The Design and Outcomes of Story-Enhanced Games to Teach Computer Science Concepts

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Purpose/Research Questions

In this study, we explore the use of game-based learning for promoting understanding of computer science (CS) concepts. We hypothesized that appropriately designed games might be effective in engaging young people in the kinds of thinking and practices that are foundational to CS, beyond programming. Our target population was middle school girls (ages 10-14). Middle school is a time when many girls lose interest in or choose not to pursue many STEM fields, including computer science, making it a critical point for intervention. Gaming is popular among this population; a national survey in 2008 found that 83% of teen girls played digital games at least every few weeks, and that proportion is now likely higher (Lenhart et al, 2008). However, designing educational games that integrate educational content with engaging game play is challenging, with many unanswered questions about what game design elements are important or how different kinds of games appeal to different audiences.

The purpose of this study was to design and test a story-enhanced game intended to improve girls' understanding of data representation, a core concept in CS. Our primary research question was:

> How might story and game play be effectively integrated in a game aimed at fostering understanding of data representation among middle school girls?

To address this question, the initial stage of our research consisted of design-based research focused on the development and testing of the game. In the second stage of our research, we gathered evidence of the game's effectiveness, addressing the following questions:

> How does girls' understanding of data representation change after playing the game?
>
> What levels of engagement do girls report after playing the game?

Perspectives

Increasingly, computer science educators recognize that a programming may not be the best introduction to computer science, and in fact may be a deterrent. Accordingly, many initiatives focus more on broader principles and concepts rather than programming alone, such as Computer Science Unplugged (Bell et al., 2010), the Computing in the Core coalition (Grover & Pea, 2013), and AP Computer Science Principles (The College Board, 2014).

Well-designed games can engage players in active and sustained learning, allow them to take on new identities, promote situated understanding of new concepts, and provide experiences that serve as a basis for later reflection and assessment (Gee, 2007). However, our knowledge of how different game elements combine to provide both entertaining and educational game experiences is far from complete. Story is one game design feature that has received insufficient attention in research on educational games. Story is widely reported to be an aspect of games particularly important for girls; for example, in one study, when girls were asked to design their ideal games, engaging characters and rich narrative were very important (AAUW, 2000). Yet we know little about the actual value of story when combined with games for enhancing learning in CS or in other fields. It may be inappropriate to generalize about the role of story across domains; for example, story might be more or less helpful to learning in more abstract domains like computer science as compared to fields like history or psychology. Furthermore, stories involve many elements, such as plot, character, setting, and conflict, and these elements can be incorporated into games in varied ways. A key question in the use of story in educational games is how to best utilize a range of possible story formats.

Methods/Data Sources

Game Design. While our ultimate goal is to inform the design of a digital game, in this research we report on the design and testing of an analog (non-digital) game. Creating an analog game was less expensive and allowed the team to more rapidly iterate and modify game features. The game was developed collaboratively by a team including computer scientists, educators, and a writer/game designer. Initial activities included identifying and analyzing STEM-focused digital and analog games, to determine how different story elements were used; for example, if the games had a recognizable plot, the nature of the game protagonist, and so forth. In addition, focus groups were conducted with middle school age girls about their game play and story preferences. These activities informed the identification of potential game mechanics and storylines. In particular, we discovered that a story context rather than a fully developed story narrative was used in almost all of the games that were not abstract puzzle type games. Accordingly, we chose to test this approach to story in the game we designed and tested.

We drew on the College Board's Advanced Placement (AP) CS Principles framework (The College Board, 2014) to identify the central concept for this game. Of seven “big ideas” in this framework, we selected *representation of data and information*. In choosing this concept, we relied on the following criteria: (a) Can aspects of the concept be taught in an age-appropriate way? (b) Is the concept general enough to be understood by a student with no prior computer science training? and (c) Does the concept have the potential to be explicated through a game? The game was developed through an iterative process, including creation of design documents, prototype testing, and pilot testing with middle school age youth.

Game Implementation. The final game was played in an afterschool program over two sessions, each lasting about an hour. Sixteen girls ages 10-13, from varied socioeconomic backgrounds, participated in the study. The girls completed an 8-item pre- and post-assessment of their understanding of data representation and responded to a 3-item engagement survey at the conclusion of game play. The sessions were video taped and researchers recorded field notes describing game implementation and girls' reactions to the games.

Measures. Understanding of CS concepts has been assessed in various ways. These assessments include tests of declarative knowledge (i.e., definitions of concepts or abstract principles) as well as procedural knowledge or more practice-focused assessments (Brennan & Resnick, 2012). We created a brief assessment with three multiple choice questions about the general nature of encoding/decoding and five questions requiring learners to create and interpret a series of simple binary and run encodings. Multiple choice questions were worth one point each, application questions were scored on a half point scale from 0 to 1 or 0 to 2 points each, and the maximum possible score was 12.

To assess engagement, we collected participant responses to a three item assessment of concentration, interest, and enjoyment in learning (Hektner, Schmidt, & Csikszentmihalyi, 2007). Participants responded to the following questions on a 5-point scale, from a high of "very much" (4) to a low of "not at all" (0): "Did you enjoy what you were doing?", "Did you find the activity interesting?", and "How well were you concentrating?"

Results

The Hidden Image Game introduces students to the idea that all data is represented on a computer with numbers, be it a math equation, a text document, or an image. The game also introduces the idea that there may be ways to represent the same data with fewer numbers, thus saving space, though making the encoding/ decoding process more complex. An important feature is that the core game mechanic (what the players do) is directly related to what the players are intended to learn. Players compete one-on-one (or two-on-two) to accurately translate one data image representation to (or from) its numerical representation, while guessing the meaning of the image. This game has a pre-game matching activity and 3 levels of play. Images are represented on grid sheets with colored squares and numbers; players move from creating and interpreting simple binary codes to more complex run decoding and encoding.

In the narrative context of the game, players take on the role of humanitarian aide workers on a mission to help refugees of war travel from refugee camps to safe houses, out of a very dangerous country. Players use code for communication with field agents and refugees about dangers such as landmines or the changing location of safe houses. The story and theme were selected based on prior literature suggesting

that girls are interested in games and stories that allow them to help others or serve a social good (Munley & Rossiter, 2013). A game facilitator reads a brief script before each game level that situates the subsequent task in the story context. For example, at the beginning of the third level, the faciliator explains "The next mission is for all the coders, at all levels, to gain some additional field experience and use what you have learned to encode the newest image and transmit it back to camp. The images change every 24 hours! The faster they're encoded (and safe from prying enemy eyes), the more time families have to use them."

Outcomes. Overall, participants demonstrated significant improvement in their understanding of data representation after playing the game. The mean pre-test score was 4.09 (SD=2.59), with a range from 1 to 10. The mean post-test score was 7.25 (SD=2.54), with a range from 3 to 11.5. The mean difference across pre- and post-test scores was 3.16; paired t test results indicated the difference was highly statistically significant: $t(15)=2.82$, $p < 0.000$.

The overall mean engagement score was 3.04 (SD=.64), indicating that on average, participants were "mostly engaged." There were slight differences among mean scores on each item: mean enjoyment = 3.07 (SD=.70), mean interest = 2.73 (SD=.88), and mean concentration = 3.33 (SD=.72). Across all participants, there was only one "not at all" response: one girl responded "not at all" to the question about whether she found the game interesting, though she also replied that she found the activity "somewhat enjoyable" and was "mostly" concentrating. These self-reports were reinforced by video data and observations of game play by the research team indicating considerable participant engagement.

In the final paper, we will describe the game in greater detail, as well as report our findings from video recordings and field notes about how girls responded to the game and the dynamics of game play, as a means of further illuminating how story context affected their learning and engagement.

Significance

Integrating educational content, game play, and story is challenging. The design team struggled with combining game mechanics and story context in ways that seemed plausible and meaningful. Using an analog rather than digital game format meant that constructing a "real-life" immersive world was not feasible; instead, we aimed to create a fictional setting that would capture players' imaginations with few props. Our choice of story context was inspired by previous work suggesting that girls are particularly motivated by STEM activities that engage them in helping others or contributing to the social good (Munley & Rossiter, 2013). The team identified a central premise that was consistent with this theme, offered a means of instantiating the CS concept, and seemed to be emotionally appealing. A premise sets

the time and place, the main characters and the player's objective or problem to be addressed (Fullerton, 2008). Our findings indicate that playing *The Hidden Image Game* improved most girls' understanding of data representation appreciably and that the girls found game play to be engaging. While participants were responsive to the story context, it seemed at times to be peripheral to their engagement with the game. and further investigation will be necessary to determine the effects of story on learning. In further research we intend to compare outcomes and engagement of girls who play the game in different story conditions, to obtain more insight into whether a fully developed story or story context is helpful to either engagement or learning for this population.

Lastly, during our design phase, it became clear that some CS concepts were more easily translated into game mechanics and story than others. What CS content is most suited to learning through story-enhanced games, or through games at all, remains an open question, particularly in relation to broadening participation of under-represented groups. Certainly games are not a panacea, and we need a better understanding of how strategies such as games might be a gateway to the development of interest and commitment to CS among the populations we hope to reach.

References

AAUW (2000). *Tech-Savvy: Educating girls in the new computer age*. Washington, DC: AAUW.

Bell, T., Witten, I.H. & Fellows, M. with R. Adams and J. McKenzie. (2010). *Computer Science Unplugged*. *Teacher's Edition Parts I, II and III*. Available: http://csunplugged.org/teachers-edition

Brennan, K. & Resnick, M. (2012). *New frameworks for studying and assessing the development of computational thinking*. Proceedings of the 2012 Annual Meeting of the American Educational Research Association, Vancouver, Canada.

The College Board (2014). *The AP Computer Science Principles*. Available: https://advancesinap.collegeboard.org/stem/computer-science-principles/resources

Fullerton, T. (2008). *Game design workshop: A playcentric approach to creating innovative game,* (2nd ed.). Boca Raton, FL: CRC Press.

Gee, J. P. (2007). *What videogames have to teach us about learning and literacy* (2nd ed.). New York: Palgrave.

Grover, S. & R. Pea, R. (2013). Computational thinking in K−12: A review of the state of the field. *Educational Researcher*, *42*, 38-43.

Hektner, J.M., J. A. Schmidt, J.A., & and M. Csikszentmihalyi, M. (2007). *Experience sampling method: Measuring the quality of everyday life.* Thousand Oaks, CA: Sage.

Lenhart, A., Kahne, J., Middaugh, E., Rankin MacGill, A., Evans, C., & Vitak, J. (2008). *Teens, video games, and civics.* Washington, DC: The Pew Internet & American Life Project.

Munley, M.E. & Rossiter, C. (2013). *Girls, equity and STEM in informal learning settings: A review of literature*. Available: http://girlsrisenet.org/sites/default/files/SAVI%20Lit%20Review%20Sept%202013.pdf