PLANET K: THE APPLICATION OF GAME AND INSTRUCTIONAL DESIGN PRACTICES IN THE FORMATIVE EVALUATION OF AN EDUCATIONAL GAME PROTOTYPE

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ABSTRACT

Formative evaluation, an essential component in the design process for high quality instructional materials, can help designers meet the sometimes contradictory goals of educational games, namely high levels of player engagement and enhanced learning outcomes. To address these goals, we drew on research-based best practices from two fields: entertainment game design and instructional design. We applied Merrill's e3 framework to guide the development of questions for our formative evaluation of an early prototype of Planet K, a video game designed for undergraduate electrical engineering and computer programming students to help them learn principles of digital circuit design. A usability study and expert review were conducted, resulting in five categories of revisions, which were then made to Planet K. A pilot test of the new iteration of the game showed that this approach to formative assessment successfully enhanced the game's impact on learning.

KEYWORDS

digital circuit design, educational game, e3 Framework, formative evaluation, game-based learning, game prototype, iterative design, Planet K

1. INTRODUCTION

Game designers have long engaged in a variety of formative evaluation practices during the design and development process for a game, the goal of which is to improve players' overall experience of the game. These practices include internal design reviews, usability testing, and playtesting [1-3]. However, as games gain credibility within education as a means to engage learners, these practices may be insufficient to address the primary goal of educational games, namely to create the conditions for players to reach established learning outcomes.

Instructional designers have also long engaged in formative evaluation, but the primary focus of this evaluation has typically been to determine whether a particular instructional material or approach leads to learning, and how the instruction can be enhanced to improve learning outcomes. Formative evaluation practices include professional reviews, one-on-one or small group evaluations, small scale pilot tests and larger scale field tests. In addition to examining learning outcomes, instructional designers typically gather data about learner attitude toward the instructional materials at multiple points throughout formative evaluation [4-6] that can be used

to anticipate student engagement. However, for instructional designers, engagement is not an end in itself but rather a means toward increasing learners' time on task and motivation to persevere in a particular area of study.

Formative evaluation is especially important in educational games because of the tension between the two main goals of these games, namely engagement and learning. Mayer and Johnson [7] argue that the gaming components of an educational game may enhance engagement, but also can increase the need to process material extraneous to the learning objectives; this increased cognitive load can undermine learning. Meanwhile, learning components can diminish the motivation to continue playing, which decreases the potential of the game to engage the learner in sustained, deeper levels of engagement essential to generative learning. Though designers attempt to capitalize on the engaging nature of games to make learning more compelling, decisions made to enhance one of these goals can undermine the other.

Given that educational games fall within the natural purview of both game designers and instructional designers, both fields can contribute to our understanding of how best to refine educational games through formative evaluation. Two related characteristics of formative evaluation common to game and instructional designers is that formative evaluation should be iterative and should evolve over the course of a project to reflect ever more nuanced issues [8-10]. In this article, we describe the formative evaluation we did with the prototype of *Planet K*, a computer-based game designed to help undergraduate engineering students learn digital circuit design. Our process drew on the types of testing done in the fields of both game and instructional design and can serve as an illustration of the multiple directions from which an educational game needs to be reviewed while still a prototype.

To guide the design of our formative evaluation, we considered the implications of Merrill's e3 framework [5] for how it could inform the formative evaluation of educational games. Merrill has long argued that good instruction must be *effective*, *efficient*, and *engaging* [11]. *Effective* learning materials help learners reach established learning objectives. Examining the effectiveness of a learning game from an early stage is made all the more important by the fact that, even though research has begun to emerge that suggest that games can impact learning [12], there is concern within the field that the effectiveness of games to promote learning is still understudied [13]. For games to gain credibility in education, formative evaluation must focus from an early stage on whether a game leads to measurable learning outcomes and on identifying ways to refine that game to better support learning.

Efficient learning materials help learners reach desired learning outcomes in the least amount of time necessary, a goal at which games may not excel. Suits [14] argued that games are inherently inefficient, and research has supported this. For example, Adams, Mayer, MacNamara, Koenig, and Wainess [15] compared two different games with slide-presentations of the same content for each and found that students in the slide-presentation treatment condition learned more in less than half the time. Games may have other advantages that justify their use, but the goal of making instruction efficient does suggest a number of guidelines that should be considered in the formative evaluation of a game. The extra time a learner needs to invest in a game over other more direct approaches to instruction should be spent on tasks that support meeting the learning objectives of the game. In other words, time spent figuring out an interface or learning complicated rules of play have value only if they also help the learner to reflect on the content they are learning. Formative evaluation therefore should include an examination of how players are spending their time and whether that is a productive use of their time from a learning perspective.

Engaging instruction maintains learner interest, thus increasing *engaged* time on task (time students spend actively engaged in a task, as opposed to the time allocated for the task), a variable shown to enhance learning outcomes [16]. Instructional designers often draw on Keller's ARCS model of motivational design to make instruction engaging [17]. This model suggests that in order to establish and maintain learner motivation, instruction should be designed with four factors in mind: attention, relevance, confidence, and satisfaction. Games fare well from the perspective of the ARCS model. An engaging storyline, appealing graphics, and immediate interactivity are likely to gain the learners' attention. The relevance of the game to a learner's progress toward a learning goal may not be readily apparent, though some educational games cast players in the role of an expert or decision maker in a field (epistemic games), which can help learners to recognize real world uses of the information and skills addressed in the game [18]. Games naturally promote confidence by ensuring early success and building gradually to more challenging levels, providing feedback within the context of the game so that learners develop a sense of control over the outcomes. Finally, good games are satisfying by their nature, providing players with a sense of achievement as they progress or "beat" the game. However, attention, relevance, confidence and satisfaction are not necessarily sufficient when learners are expecting what they believe games are supposed to deliver, namely "fun." For instructional designers, fun is a gratifying (and perhaps surprising) outcome, but would typically give way when it is at odds with learning outcomes. Nor does the ARCS model help in identifying game features that limit playability, undermining the user experience. Clearly, practices drawn from entertainment game designers could strengthen formative evaluation for learner engagement.

2. OVERVIEW OF PLANET K

Planet K [19] is an educational game designed to help players learn how to design digital circuits. The target audience for the game is primarily undergraduate engineering and computer science students, though we also anticipate using it with advanced high school students interested in pursuing engineering or computer science degrees. In *Planet K*, (K is for Karnaugh) players enter a 3D virtual environment: an abandoned alien world in which they must repair various technologies and overcome obstacles by designing or fixing circuits (see Figures 1 and 2). In the prototype we tested, the premise is lightly humorous; the player is cast in the role of "Space Cadet" and sent on a secret mission. His ship crash lands on an alien planet and must be fixed before he can continue on the journey. The ship's computer (a.k.a. "Grandmother") tells the Cadet that items needed to repair the ship can be found on the planet. The player encounters digital design problems at "pylons" scattered throughout the game environment. Solving the problems in a pylon changes the environment so that the player can advance.

Figure 1. Opening cutscene in *Planet K*.

Figure 2. World environment in *Planet K*.

The game is organized into five *worlds*, though the prototype we tested included only worlds 0, 1, and part of 2. Digital circuit design problems are presented in the form of truth tables, Boolean expressions, or word problems (see Figure 3). The player can drag and drop gates and custom building blocks from an inventory box onto a board that has the external inputs and outputs, and make connections. Players can examine their circuits using Logic Flow, a tool that allows them to follow the circuit from inputs to outputs observing what happens for each input combination, which supports debugging. The game also contains Logic Help, a resource that provides structured, textbook-like material about all topics addressed in the game.

The development of *Planet K* was funded by the National Science Foundation [grant number 1225716]. To learn more about *Planet K*, you can visit the website at http://planetk.tamu.edu/.

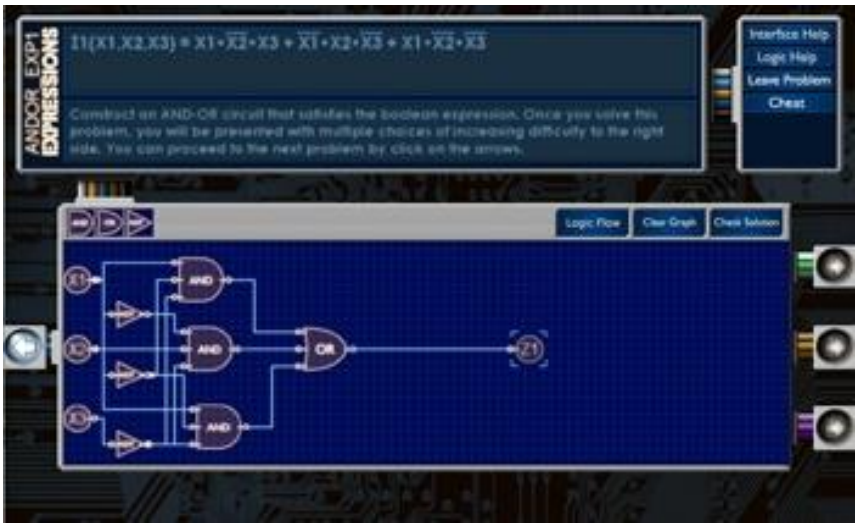

Figure 3. Digital circuit design component in *Planet K*.

3. QUESTIONS

In our early testing of the prototype for *Planet K* we sought to reflect on how to improve its effectiveness, efficiency, and engagement. The specific questions here were shaped by the stage of development of the game and are not the only questions relevant to these goals of an educational game. However, they are examples of questions that provide useful insights into an prototype of a game, insights which can lead to thoughtful iterative design and steady improvements in the game.

Effectiveness: The results of early testing of a game prototype are not likely to show that it is more effective than other learning approaches as a means to help players achieve the established learning objectives. Rather this testing can yield insights into both the game, in terms of barriers to learning and types of support that can be built in to support learning, and the test itself in terms of its alignment to the learning objectives addressed in the game and it validity (whether it actually measures what it is designed to measure). Therefore, at this early stage of evaluating a prototype it is important to consider whether there is some indication of the potential of the game to lead to learning. To reflect on this, we asked two questions:

1. Do students who use the video game show improvement in designing combinational circuits?
2. Do students believe a video game that is an expansion of the prototype would enhance learning?

Efficiency: Though games may not be the fastest way to learn, the extra effort they require should be directed toward content rather than game mechanics. In examining the efficiency of a game, it is important to determine if players can use the game features with a minimum of investment in figuring out the interface or functionality of the various components of the game. At this early stage in the development of *Planet K*, we wanted to know what features within the game were confusing or awkward for players. We therefore asked

3. Is the prototype intuitive to use? How can it be improved?

Engagement: At the early stage of testing a game prototype, player opinion about the quality of their experience in the game and which features make the game enjoyable and compelling can be invaluable. Because an early game prototype is unlikely to require very long to play, it is difficult at this point to reflect on how the full game is likely to impact time-on-task for learning through observation or game logs. We therefore collected data to gain an understanding of the opinions players had about the game as a whole and about specific game features. Our question was

4. What do students like/dislike about the prototype premise and format?

4. METHODS

In order to answer the research questions, we drew upon three different techniques for evaluation: usability testing, expert review, and pilot testing. The usability test and expert review were conducted approximately three weeks before the pilot test, and revisions based on some of these results were made to the game prior to the pilot test.

The usability study was conducted on two days. Two undergraduate and two graduate students enrolled in electrical engineering classes at a large university participated in one-on-one tests of the game during which the internal evaluator for the project observed the participants using the game, interrupting to ask questions about user actions and opinions.

Participants were shown how to log into the program, then were asked to begin using it without additional help, sharing their reasons for their actions, concerns, and suggestions as they progressed through the program. The evaluator took notes as participants worked, recording students' points of confusions and suggestions, as well as observations about what tools they accessed within the program. Each test lasted approximately 45 minutes. The following questions were used to guide discussion; additional questions based on students' responses and suggestions were also posed.

- Was there any time when you wanted to quit the game because of the interface issue?
- It seems like you find this section frustrating. Could you tell me the reason for it?
- Did you have any trouble figuring out how to do something you wanted to do?
- Do you think that the game should start with a tutorial on how to play?
- If students accessed Logic Help: Did you find the information in Help to be useful? Would it be better to be able to see a video of someone solving a problem?

The expert review was conducted by the internal evaluator in conjunction with the usability study. The internal evaluator was an expert on instructional design with over a decade of experience in designing educational games. The expert first played through the prototype, noting possible issues to examine further during the usability study. After gathering data from participants in the usability study, the expert again played through the game and consolidated results from the usability study with insights from gameplay and knowledge of effective instructional design.

The pilot test was administered with 13 volunteer students: nine males and four females. Nine of these students were freshmen enrolled in an Introduction to Engineering course at the time of the study or the previous semester. These students were considered members of the target audience for this game. Seven students were majors in computer engineering and six were majoring in

electrical engineering. Students logged into the video game and were allowed to play for up to 75 minutes. Two instruments were used for data collection: a participant survey and a concept test. The participant survey consisted of 27 items; 8 items dealt with demographic information,

14 were Likert-style items with four responses ranging from Strongly Agree to Strongly Disagree and addressed opinions about the game, and 5 were open-ended questions. The concept test consisted of two items that asked students to solve problems about the design of two-level sum of products combinational circuits using truth tables, which were similar to the ones presented in the game. The test was administered both before and after students played the game. Both the pre and post test versions presented the same types of problems but the problems themselves were not identical.

Students completed consent forms then took the pretest version of the concept test. Students then logged into the video game. Nine of the 13 participating students finished before the end of the 75-minute period allotted to game play. After they finished playing the game, students were asked to complete the participant survey and posttest.

5. RESULTS

5.1. Usability Study and Expert Review

The usability study and expert review resulted in 16 suggestions for modifications to the prototype. We have grouped these suggestions into five general categories that may reflect the types of revisions typical for early game prototypes.

5.1.1. Navigation

All of the participants in the usability study expressed some frustration with navigation through the 3D world, including that movement was to free and fast and that they could roam too freely around the environment, both of which were disorienting. Suggestions to rectify these issues included slowing down the mouse and setting boundaries around the ceiling and floor of then environment so a player was restricted in where they could “look” and providing a map of the entire environment or constraining players’ path through the environment so they could access only limited portions of it at a time.

5.1.2. Orientation

Results suggested that players needed better support in developing a sense of what the game contained and how to progress through it. All participants were unsure of how many problems there were to solve, how well they were progressing in the game, and how their actions were connected with the premise of the game, namely to gather items to repair their ship. Suggested revisions included providing an overview of the game, more training in the first world, or a problem map players could access at will. Players also suggested various plot developments and tasks that could enhance the storyline and connect their actions within the game to the overall premise.

5.1.3. Intuitive Tool Design

Six of the suggestions that arose from this round of formative evaluation were related to specific tools with the game. These included suggestions such as making the interface help resource easier to scan, adding video-based demonstrations to Logic Help rather than just offering text-

based guidance, changing the names of buttons to be more specific about their function, and establishing a sequence of how the game would allow the player to try again after an incorrect design.

5.1.4. Support for Learning

Participants were able to complete the problems in this early prototype, though some struggled and requested both better support if they got stuck and a way to skip a problem they could not figure out. Suggestions for dealing with this issue was to make Logic Help a more robust resource, containing context-sensitive help for the current problem players are tackling when they access it, as well as the need for a protocol for how players could skip a problem they could not solve so that their progress in the game was not halted.

5.1.5. Media

The only media issue that arose during testing concerned the background audio, with participants muting the game after a few minutes of play. They suggested the use of background audio while moving around within the environment, but silence when the player was designing circuits.

5.2. Pilot Test

Based on the results of the usability study and expert review, a number of changes were made to the prototype prior to conducting the pilot test. A simple, text-based opening sequence was developed to provide a context for player's actions within the game environment and a monkey character appeared in dialog boxes during worlds 0 and 1 to provide guidance. An interactive map was developed to help players stay oriented within the environment. Basic usability and navigation revisions suggested above were implemented.

5.2.1. Participant Survey

The demographic data from the participant survey showed that males reported having played video games for more years and for more hours a week than females. All students responded favorably to the idea of teaching course material in electrical engineering through video games. The means for the Likert items are shown in table 1. These items were scored on a 4 point scale, with 4 = strongly agree and 1 = strongly disagree.

Table 1. Means for Likert Items in Participant Survey.

Item	Overall Mean	Mean for Males	Mean for Females	Mean for Lower Classmen	Mean for Upper Classmen
1. I was quickly able to figure out how to use the Video Game prototype.	3.31	3.44	3.00	3.22	3.50
2. I found it easy to navigate through the 3D environment.	3.23	3.33	3.00	3.33	3.00
3. I felt that I always knew where I was within the 3D world.	2.77	2.78	2.75	2.67	3.00
4. I was provided with clear exit points in the game.	3.38	3.33	3.50	3.22	3.75
5. I had access to help on how to build circuits and instructions within the game when I needed them.	3.69	3.67	3.75	3.56	4.00

6.	It was easy to figure out how to solve the first problem.	3.69	3.67	3.75	3.67	3.75
7.	Once I figured out how to solve the first problem, the remaining problems were easy to figure out.	2.23	2.00	2.75	1.89	3.00
8.	I got useful feedback on how well I was doing as I worked on each problem.	2.92	2.67	3.50	2.67	3.50
9.	I would prefer doing problems in this manner to doing them on paper.	3.31	3.22	3.50	3.56	2.75
10.	I am more motivated to practice problems by this method than through other methods.	3.46	3.44	3.50	3.44	3.50
11.	I improved my understanding of combinational circuits by playing this game.	3.08	3.00	3.25	3.11	3.00
12.	This game would be a good approach for novices to learn about combinational circuits.	3.00	2.78	3.50	2.89	3.25
13.	This game is a better approach for learning about combinational circuits than the approach used in the class where I first learned about combinational circuits.	3.08	2.89	3.50	3.22	2.75
14.	In general, video games can be a good way to learn about many topics in electrical engineering.	3.46	3.33	3.75	3.44	3.50

The participant survey contains open-ended questions; the following is a summary of the responses participants gave.

The video game prototype switches between 3D AND 2D. Did you find that annoying? Overwhelmingly, participants said they did not find this feature annoying or even notice it.
What features, if any, of the video game prototype were confusing or difficult to use? Participants identified three confusing features: how to create wires and make connections to the gates, the lack of explanation for why a circuit did not work (feedback only indicated whether a solution was correct or not), and the use of WASD keys was confusing for participants with little gaming experience.

What features would you like to see added/changed/ deleted in the video game prototype? Multiple suggestions focused on making the game more challenging, such as limiting the number of gates a player could use in designing a circuit , providing time limits, or including bonus levels with more complex circuits. Other suggestions focused on providing support from when players become stuck, including the provision of hints or explanations that players could access.
What did you like about the video game prototype? Participants liked the Logic flow feature. They also said they enjoyed the sense of achievement they got through solving the problems and thought the game was challenging and fun.

5.2.2. Pretest/Posttest

The pretest and posttest were completed by the nine students who were members of the target audience. Each of the two problems on the test was worth 1 point. It was possible for students to receive a score of 0, .5, or 1 on each of the two problems, meaning that scores ranged from 0 to 2.

The mean score for the pretest was .22, and the mean score for the posttest was .72. Eight of the nine students received a score of 0 on the pretest; one student received a perfect score, indicating that this student was already proficient in solving the types of problems addressed in the game. Of the remaining eight students, four students improved their scores on the posttest, while four students again received a score of 0. Because of the small sample size, no analysis of variance was conducted.

5.3. Application of Results to Formative Evaluation Questions

Participants' reaction to the game was generally positive. All students appeared to be genuinely engaged in the game during the pilot test. Several students continued to play the game well beyond the allotted time in an effort to reach the exit and complete the game. We also observed that students were more methodical in their approach to solving the later-stage problems, while they used more of a trial-and-error approach to the early stage problems. This seems to indicate

that students did learn something about the process of solving the circuit design problems, although an analysis of their performance on the posttest does not necessarily demonstrate this learning.

After the completion of the pilot test, we again examined the results in order to determine the further revisions and additions most likely to enhance player learning and engagement. Drawing on the results of the usability study, expert review, and pilot test, we developed the following answers to our four questions.

5.3.1. Do students who use the video game show improvement in designing combinational circuits?

The difference between pretest scores (mean = .22 out of 2.00) and posttest scores (mean = .72 out of 2.00) suggests that at least some of the participants in the pilot study did improve their understanding of combinational circuits by playing the video game. Given the brevity of the game, this rise in scores is promising. However, the results suggest that learning could be enhanced in the game by adding some features that would provide instruction and support for students if they experience difficulty in solving the problems.

As a result of our testing, we developed two modifications to enhance learning from this game. First, we completely revised Logic Help to be an extensive context-sensitive information resource explaining the key concepts that the game is designed to help students to practice. Logic Help is available throughout the game and under player control; players can click the Logic Help button while they are using the digital circuit design interface at any time. Second, a Check Solution feature was enhanced to better help players determine which parts of the problem had been successfully solved and which had not. For example, if a problem is presented in the form of a truth table, when players click the Check Solution feature the game displays which rows have been satisfied and which have not.

Given that four of the nine members of the target audience who participated in the pilot test failed to show improvement from pretest to post despite the relatively high score on the attitude item "I improved my understanding of combinational circuits by playing this game," we decided that we needed to develop a new concept test that was better able to assess the range of objectives addressed in the game and the different degrees of achievement of those objectives.

5.3.2. Do students believe a video game that is an expansion of the prototype would enhance learning?

Students' responses to the item "In general, video games can be a good way to learn about many topics in electrical engineering" on the participant survey suggest that they generally support the use of games for learning in electrical engineering (mean = 3.46 out of 4.00). However, their responses to the items "This game would be a good approach for novices to learn about combinational circuits" and "This game is a better approach for learning about combinational circuits than the approach used in the class where I first learned about combinational circuits," though still positive, suggest that they are less certain about whether this particular game would be an effective method for novices to learn about combinational circuits and whether the game is superior to classroom instruction (means = 3.00 and 3.08 respectively out of 4.00). One possible reason was that several participants (primarily the males and lowerclassmen) felt the feedback offered in the program was lacking ("I got useful feedback on how well I was doing as I worked on each problem" mean = 2.92 out of 4.00). Though these results are generally positive for an early prototype, they reinforced the need to provide additional supports for learning within the game.

5.3.3. Is the prototype intuitive? How can it be improved?

The participant survey showed that all participants felt that the game was intuitive to use (3.31 out of 4.00) and they were able to navigate through the 3D environment comfortably (3.23 out of 4.00). The high score (3.69 out of 4.00) on the question about sufficient access to help and instructions suggests that the prototype provided the needed guidance to navigate through the

environment and use the features in the problem interface to design circuits. However, some participants expressed some initial confusion in learning how to create wires and connect them to gates. We therefore expanded the Interface Help feature to include a brief video of how to get started with the tools in the problem interface.

One area we identified as needing improvement was in user orientation within the game. Even with the map feature that was added between the usability study and the pilot test, some students felt disoriented in the 3D world, as shown by the score on item 11 of the participant survey which asked if they always knew where they were within the 3D world (2.77 out of 4.00). As a result, we determined that the 3D world needed a more memorable terrain, and that players needed less freedom in their path through the game, with some sections becoming linear and others offering a limited number of choices within a given section of a world.

5.3.4. What do students like/ dislike about the premise and format of the game?

Participants' reaction to the game was generally positive. Responses on the participant survey suggest that they prefer solving problems within the context of the video game to other options and that they liked many aspects of the gaming environment, including the sense of achievement derived from making progress in the game, the opportunity to track their designs using the Logic Flow feature, and the overall challenge and fun of the game.

Though altogether students were quite positive about the game, they did offer some suggestions for improvements to its premise and format. First, in both the usability study and the pilot test, some students suggested adding a narrative to the game that would tie solving the problems together and which could make the game more challenging. Even though a basic storyline was added between the usability and pilot tests, students still felt a limited sense of purpose for navigating within the environment. Though we had anticipated needing to expand and enrich the

game's storyline, students' comments showed the importance of rewarding their efforts to design circuits by advancing them within an interesting narrative. We recognized that, though an interesting premise might initially engage learners, maintaining their engagement would require establishing multiple challenges within the 3D environment and a compelling narrative arch with a satisfying climax and resolution. Second, throughout both the usability and pilot tests, students requested additional features that they could access when they were unable to solve a problem. Access to a better information resource on the skills practiced in the program and explanatory feedback for incorrect solutions were two suggestions students offered. As discussed above, we decided to develop Logic Help into a context-sensitive, more comprehensive resource. We also decided to create a Skip Problem button that would allow players to skip up to three problems in any world before halting their advance in the game. This feature would mean that if students simply could not solve a specific problem (e.g. they might misunderstand it or have made a simple mistake they do not recognize), they could still continue to play, but they cannot simply skip any problem that looks too challenging.

One other suggestion that came out of testing the prototype was that the game should offer additional levels or bonus problems. We did not take this suggestion as is, but interpreted to mean that players want some level of control over which and how many problems they solve. We therefore implemented a complicated feature: the problem map. Within each pylon, students can choose different paths through the problems it contains. Students who want to go straight to the most challenging problems can take a path that skips several simpler ones. Students who want additional practice can choose a path that includes more problems. If a student changes his or her mind, they can change their path within the pylon. In future tests we will examine how this feature impacts student engagement with the game.

6. DISCUSSION

Formative evaluation is an essential part of the design process generally, and is particularly necessary when design is made complex by varied and competing goals, as in educational games.

It is therefore important that as games become part of mainstream educational materials that designers share the ways in which they refine their games through formative evaluation. Our work thus far with *Planet K* led to several insights into effective formative evaluation practices that we believe apply more broadly to educational games.

First, it was clear from our results that the use of diverse sources of information resulted in richer insights into the types of revisions that could enhance both learning and engagement in *Planet K*. Drawing on the practices of both game designers and instructional designers helped to identify the need for revisions tailored to the complex goals of an educational game. The usability test and expert review not only led to the identification of some interface revisions but also laid the groundwork for some of the questions we asked in the attitude survey during the pilot test. The results of all the different data sources showed not just a need for better feedback and help sources within the game, but also suggested some specific ways in which these components of instruction could be improved.

Second, educational games are, by their nature, not efficient forms of instruction. Their goal is less to minimize the time necessary for learning and more to promote sustained engagement and continued interest. However, designers still need to consider efficiency in the design of their games. This means eliminating or modifying game features that are laborious or confusing so that the player does not waste time on tasks irrelevant to the desired learning outcomes or the compelling aspects of game play. Player time spent on activities such as learning how to use various interface features or finding resources that can help them when they are unable to solve a

problem/progress within the game undermine learning and discourage continued engagement. Usability testing is particularly helpful early in the development of a prototype in identifying potential barriers to efficiency. For example, in our usability test we were able to identify navigational and tool design issues that slowed students' progress.

Third, early testing of a game can lead not only to insights into modifications that can enhance the effectiveness of the game but to lines of research that should be done to inform the design of other games. For example, we recognized during the testing reported here the need for better support within the game for player development of the knowledge and skills relevant to circuit design. We therefore decided to enhance a feature called Logic Help that players could access as they worked on problems. However, we are uncertain of the best format for this help to take. For example, a comprehensive, searchable resource might help players zoom in on the specific questions they have. Or a context-sensitive feature might bring them to all the information they need for a specific problem. If so, would this better be delivered through text or video? Or a system of hints or partial solutions might provide enough of a scaffold for players to figure out the problem and intrude less on the game experience than more textbook-like features. Research in this area could yield insights into supporting players in games where they solve well-structured problems.

Finally, our work here was on the formative evaluation on an early prototype of an educational game, and as such, the questions we posed were ones that were useful for an early prototype. Our evaluation was structured by established criteria in Merrill's e3 framework for instructional materials: effectiveness, efficiency, and engagement. Though this general structure might be useful as a game matures, the questions posed should vary depending on the stage of the prototype. For example, in terms of effectiveness, we sought only initial indications of the potential for learning and how we could improve our measures so that we could capture it. In later stages, questions related to effectiveness would not examine whether learning occurs but how to optimize the features and resources within the game to maximize learning. Likewise, for engagement we sought only players' initial impression of the game: whether and what they liked and didn't like and whether they thought the prototype showed potential to become an interesting approach to learning the topic. Later rounds of formative evaluation would focus on more

challenging questions about engagement such as time on task compared to other approaches and perseverance in the face of difficulties. Because these are different types of questions, approaches such as A/B testing might be more appropriate as a product matures since by then basic usability issues should have been resolved and revisions are likely to be more fine-grained.

7. CONCLUSION AND FUTURE RESEARCH

Educational games represent a union between two diverse fields: instructional design and game design. Given that a successful educational game stands on two legs – learning effectiveness and engagement – the formative evaluation of these games needs to draw on the tools and techniques of both instructional and game designers.

This article reported the results of the formative evaluation conducted early in the development of an educational game. More discussion is needed within the field about effective evaluation practices for the entire life cycle of game design and development. Though formative evaluations need to be tailored to the needs of each individual project, discussion within the field on effective techniques at different stages can help to enhance the impact of formative evaluation on iterative game design.

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