Evaluating Design Patterns for Intentional Learning in Educational Video Games: Identifying a Common Language for Interdisciplinary Collaborations

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Abstract. As educational video games (EVGs) grow in popularity as instructional technologies, forging a link between the fields of design education, the learning sciences, and instructional design is essential to increasing probability of intentional learning. Moreover, as interdisciplinary teams comprised from fields such as visual communication, creative technologies, and human-computer interaction work together, a common language is needed to communicate intentions and concerns. Following the release of the CandyFactory app, an EVG designed to encourage middle school students to think deeply about fractions, our research team assessed the app for design, usability, and engagement. To understand how the design of the app helped or hindered the game's success, we conducted internal usability testing, observed play-testing sessions with middle school students (n=16), and interviewed middle school mathematics teachers (n=6). The team listed the game's design patterns and used feedback from these three pattern groups to assess the strengths and weaknesses of each pattern. The patterns were: *technical implementation*, *educational appropriateness*, and *fun and enjoyment*. By analyzing the CandyFactory app's design patterns, we discovered that although students enjoyed playing the app, multiple aspects of the game design impeded the intended designed learning experience. Identifying these problem areas underscores the need for a more holistic approach to game development, including iterative usability testing during the design and development stages, prior to deployment and implementation. EVGs created absent design and usability considerations from multiple perspectives could fail to achieve intended instructional objectives.

Keywords: design patterns, game design, educational video games, mathematics, middle school education, qualitative usability methods

Since at least the 1980s, educators have formally explored the use of video games as instruments of teaching and learning (Malone, 1981). Despite interest in this technology, recreational video games have often been viewed with skepticism in academic settings, with detractors claiming them to be frivolous forms of entertainment (Van Eck, 2006). As educational video games (EVGs) grow in popularity, the discussion has shifted from a focus on the purpose of games towards an understanding of how game design intentionally influences behavior and learning.

What makes well-designed EVGs potentially effective teaching tools is the ability to place learning within a meaningful context. Video games provide a world in which players can develop and practice new skills in a designed immersive medium. A well-designed game motivates players to persist in the face of calibrated challenges. In EVGs, this in-game motivation acts as a catalyst in learning and encourages students to further their understanding with every session of play (Devlin, 2011). With a growing interest in EVGs, educators see an opportunity to help students master challenging material in an enjoyable learning atmosphere (Gee, 2003).

Video games are now used to teach difficult concepts including, "people management, difficult to learn software, complex financial products and intricate social interactions" (Prensky "Digital Game" 2001, p.9). One study conducted with high school students divided a class into two groups to teach computer memory concepts. Both groups had the same learning objectives and material but one group used gaming as the instructional technology. The students in the gaming group exhibited significantly greater knowledge of the material as well as viewed the application more positively than the control group (Papastergiou, 2009).

Given that EVGs have the potential to be powerful learning tools, the challenge becomes designing an engaging game that motivates students in an intentional way. The success of an EVG, therefore, might be evaluated by the ability to incorporate learning objectives into the gaming environment that absorbs students into game play. While the former challenge rests on the ability of educators to translate their material into a gaming format, the latter requires significant input from designers. For professionals from diverse design fields to work together successfully there must be a common language used to communicate the problems they seek to address. By moving in this direction, the likelihood of EVGs that satisfy criteria of success from each field could increase.

Game design patterns can be used as a common language system to effectively communicate educational and game design principles. The term "design pattern" was first introduced by Christopher Alexander to describe a reoccurring architectural design problem (Alexander, 1977). The term has since been adapted for computer science and game development to describe commonly recurring elements of design (Gamma et al., 1993). According to researchers Björk and Holopainen, "game design patterns describe a part of the interaction possible in games, and together with other patterns they describe the possible game play in a game" (2005, p.4).

Given many types of games for educational and recreational purposes, there are a correspondingly large number of possible design patterns (See Appendix A 1 for design pattern examples; Kinzer et al., 2010). For EVGs, identifying design patterns could help locate synergies between the recreational and learning components in games (Kiili, 2010). When design patterns are organized to refer to one another, they create a "pattern language" (Huynh-Kim-Bang, 2010). Although this pattern language is useful for describing a game, it is incapable of judging the effectiveness of the design. Instead, it can be a useful tool for identifying areas for improvement (Björk & Holopainen, 2005). In the case of the app, the research team identified relevant design patterns, then sorted them into three categories based on the Games for Learning Institute's game design rubric: *technical implementation*, *educational appropriateness*, and *fun and enjoyment* (Kinzer et al., 2010). **Technical implementation** addresses the programming and execution of game design patterns. **Educational appropriateness** assesses the game's ability to address learning objectives relative to students' education levels. **Fun and enjoyment** assesses the game's ability to entertain and engage students to achieve the educational end-goals. An analysis of the CandyFactory app design patterns, using the Games for Learning Institute rubric, identified areas of strength as well as weaknesses that should be addressed to make the app, as well as similarly designed media, more effective.

The Candy Factory App: Introduction & Purpose

The CandyFactory app, available for download from the Apple iTunes Store, is an EVG designed for the iPad to support middle school students in the conceptualization of fractions. Students work through five game levels that are designed to provoke the development of more and more sophisticated conceptions of fractions. The five levels correspond to the five fraction schemes described in Table 1 (Norton, Wilkins, Evans, Deater-Deckard, Balci, & Chang, 2014; Steffe & Olive, 2010). The goal of app is to work through five levels (or *shifts*) of a fictional candy factory to earn a promotion. For each level, students race the clock to complete customer orders and earn achievements based on performance.

In level one, students can apply a part-whole fraction scheme—the most basic fraction scheme. Students begin by using visibly partitioned candy pieces to assemble a variety of customer orders. Students can count the number of pieces in the candy tray (n), then select the number of pieces needed to fill a customer order (m) , to create the fraction of the whole (m/n). At this level, students work with proper fractions; i.e., the number of pieces in a customer order will never exceed the number of pieces available in the candy tray. Beginning with a simple part-whole relationship (m/n) helps acquaint students with game play before progressing onto more complex relationships.

In level two, students are challenged to develop the partitive unit fraction scheme (PUFS). Students no longer work with visibly partitioned candy. Instead, they must use finger swipes to slice each bar into smaller pieces of equal size. They then select a single piece to create a unit fraction (1/n) that will match the order size. Imagining the whole as a repeated unit fraction helps students transcend the part-whole concept of fractions and begin to understand unit fractions as sizes relative to the whole.

Level three also concerns a generalization of the PUFS—the partitive fraction scheme, which and requires students to produce non-unit proper fractions to complete the customer order. This involves a generali-

Table 1: *Fraction Schemes*

Part-Whole Scheme	Players conceive of fractions, *m/n*, as *m* parts out of *n* equal parts in the whole. For example, producing 3/5 of a candy bar means pulling out three of five equally sized pieces.
Partitive Unit Fraction Scheme (PUFS)	Players conceive of unit fractions as a size relative to the whole. For example, having a 1/5 piece means that five iterations (or copies) of the piece would produce the whole.
Partitive Fraction Scheme (PFS)	Players generalize the PUFS to all proper fractions, so that they can conceive of fractions like 3/5 as three iterations of 1/5.
Iterative Fraction Scheme	Players can iterate unit fractions beyond the whole without losing track of the whole. For example, players conceive of 7/5 as seven iterations of 1/5 while simultaneously understanding that the whole is five of those parts.
Reversible Partitive Fraction Scheme	Players can reverse the actions of the PFS and IFS, producing the whole from a given fraction of it. For example, players can reproduce the whole candy bar from a 3/5 piece by breaking the given piece into three 1/5 parts and iterating one of those parts five times.

zation of the PUFS. Students should begin to conceptualize all proper fractions as sizes relative to the whole, and to conceptualize m/n as m copies of the unit fraction (1/n).

Level four relates to the iterative fraction scheme. Students are asked to produce any fraction, including improper fractions (a scenario of m/n where m can be greater than n). Although the logic required to complete orders in level four may appear similar to the partitive fraction scheme introduced in level three, the reasoning involved is qualitatively different. To properly produce the improper fraction, students must coordinate the unit fraction, improper fraction, and the whole within the improper fraction. Students who do not coordinate these three units will often confuse the improper fraction with the whole (Tzur, 1999).

Lastly, level five provokes players to develop a *reversible partitive* fraction scheme. This final level works in reverse of level four. Upon entering level five, students are informed that a mistake in the factory caused orders to be made a fraction of what the customers wanted. To correct this mistake students are given the fraction (proper or improper) and asked to produce the whole from it. For example, a student could be given a piece that is 7/5 of the whole. The student will need to slice the given piece into 7 parts and make 5 copies of that piece to produce the correct order.

To encourage game play and help assess progress, students receive a performance review at the end of every level (referred to as a shift log) and are awarded trophies based on the speed and accuracy of their work. Additionally, players also receive in-game feedback during each level (or shift). The game's antagonist, Boss Cog, appears on screen to chastise students when they submit an incorrect order or take too long to complete an order. He also offers praise when students submit correct orders and informs students when their shift is almost over.

To assess whether the game's design aided in the overall goal of helping students to progress along the five levels of the fraction scheme, a design research team was organized to conduct a full usability analysis of the currently deployed application. The team was comprised of professors and students from the fields of instructional design and technology, the learning sciences, creative technologies, mathematics education, and visual communication. The goal of this study was to identify areas where the game's design and functionality impeded the underlying educational goals, and provide possible design suggestions to increase the usability of the CandyFactory app.

Research Methodology

Three usability studies produced multiple data streams to complete the holistic evaluation of the app. First, task based usability techniques (Abel & Evans, 2014) were applied during internal review, interactive observational techniques of usability analysis were incorporated during the second phase (Millen, 2000), and lastly face-to-face interviewing was completed with classroom teachers. Each data stream provided insight into the usability of the app and collectively revealed, using the Beyer-Holtzblatt (BH) Contextual Design methodology (BH Method), opportunities to increase overall usability.

First the research team conducted the internal task-based usability testing in Fall 2012. Six team members played through the app and documented any issues encountered relating to the user interface, mechanics, and overall game play. Results were organized into six (6) categories: game play, in-game feedback, interface, narrative, rewards and visual measurement. For each category, issues were identified and interpretations made by the team to reach a consensus as to criticality. Appendix B represents the agree on critical issues that potentially prevented the game from attaining stated learning goals as well as reduced enjoyment and replay-ability.

Following the internal game assessment, the research team conducted an on-site interactive observational playtesting study at a local middle school. Research team members conducted moderated one-on-one interviews and interactively observed playtesting with sixteen students (n=16, gender balanced: 8 males, 8 females, randomly selected to participate by their classroom teacher, load balanced: all asked to perform the same tasks). Prior to participation in the playtesting, the students answered several pretest questions for the moderator regarding their familiarity with the app and their affinity for the game (see Appendix C). Students then began playing the game while the moderator observed their game play and prompted the students with occasional questions regarding the game's design, objective and challenges (See Appendix C for both qualitative questions and interactive observational usability task questions). As the students played, researchers noted when students struggled with tasks, became frustrated by game mechanics, or had difficulty understanding game elements. Incorporating the interactive observational usability technique allowed a more passive role in questioning the students resulting in more qualitative data with minimal disruption of normal game play.

Finally, the team conducted face-to-face interviews with six teachers from a local middle school to capture data on the game's effectiveness as a teaching tool, and other comments regarding the overall design and use of the app (see Appendix D). These teachers have been recruited by the more comprehensive funded research project to incorporate EVGs into the middle school mathematics classroom. These teachers were provided a 2-day introduction to the app, suggestions on how to incorporate the app into lesson plans, and support materials to increase probability of success with adoption.

Once complete, data from all three usability sessions was assimilated into a spreadsheet and analyzed using the BH Method (Holtzblatt & Beyer, 2013), which builds on an original affinity model of analysis created by Jiro Kawakita, commonly referred to as the KJ Method (Kawakita, 1982). Kawakita devised the KJ-Method when standard anthropological techniques proved inadequate to analyze the massive amounts of qualitative data he had amassed during research for the Japanese Government. Business researchers and strategists incorporate KJ-Method when they generate affinity diagrams. Essentially the KH Method assists with data analysis by grouping, organizing, and sorting data into reoccurring thematic areas. Once identified, the thematic areas contain subsets and indicators of all usability data collected. Ultimately, feedback from these three data-streams was compiled to identify strengths and weaknesses of the app to gain a better understanding of the target audience, and gather insights to provide design improvement suggestions for future iterations of the app as well as any future EVGs created by the publishing university. These efforts focused on such features of the app as game play, tutorial mode, trophies and bonus money, characters, and game mechanics. Appendix F provides excerpts from the usability report and further detail can be found in Abel and Evans (2014), and Evans, Abel and Musselman (2013). In conclusion, it should be noted that for the purposes reported, the BH Method is one implementation of the original KJ Method, and is adapted for usability testing resulting in a more holistic evaluation of the system being tested. Additionally the BH Method lends itself to rapid generation of descriptions and potential solutions to usability data.

Results

Based on data gathered from the three-phased usability study, the research team created a list of game design patterns that were then grouped into the three categories defined by the Games for Learning Institute rubric (Kinzer et al., 2010). Grouping the design patterns in this way created a pattern language that was used to describe and assess the app's technical implementation, educational appropriateness, and fun and enjoyment.

Technical Implementation

Given that the assessment of technical implementation is based on the game's ability to seamlessly integrate design patterns into game play, it is necessary to discuss the game's mechanics: "methods invoked by agents for interacting in the game world" (Sicart, 2008, p.1). For example, Miguel Sicart describes the 2006 Nintendo game *Orbital*, in which the player flies a small unit around space collecting items, as an exemplar of executing this design pattern type. As the player collects more items the unit grows, and as it increases in size is able to create its own gravitational field. Sicart claims that the game mechanics are attraction/repulsion actions, the gravitational fields of the planets, and even how the player can use gravity to propel the flight (2008).

For the app students were overall able to proficiently navigate through the user interface and were knowledgeable about game settings and features (see Appendix E). Nevertheless, the game research team identified two game mechanics that created difficulties for players and might unintentionally prohibit engagement and learning.

Redundant icons and actions created confusion and slowed play. To ship an order in the app, the player must first tap a small shipping icon to activate a larger shipping icon. The player must then drag their completed order to this larger icon. The use of redundant shipping icons coupled with the different methods of interaction (tapping and dragging), created confusion. Some players attempted to drag their completed order to the shipping icon, rather than tapping the icon and then dragging their orders. This confusion slowed game play and created unnecessary frustration.

Selected interaction physics greatly slowed game play. A portion of students reported frustration with the swiping mechanic used to separate candy pieces into smaller units. The swipe to cut feature was introduced in the level two. In level one, users could select the number of partitions they wished to make with a button press. The repeated act of swiping slowed some students and many were unsure how to remove unintended swipes, which created confusion and frustration. In some cases students spent an inordinate amount of time methodically swiping in even increments because they were unaware their partitions would be evenly divided on the next screen. Although the swiping mechanic made the levels more interactive, some students seemed more willing to exchange the less time-consuming button push if it meant having more time to solve problems and earn trophies. Correcting these mechanical issues will help make the app user-friendly and optimize game play.

Educational Appropriateness

In participating middle schools, the app was introduced during class time as a way to complement instruction on fractions. A majority of students participating in the study reported the app helped them learn fractions. Despite a positive assessment from students, the research team used design pattern analysis to locate possible areas for improvement to maximize learning objectives.

Time constraints became counterproductive in higher levels. Although some students attempted to solve levels via trial and error, having a timed component meant only students who had mastered the underlying concepts would be able to earn the highest awards. Having a time constraint encouraged repeated game play as students attempted to improve their scores over previous levels. However, in higher levels, students reported non-constructive frustration relating to an insufficient amount of time to complete tasks. Although students have the option to turn off the clock, this is not necessarily encouraged or allowed in a classroom setting. Alloting students more time for higher levels could encourage students to carefully consider each problem rather than defaulting to trial and error.

In-game feedback became a distraction. When students make a mistake or run low on time Boss Cog animates onto the screen to chastise the player. Although this may be an effective motivator for some students, the animation itself defies the Split Attention Principle, which states that learning is hindered when learners are forced to split their attention between several sources of information (Ayres & Sweller, 2005). In this case, students are trying to understand why Boss Cog is reprimanding them (either for poor performance or to warn them about time) while also trying to complete the next order. In addition to breaking the Split Attention Principle, the placement of Boss Cog is directly over key information necessary for the student to complete the current order.

Post-game feedback did not clearly indicate where students had erred. At the end of each level, a shift log appears to show students their evaluation for each level. The shift log shows their overall performance and how long they took to solve each problem. Teacher feedback indicates the shift log should clearly indicate which orders were completed incorrectly to help students identify areas of improvement. Including the solution to incorrectly filled orders also provides another learning opportunity for the student.

An additional tutorial may be necessary to introduce students to new goals. Game narration helps guide students through the levels of the app and helps establish level expectations. Upon starting a new game, students click through a tutorial that explains the goal of levels one through four. Although level five begins with a narration that sets up the new task, students reported difficulty knowing what was expected in this level. Including a tutorial for level five could help address this issue.

Fun & Enjoyment

The research team identified design patterns that were implemented successfully to help maximize fun and enjoyment:

In-game motivation kept students engaged. Students receive two types of motivation in each level – trophies and bonus money. Trophies are awarded based on three criteria – speed of completion, order accuracy and customer satisfaction. Students reported that they replayed levels in order to collect more trophies. Bonus money was a less effective motivator because students said it was unclear what reward they would earn for the bonus money but many indicated they would be more willing to work for the bonus money if they could exchange it for in-game rewards.

The app incorporates multiple mechanics that allow students to interact with the game space. Learning materials with interactive components are more likely to engage students than static graphics (Lowe, 2003). The app incorporates three types of dynamic representations: "transformations, in which physical properties of an object are altered, translations, in which objects are moved from one place to another, and transitions, in which objects appear or disappear" (Lowe, 2003).

Icons helped students quickly adapt to the game interface. Once students complete the pre-game narrative and tutorial, icons and other images are significantly more prevalent than text. Using visualizations over text is particularly useful when a subject is unfamiliar to the learner (Plass et al., 2009). Minimizing the time required to familiarize themselves with the gaming environment allowed students to quickly immerse themselves in game play.

Students enjoyed manipulating game objects. In each level of the app, students were able to manipulate game pieces to assemble customer orders. Customer orders are a fraction, either proper or improper, of the available candy's size. Manipulating the available pieces helped students develop the underlying skills needed to visualize fractions.

Students felt the overall aesthetic of the app was very polished. Students overwhelming responded positively to game graphics including the game interface, characters, colors and candy. Although games can be fun without impressive visuals, students responded enthusiastically to the app imagery.

By assessing the game construction, it was also possible to determine areas for improvement to maximize enjoyment:

Allowing students to modify their game interface could increase engagement. Currently the bonus cash does not relate to any game elements. Nevertheless, when asked what they would buy with their money, the majority of students said they would like to buy more candy. Allowing students to select new candy will give them the ability to customize features of their interface and increase engagement.

Uneven shifts in difficulty between levels created frustration and visibly disrupted the student's reasoning process. One of the primary goals in educational video game design is to balance the challenge of learning with enjoyment, or rather create "hard fun" (McGonigal, 2011). Games are more engaging when a challenge adjusts along with a player's experience (Sweetser, 2005). Students were able to translate their knowledge from Level 1 to solve Level 2 tasks with some assurance of success. In Level 2, students are expected to conceptualize unit fractions as sizes relative to a given whole (example: 1/4, 1/6, 1/10), which most did successfully. In order to amass the full collection of trophies, students replayed Level 2 until they had mastered this concept. Level 3 however became disproportionately challenging. Students seemed less capable of applying the concepts developed in Levels 1 and 2. In Level 3, students are required to imagine a unit fraction of the given whole that can be iterated (or copied) in order to produce a non-unit proper fractions – especially difficult examples include 5/9, and 8/9. Failure rates were significantly higher in this level with no students completing Level 3 to the same standard set in previous levels. Most students relied on trial and error, even upon multiple replays. This lapse in performance suggests the increased challenge is too great to be productive for the players. It is likely that imagining 1/7 of a whole is not sufficient for students to visualize the difference between 6/7 and 7/8. Although a certain degree of challenge is necessary to create a fun gaming atmosphere, this leap produces the opposite result. One way to help students overcome this cognitive hurdle is by adding an intermediate level between current Levels 2 and 3, that includes only complements of unit fractions, (n-1)/n (for example, 6/7 or 7/8). In fact, in a separate study of the app's implementation, researchers found some students independently employing "the complement strategy" to solve tasks at Level 3 (Boyce & Norton, 2012). By focusing students' attention on the missing piece (e.g., 1/7 as the missing piece between 6/7 and the whole), the new level could help students transition from working with unit fractional customer orders (e.g., 1/7) toward customer orders that involve several iterations of those unit fractions (e.g., 6/7 as six iterations of 1/7).

Incorporating a social component to encourage mild competition could be one way to increase engagement and repeated game play. This could be done by creating a classroom progress board that tracks student achievements in the game.

Despite possible areas for improvement, in student feedback sessions, students were asked how they would rate the game overall on a scale of one to four, with one meaning "not at all" and four meaning "very much." The average student rating was three. When asked how likely they are to recommend this game to a friend with one being "very unlikely" and four being "very likely," the average student response was 2.9.

Discussion

The research team discovered that students who participated in this study enjoyed playing the app and felt it helped them understand fractions. Nevertheless, assessing student game play through the lenses of design pattern analysis and usability testing techniques helped identify elements that impeded the learning process.

In the game, to "ship" the order, the player has to press a button and then drag the box towards another button to complete the action. This is a redundant interaction that sometimes causes players confusion. By streamlining this interaction one can increase use and ease frustration while making the game more enjoyable.

When the students were feeling rushed in higher levels (Levels 3 through 5), they would attempt to win via trial-and-error. For example, instead of taking the time to think through the problem presented to them and coming up with an appropriate solution, they would haphazardly try to divide up the candy bar as quickly as possible to try to get it to fit the order. In other cases, they would divide up the candy bar as small as possible to be able to fill the order exactly, but this would cause the player to take more time to fill the order. This method often produced fractions that could be simplified, thus using this method suggests students were having difficulty visualizing the bars as fractions of a whole and were merely aiming to get one image to correspond with another. If more time were given to higher levels, perhaps it would deter this action that defeats the purpose of the game.

Another way to help ease the student into higher levels is to introduce a new, intermediate level to help bridge the gap between Level 2 and the higher levels. As it stands now, it appears that the students are not properly prepared for the higher levels and they have trouble visually measuring the candy into complicated fractions. Providing better tools for visual measurement could help reinforce the partitive relationship and encourage students to methodically work through each problem.

The majority of the students reported feeling comfortable with in-game expectations, but the research team observed that students did not know what to do upon reaching Level 5. Unbeknownst to them, they need to find the reciprocal of the fraction given, which they would not know to do without either guessing or instructor guidance. Offering optional tutorials for each level would allow for students familiarize themselves with each level without slowing game play for those already acquainted with the rules and expectations. For example, for Level 5 designers could incorporate support that guides students to reason that, if the given fraction is 3/5 for example, they need to produce 1/3 of 3/5 (i.e., 1/5) to produce the whole (five iterations of 1/5).

Students found in-game feedback from Boss Cog too distracting. His presence is intended to motivate players, but instead his many appearances distract or confuse players. Boss Cog currently appears to assess orders, denounce players for taking too long on an order, or warn players the shift is about to end. Players were occasionally unsure of what prompted Boss Cog to interrupt their game and had to pause to determine the cause. To minimize confusion and distraction, Boss Cog could either not animate on screen or he could only appear to inform the players of one issue – for instance he could praise or condemn correct and incorrect orders. Removing warnings related to time will allow students to feel motivation to please Boss Cog without constant interruption.

At the end of each level, a shift log appears which details all the orders the player filled. It explains in each order what the correct fraction was and what the player entered. Currently, there is no visual distinction between correct orders and incorrect orders, so a quick glance will not be sufficient to gauge performance. Clearly indicating incorrect orders would be useful to allow the player to identify areas of improvement.

Competition can increase motivation to perform well, thereby creating a social component to the game that encourages a bit of inter-classroom competition. As long as it is done in a way that does not discourage students, it could increase engagement in the game and drive the students to play the game multiple times. In turn, this would get the students to practice their fractions more frequently, which is needed for them to fully understand and grasp the concepts.

Currently, when the player completes a level exceptionally well, they are rewarded with bonus cash. As of yet, the cash cannot be used to do anything, but students have expressed interest in being able to use the cash to buy things within the game, like different kinds of candy or personalizing the game space by dressing up the characters. Anything to make the game more enjoyable will encourage repeated playing, which, again, will help students comprehend fractions.

Implications

The research team identified numerous instances where the design of the game interfered with game play and potentially disrupted the learning process, running counter to the intentionality of the effort. Game elements that create confusion with the subject matter have the potential to discourage students who wish to avoid feelings of failure. Identifying limitations of the app help underscore the need for greater collaboration between design educators and instructional designers early in the development process. This insight is not new in that Hirumi et al. (2010) have made a similar call for this type of collaboration. On the other hand, the current report provides a case study of the implications of such a call. In line with Hirumi et al.'s proposal, we advocate that EVGs that fail to consider design and usability may miss the opportunity to provide instruction to willing and receptive participants.

The methodology employed by the research team suggests that internal usability testing should be conducted early, and often, during the development process, and certainly prior to deployment. Following the release of the app the research team conducted internal usability testing that identified multiple design weaknesses that had the potential to confuse and frustrate players. These issues were later corroborated by student feedback in playtesting sessions, suggesting internal sessions are very valuable when identifying usability and design flaws. As the design, development and deployment of EVGs matures, and interdisciplinary collaboration among many fields invested in design increases, additional reports should emerge. Nevertheless, cases like that for the app demonstrate that much work is needed to coordinate the varying priorities and investments from designers of related fields (Ebner & Holzinger, 2007).

One clear implication of this research demonstrates the capabilities of non-usability experts to identify design issues during internal testing of EVG's. Prior research indicated usability experts were needed to identify concerns in the usability domain (Dumas, 1999); however, this research demonstrates that experts in usability testing are not necessarily required to identify major usability concerns. As validation for this claim, in the case of this research, playtesting students later validated 100% of the concerns uncovered by the internal research team. For these reasons, EVG designers and developers should being internal usability testing during the initial paper prototyping and design phases in an effort to eliminate usability concerns prior to deployment.

A second implication of this research points to the importance of incorporating qualitative data in the evaluation of EVG's. The most popular usability methods rely solely on quantitative data streams: time on task, number of errors, number of clicks, etc. (Dumas, 1999) and virtually ignore qualitative data. In the case of evaluating children's EVG's qualitative data helps uncover children's preferences and desires (Hanna, 1999). By applying the BH Method of data analysis, researchers were able to identify emergent themes of particular interest to the students, and moreover, the usability of the app. The research team found the BH Method to be extremely helpful while analyzing the large amount of qualitative data, and encourages the use of this method during the iterative design process.

Early, and often, usability testing could have the potential to save time and resources. More importantly, it could reduce the need for multiple game releases. A student who is confused by one iteration of an EVG may be unwilling to play a later release, even one that addresses the original problems. To produce the best possible game and maximize student participation and engagement, the research team recommends early, and frequent internal gaming sessions to test for usability issues. Though this is a known issue for any game or instructional designer worth their salt, it oftentimes becomes problematic as contingencies such as school calendars compel designers to move forward with "good enough" prototypes. As Winn and Heeter (2006) note, playtesting is the critical point at which these concerns should be identified. Nevertheless, playtesting is not yet subsumed in the instructional designers vocabulary and there are few available prescriptions available to those who design EVGs.

Conclusion

Learning scientists, instructional designers, and content area experts have for some time invested in a notion that video games could be adopted or designed to motivate and engage students in learning (Charsky & Mims, 2008; Dodlinger, 2007; Robertson & Howells, 2008). In this article we have attempted to make a case that design patterns could serve as a lingua franca for designers collaborating from potentially related disciplines: learning sciences, instructional design, and design education. We presented details through a design study on an evolving process of evaluating EVGs for middle school mathematics. Our goals are to not only improve internal workflow processes, but to share with others attempting to leverage the features of recreational video games for intentional learning purposes. Our conclusion is that leveraging gaming design patterns is an effective way to identify areas of strength and weakness when assessing the engagement and learning value of EVGs. The methodology outlined in this report could be adopted to improve or revise processes for designing, developing, and deploying EVGs.

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Appendix A: Games for Learning Institute Design Patterns (Kinzer et al., 2010)

1. Constructing things is fun and helps learning
2. Strong Narratives provide sufficient incentive and clear goals to solve hard puzzles/problems
3. Time and resource constraints make games fun and can improve learning
4. First person shooters do not automatically provide incentives to learn
5. Games can be engaging without stunning visuals
6. Games that include summations of statistics or cumulative achievements
7. Kids will engage in rote tasks for small incentives when it leads up to larger incentives later
8. Scaffolding can be used to make games adaptive to learners' specific needs (prior knowledge, abilities, etc.)
9. Games can be engaging, even addictive, without being always fun
10. The stronger the intrinsic motivation of the game content the less extrinsic motivation is required to engage players
11. A social component (collaboration, competition) makes games fun/engaging
12. Polish: a well-tuned end experience with no rough edges in appearance or interaction is a key factor in making or breaking fun
13. Strong Sense of Progression: game gradually releases information to players and allows contained practice and then mastery that is then built upon, or scaffolded.
14. Character Specialization: The notion that social games such as massively multiplayer online games provide structured experiences in which players take on specialized roles and work together to solve problems, providing powerful learning opportunities.
15. Role-playing and emotional engagement with subject matter: game positions the player deeply in the center of a situation, taking on the perspective of others who are faced with the actions and choices and situations that the game portrays.
16. Exploration of moral and ethical dilemmas: game lets players think about and experience dilemmas instead of *telling* them how to feel or what to do.
17. Exploration of systems – game allows player to viscerally experience abstracted principles, their constraints and possibilities, such as those of physics or engineering.

Appendix B: Research Team Usability Study

Category	Issue	Interpretation
Visual Measurement	The ruler lines don't actually line up with anything.	Without a reliable measurement tool it is very hard to visually measure how a fraction relates to the whole.
Visual Measurement	Candy Bar in tray and on screen should align	It is hard to visually measure how a fraction relates to the whole.
Visual Measurement	The images in level five transform when being measured, which is very confusing.	It feels visual measurement is not the goal of level five but this is not clearly stated.
Rewards	Trophies have numbers that do not correspond with their awards - ex "3" might be "10" orders.	It's difficult to understand what actions will earn a reward.
Interface	The flat menu is less engaging. I wish the buttons had more action.	Interaction elements are more fun and engaging
Interface	The flat screen doesn't immediately look like a touch map.	Lack of visual cues diminish gameplay experience
Interface	The green next arrow is hard to find against the brown background	Players lose time trying to locate navigation icons.
Interface	Next arrow is too small	Players lose time trying to locate navigation icons.
Game Play	Final ship button has no way to cancel	There's no way to undo an incorrect answer.
Game Play	Animations take too long	Slow animations make it difficult to achieve objectives. Time constraints should relate to problem solving.
Game Play	After selecting the candy you shouldn't have to hit a next arrow. It should just continue after choosing the candy	Redundant actions slow game play.
Game Play	Shipping the candy has redundant steps. Once I tap ship, it should just ship. Or I should just drag the order to the shipping box. Just one step instead of two	Redundant actions slow game play.
Game Play	Finger swipes to slice slow down game play, increase errors and add very little to game play	Repeated mechanics that do not add to the learning component and slow game play should be eliminated.
In-Game Feedback	Boss Cog tells players to go "faster, faster!" regardless of their actual playing speed.	In-game feedback feels inconsistent and distracting.
In-Game Feedback	Boss Cog blocks the order on higher levels making the participant lose time.	In-game feedback can create visual clutter.
In-Game Feedback	Boss Cog pops up with multiple warnings that are distracting to game play.	Constant popups break concentration and interrupt game play.
Narrative	The objective of level five is unclear.	The narrative that introduces level five does not sufficiently explain the goal of this level.

Appendix C: Student Questionnaire

How easy is it to play this game? (1-4)

Would you tell a friend about this game? Yes/No?

If you didn't have to for class, would you play this game again? Yes/No & Why?

What do you think is really cool about this game?

What don't you like about this game?

Do you understand fractions better after playing this game?

Ask student about each button on the main menu and what it does.

How many levels have you been able to complete?

What do you think of the characters?

Do you enjoy playing the game? What do you like about it?

What do you think about the game screen? Layout? Swipe actions?

Did the teacher offer enough information on how to play the game?

Is the game easy to understand?

Have you used the tutorial? Was the tutorial helpful?

What do you think about the feedback on the shift log? Is it helpful? How could we improve it?

What do you think about the higher levels? The candy changing?

Was the change in task for the higher levels made clear? How could it be made clearer?

What do you think about the game mechanics? Shipping? Drag to trash?

What do you think about the bonus? Did they make you want to work harder?

Appendix D: Teacher Questionnaire

How would you rate this game overall?

How easy is it for you to play this game?

How easy is it for your students to play this game?

How likely would you be to recommend this game to a friend/colleague?

How effective do you think this game is at teaching your students fractions?

What is your favorite part about this game?

What is your least favorite part about this game?

How many levels have you been able to complete?

How many levels have your students been able to complete?

Do your students enjoy playing the game? What do they like about it?

What do you think about the game screen? Layout? Swipe Actions?

Is this game easy to explain to your students?

Did you find the tutorial helpful?

Did your students find the tutorial helpful?

What could have made the tutorial more helpful and/or effective?

What do you think about the shift log? Is it helpful?

How could it be improved?

What do you think about the higher levels?

How could the change in task be made clearer?

What do you think about the game mechanics? Shipping? Drag to trash?

What do you think about the trophies and the bonus money?

What do your students think about the trophies and the bonus money?

Do they make your students want to work harder?

Do you think this game is engaging? Why or why not? How could this be improved?

Do you think this game is fun? Why or why not? How could this be improved?

Do you think this game is challenging? Why or why not? How could this be improved?

Do you think this game is interactive? Why or why not? How could this be improved?

Do you think this game is rewarding? Why or why not? How could this be improved?

Is there anything else that you would like to see added to this game or any future games?

Appendix E: Student Questionnaire Results

Frequently Cited Issues

Boss Cog blocks the game space and is distracting

Game play is slowed by the effort needed to multi-tap or make constant swiping gestures

Only half of the students understood they could swipe up in order to undo a cut

Upper levels are nearly impossible to complete in the given amount of time

Overall Game Affinity

Question	*Average*
How would you rate this game overall on a scale of 1 to 4 with one being bad and four being good?	3/4
How likely would you be to play this game outside of school?	2.6/4
How likely are you to recommend this game to a friend?	2.9/4
How much do you think this game has helped you learn fractions?	3/4

Familiarity With Game Menu

Task	*Percentage of students familiar with task*
Start a new game	100%
Load options	100%
Unlock game levels	68.75%
Turn sound on/off	87.50%
Turn timer on/off	93.75%

Appendix F: Examples of Recommendations Derived from Usability Studies.

Category: GAME PLAY Observation	Interpretation	Recommendation
No way to track personal progress.	Students want to challenge themselves and track their personal progress.	Provide a login system, which would allow students to track individual progress.
Students observed using trial and error to solve the problems.	Students discovered ways to 'drag and compare' slices before committing to an answer.	Disallow the dragging of images on-screen by locking their location.
Animations between steps are too slow and make it difficult to 'race the clock.'	Students are encouraged to play faster; however, they become frustrated with the game mechanics	Streamline gameplay by eliminating or accelerating animations

Category: CHARACTERS Observation	Interpretation	Recommendation
Boss Cog blocks the order on higher levels.	Gameplay should not be made difficult by bad design decisions.	Reanalyze the game action triangle (area of interaction) and rearrange elements to better facilitate play and engagement, including characters.
President Carmello does not have a strong presence throughout the game.	Why introduce a character that doesn't hold a major role in the game narrative?	Consider Carmello as a problem-solving assistant possibly providing prompts when player seems 'stuck' on a problem.
Boss Cog appears often, potentially leading to too much negative prompting.	Negative feedback can lead to disengagement.	Consider changing back-end intelligence to lessen appearance of Boss Cog.

Category: GAME MECHANICS Observation	Interpretation	Recommendation
Drag to ship is redundant and slows down game play.	When pressured to compete against the clock, unnecessary interaction frustrates player.	Analyze game-play interactions to eliminate unnecessary interaction.
Final ship provides no opportunity to cancel.	Warn me before I commit.	Incorporate a 'back,' or 'cancel' option.
Excessive number of taps, clicks, swipes, etc. to complete order.	See above.	See above.