carroll & Kay, 1988; D’Mello & Graesser, in press; VanLehn, Siler, Murray, Yamauchi, & Baggett, 2003). Not all experiences of confusion are beneficial for learning, however. For example, if a pedagogical agent speaks in a foreign language that the student does not understand, hopeless confusion that does not benefit learning is likely to occur. In contrast, productive confusion occurs in situations that can eventually be resolved by the student or with scaffolding supports by the learning environment. Thus, it is not the mere experience of confusion that leads to deeper learning; rather it is the effortful cognitive activities (e.g., problem solving, deliberation, reflection) that learners must engage in to resolve their confusion that leads to learning (VanLehn et al., 2003; Kapur, 2008).

The challenge then, which was posed to workshop participants, is how to create moments of productive confusion and then provide the appropriate scaffolds to ensure that students are able to successfully resolve their confusion. Among the many ideas were three overarching approaches to designing for productive confusion: (1) present contradicting information, (2) present a puzzle (or puzzling situation) to be solved, and (3) present a challenging problem that is beyond the student's current ability level. For the presentation of contradictory information, suggestions included showing students' multiple methods of solving a math problem and then discussing why one method was more effective than another. This type of activity can help students to not simply recognize the correct solution method but also reach a deeper understanding of *why* it is the correct method. The presentation of a puzzle (or puzzling situation) and a challenging problem were similar in that the student would not be able to quickly and easily solve the math problem and would instead have to deliberate over what is known and what are the possible methods for solving the problem. For example, one group proposed presenting a crime scene type of scenario that would require students to use their math skills to solve the crime.

In research with learning environments that are not game-based, confusion has been successfully induced to create learning opportunities. Confusion was experimentally induced during learning through system breakdowns, contradictory information (Lehman et al., 2013), and false system feedback across a series of experiments. Space limitations preclude a detailed discussion of these studies; however, they all revealed that confusion induction and regulation was generally a successful learning strategy. Across all three methods of confusion induction (system breakdowns, contradictory information, false feedback), students performed better when they were in a confusion induction condition than a no-induction control condition. In addition, when trajectories of participant confusion over time were investigated in the system breakdown experiments, findings illustrated that participants who had partially resolved their confusion performed better on a comprehension task than their counterparts who could not resolve their confusion.

Although the workshop discussion and previous research have proposed several methods to create productive confusion during learning, there is still a great deal of work left. First, for any method of confusion induction to be inducing *productive* confusion, the student must be capable of eventually resolving their confusion. This then requires the learning environment to also contain methods of aiding confusion regulation for when students cannot resolve their confusion on their own. Second, there are many different types of individual differences (prior knowledge levels, motivation levels, etc.) and it is unlikely that one approach to confusion induction or regulation will benefit all students. Thus, the next step in this line of research is to determine the method of confusion induction and confusion remediation that will most benefit different types of students. Future research will need to consider individual differences among students in determining the ideal combination of confusion induction and confusion regulation to maximize learning.

## Effects of Learner Motivation on Reactions to Failure

Addressing one facet of individual differences, we have looked at how learner motivation relates to gameplay and responses to failure in the context of collaborative games at a science museum. In particular, we assessed motivation through a measure of student achievement goal orientations (Dweck & Leggett, 1988). Researchers have distinguished two achievement goal orientations toward learning: mastery and performance. A mastery goal focuses on developing and mastering skills and knowledge whereas a performance goal focuses on appearing competent, such as by outperforming others or by avoiding appearing incompetent (Urdan, 2011). Research on achievement goals have suggested that mastery-oriented students thrive on challenge and often put in more effort after failure and process information more deeply, whereas their performance-oriented counterparts are more likely to respond to failure by holding back effort, declaring the task to be boring (Dweck & Leggett, 1988; Elliot, McGregor, & Gable, 1999). More specifically, those who adopt performance-avoid orientations of focusing on not appearing incompetent often attribute their failures to personal inadequacy such as intelligence, memory, or problem-solving ability rather than see failure as an opportunity for learning (Dweck & Leggett, 1988). While those performance-avoid students need more help, it is the mastery students who are more likely to seek help.

It remains to be known, however, if these motivational patterns play out in the same manner in game-based environments. Simulations at the Norwegian Museum of Science and Technology provided affordances for both mastery and performance goals, allowing us to explore how goal orientations function in a game context. The heat pump game (see Figure 1) was designed to help students learn about energy transfer and the relations among pressure, condensation, evaporation, and temperature. Students are challenged to keep the house temperature consistently warm throughout the year by physically rotating a metal crank to operate the heat pump at the appropriate speed and direction. This heats up or cools down the house as the heat pump inner workings dynamically move in real time in relation to the movements of the crank. The results screen following the game shows the percentage of time the house stayed within the desired temperature as well as a graph that highlights the amount of energy that was saved.

Prøv å holde temperaturen mer stabilt for å forbedre resultatet!

I løpet av året brukte du 47 KW timer. 15 gikk med til å drive varmepumpa, resten ble hentet fra lufta utendørs.

**Figure 1: Screenshots of the heat pump game during play (left) and at the end (right).**

Using principles of interaction analysis (Jordan & Henderson, 1995), we looked at how mastery and performance-oriented students (as indicated by self reports) interact with each other as well as with the digital artifacts in the games and simulations we designed. Preliminary video analyses and interviews with a subset of students revealed several types of information seeking after less-than-ideal game scores: *Social help seeking* (e.g., asking peers for help), *non-social information seeking* (e.g., looking at the digital simulation), and *vicarious learning* (e.g., watching someone else play to learn their technique). Within *social help seeking*, we have found *explicit* (e.g., asking a question) and *implicit* (e.g., saying I don't understand) examples. Within non-social information seeking, we have found subcategories of *active seeking* (e.g., testing out hypotheses by experimenting with the game to learn from game feedback) and *passive seeking* (e.g., reading the screen). Mastery oriented students engaged in greater number of different types of methods of help seeking to understand how the heat pump works and were more likely to seek explicit and active help to understand the scientific mechanisms of how the heat pump works. Performance oriented students sought information primarily through indirect social help seeking and passive information seeking to maximize their scores but focused on understanding the science when they thought that understanding aligned with achieving higher scores. As such, for performance-oriented students, it is particularly adaptive to have the science content and points be integrative rather than complementary.

To understand how motivation affects responses to failure in game-based learning, it is necessary to extend the current theoretical literature on achievement goals to that context. Interaction analyses contributed to a better understanding of how social dynamics and the physical and digital artifacts of the learning environment interacted with student motivation to affect their information seeking behaviors. Workshop participants discussed the challenge of designing games in a way that promotes mastery goal orientations. A major theme that emerged was reducing the negative impact of risk and incentivizing risk. Suggestions for encouraging risk-taking included incorporating a save element to reduce the cost of mistakes as well as rewarding experimental behaviors such as attempting several methods for solving the same problem. Others suggested allowing for mistakes that do not matter at the beginning, perhaps through an exploration phase of the game that is not tied to points. It was pointed out that in non-educational games, the consequences of mistakes are often much smaller and more manageable at the beginning and then grow as the game gets harder. Educational games may benefit learning by following a similar model. Understanding how students respond to failure and what influences them to adaptively respond to failure by processing information more deeply can provide insights about how to design learning environments that promote productive failure.

## Designing for Productive Failure: The Case of *MATH 180*

Illustrating how insights and research on productive failure can be applied, we discussed how *MATH 180* (Scholastic, 2013) was strategically designed to foster productive failure. The math intervention curriculum blends teacher-led group instruction with personalized and adaptive computer-facilitated learning, exploration, and practice. Below we highlight how the program addressed each of the three design challenges described above.

*1. How can we keep the freedom to learn and experiment that we find in games, even when students are aware that they are playing in a context where they may be monitored?*

Even game players can become risk averse when they feel their play is being observed and evaluated. The classroom context matters (Steuer, et al, 2013), and the first two weeks of *MATH 180* are devoted to orienting students and teachers into the classroom norms and routines that foster a growth mindset (Mueller & Dweck, 1998) and establish a climate that respects errors as a natural part of learning. The individualized software reinforces risk-taking and personal growth through, among other features, the supportive guidance of an online host and coach and a feedback system that promotes self-monitoring, self-correction, and self-control.

*2. How do we design games in a way that promotes mastery goal orientations?*

Throughout the program students receive ongoing feedback on their personal progress and growth. A News Feed on the student dashboard provides personal daily reminders of recent mathematical achievements as well as new accomplishments that are within reach. A math GPS lets students know where they are in the program and shows the connections among their evolving mathematical network of knowledge. In addition a rich and transparent badge system (see Figure 2) honors students not just for improving their math skills but also for improving their perseverance and focus. Points, scores, and badges are all clearly tied to mathematical effort, perseverance, and performance.

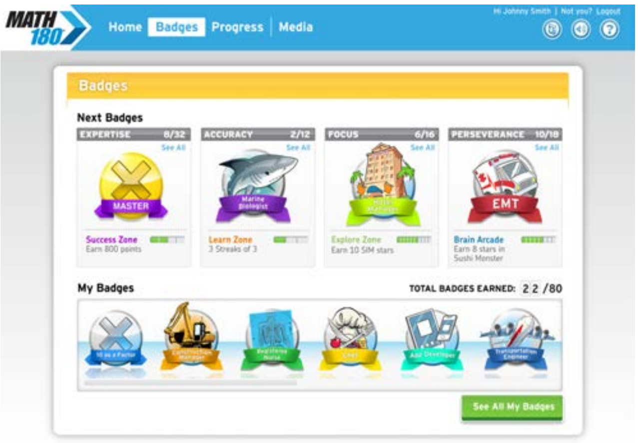

**Figure 2: Screenshot of the student badge system in *MATH 180*.**

*3. How do we promote productive confusion, creating moments that are likely to involve failure in the short-term but can help students to understand concepts better in the long-term?*

*MATH 180* creates a culture that, like gaming, welcomes challenges, where confusion and struggle are natural and expected parts of the learning process. When students expect to struggle they are less likely to surrender in the face of obstacles (Wilson & Linvelle, 1985). In addition, the program incorporates tasks that are designed to generate confusion that is productive to the targeted learning. For example, one activity asks students which number doesn't belong in this collection: 9, 16, 25, and 43. The task has multiple "right" answers because 16 could be the oddball because it's even, 9 because its digits don't add up to seven, 43 because it's not a perfect square, 25 because the digit in the ones place isn't a multiple of 3, and so on. In the context of a traditional math class, simply having more than one correct answer could be confusing to students, and the program uses these multiple possibilities to encourage more student thoughtfulness and to give them practice consolidating and articulating their reasoning.

The software games also foster productive confusion. In *You're Toast* (see Figure 3), students must butter numbered pieces of toast from least to greatest, making strings of at least three.

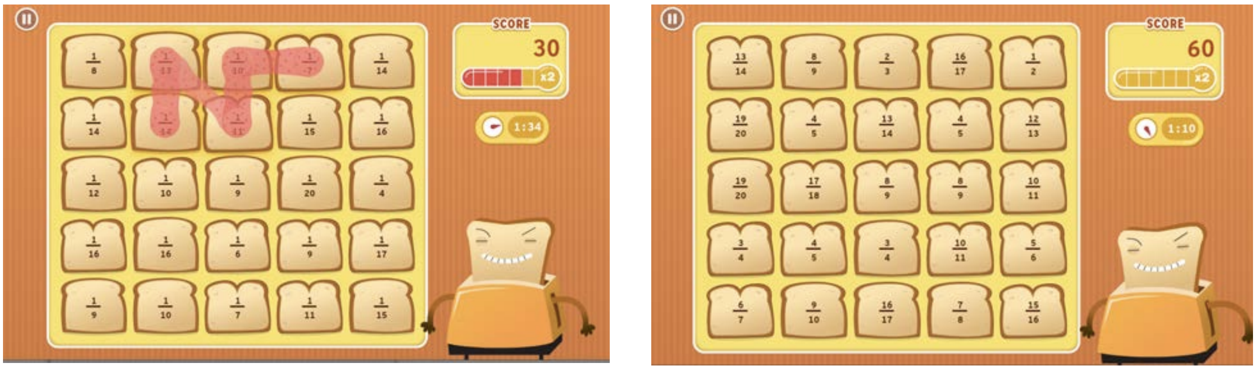

**Figure 3: Screenshot of the game *You're Toast* in *MATH 180*.**

Shifting from ordering whole numbers to ordering unit fractions creates some initial confusion because the larger the denominator, the smaller the fraction (5 < 8 but 1/5 > 1/8). Then shifting to ordering fractions one unit less than the whole generates another moment of confusion (4/5 < 7/8). This purposeful organization of content levels is meant to force students to reassess their thinking and break any over-routinized patterns.

## Conclusion

Our workshop fostered conversations about how theories and research from different fields can help us design learning environments that promote productive failure. In doing so, we explored how these different perspectives build on each other, conflict with each other, and inform design in different contexts. Video games, for instance, differ from formal learning in that for the latter, while we may embrace errors as part of the learning process, making mistakes is not always productive. A challenge to incorporating productive failure in learning is that we need to consider that at some point we want students to master certain skills. In a similar vein, athletes and sports teams anticipate a learning curve as they develop their skills and game plans. The early practices might be somewhat experimental, filled with mistakes that are quickly corrected. Over time the number of mistakes diminishes, and by the time of the big match or game, execution should be error-free. We expect and tolerate failure within the learning process, but at some point what has been learned should become routine.

Perhaps where failure belongs in a learning progression is where gaming can have a natural home. In the progression from instruction to practice to performance, it is during the practice phase that the stakes especially need to be low, the consequences of failure nil. Students are playing to learn, to gain self-mastery. Their results should be guarded or at least under their control. As students gain competence, the stakes can rise until it is really time to perform. Future research can address how to strategically integrate games into the learning progression, taking into account individual differences in motivation, prior achievement levels, and context.

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