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Desmond Bonner, *Iowa State University*
Michael C. Dorneich, *Iowa State University*

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# Developing Game-Based Learning Requirements to Increase Female Middle School Students Interest in Computer Science

Desmond Bonner, Michael Dorneich
Iowa State University

**Abstract**

This paper presents work on the development of a Game-Based Learning (GBL) application's requirements for female middle school students which teaches fundamental concepts of programming. Currently, there are not enough students who desire to pursue Science, Technology, Engineering, and Mathematic (STEM) career fields. Additionally, female are underrepresented in STEM fields, and increased female participation may help partially address this gap. GBL was used to encourage middle school student interest in STEM by allowing them to practice computer science concepts in engaging contexts outside the classroom. The game *Sorceress of Seasons* was built to teach fundamental programming concepts, and was based on six requirements specifically targeted at female middle school students. The game was tested with 15 middle school-aged students. Playing the game had a positive effect on students' attitudes towards programming, with female students reporting a larger increase in computer science interest than males when compared with their previous attitudes. The results suggest that the game may be successful in increasing interest in STEM in these students. The requirements developed to guide the design of the game played a role in the game's effectiveness, and may be useful when developing an educational tool targeting female STEM interest.

## INTRODUCTION

In 2020, 1.4 million computer-related jobs are expected to appear in the U.S (Beede et al., 2011). However, only a third of college graduates will be able to fill these jobs, seeing that only a portion of the total workforce is utilized while other groups are excluded. Therefore, women are underrepresented in Science, Technology, Engineering, and Mathematics (STEM) (Ramakrishman, 2014). Female participation in STEM has grown. Between 2000 and 2009, participation in areas such as Computer Science (CS) had decreased (Klawe, 2013, Beede et al. 2011). The way STEM is perceived at an early age may influence whether a young female will pursue these careers (Wyss, Huelskamp, & Siebert, 2012).

Recent work suggests that many female students have interest in STEM careers, but have anxiety (Desy, Peterson, & Brockman, 2011). One way to mitigate preexisting stereotypes and anxiety is to provide students with early exposure to STEM subjects such as CS (Maltese & Tai, 2010). The best time for students to be presented this is between the ages of 10-14 years old, as it is when their interest, competencies, and confidence translate into their career paths (Maltese & Tai 2010; Wang & Degol, 2013; Wyss et al., 2012). Also, a student's perception of STEM upon entering high school is closely related to their likelihood to pursue a STEM career, which suggests the importance of middle school (Desy et al. 2011; Sadler, 2012).

This information suggests that providing a positive STEM learning experience to female middle school students would have an impact on their likelihood to pursue a STEM career. One possible approach would be a hands-on, game-based experience in a STEM subject such as CS. The subject of games for learning has been explored by Werner et al. (2005) and others. However, specific requirements for female students may be needed to make games more effective for increasing interest in STEM for females. Other games have been created for increasing interest and aptitude such as *Code Spells* (Esper et al., 2014). Barriers to female participation should be addressed in the game as to make female students more comfortable with the culture of CS (Klawe, 2013). Many video games contain content which can be considered offensive to female gamers (Grimes, 2003), such as characters being hypersexualized or having accentuated sexuality.

This work in this paper describes the development of game design requirements targeted toward middle school students, with the goal of increasing interest in STEM. These requirements were used in the game *Sorceress of Seasons (SOS)*. *SOS* was tested with middle school students who were taught three fundamental concepts of programming and practiced them through play in order to evaluate the effectiveness of the requirements. Finally, lessons learned and future applications of the requirements are discussed.

## RELATED WORKS

The major themes of the work are Game-Based Learning (GBL), issues females face within STEM, and learning in general. GBL is a type of Serious game which is a game used to solve problems or provide training instead of strictly serving as a means of entertainment (Connolly, Boyle, Macarthur, Hainey, & Boyle, 2012). The goal for the learner is to be able to apply information learned from the game into the real world. Previous studies attempted to utilize GBL to increase female participation in CS/Programming (Werner et al., 2005). They include projects such as the *Girls Create Games Program* and *Storytelling Alice*, which informed SOS's development. However, they were designed for research studies, and not to be applied to classroom settings.

An aspect of classroom setting is peer instruction. Peer instruction is a valuable asset for novice CS students (Zingaro & Porter, 2014). This is demonstrated in *The Girls Create Games Program's* use of *Pair Programming* (Werner, et al.,

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2005). *The Girls Create Games Program* (GCGP) involved a class which was devoted to teaching female students programming through the creation of their own games. The students worked in pairs to use a program called *Creator*. Experimenters found that social interaction between the two students created a strong atmosphere of learning, as pairs were supportive and encouraging. The use of pairs in programming begins to address Prensky's design principle of interaction for GBL (Presnky, 2007). In addition, it is important to note that previous studies have shown that females enjoy and appreciate games which have been designed specifically for them (Stewart-Gardiner et al., 2013). Creator demonstrates the importance of a social aspect.

*Storytelling Alice* is a programming environment where students learn basic concepts by creating animated movies and games. It has been used in multiple studies where participants have tested the validity of pair programming and assessed the importance of narratives in learning as well as exploration within the programming (Kelleher, Pausch, & Kiesler, 2007). It suggests the importance of a social aspect to programming.

Other projects focus on the use of programming within a game such as *Scratch*, *Code Spells*, and *Hack 'n' Slash*. *Scratch* is a visual programming environment designed for early-education. Students use their creativity to build stories and animations (Maloney et al., 2008). The syntax for scratch is based on programming blocks which are arranged by students to create programs or actions. *Code Spells* is a game in a 3D environment which teaches concepts of Java programming (Esper, et al., 2014). Its base state does not allow for situation specific problem solving. Meanwhile *Hack 'n' Slash* is an arcade style game in which players use concepts of programming to progress.

While these games have been effective for learning, there are still some gaps which exist. For example, while the *Code Spells* game teaches programming for female students, it does not include a narrative or story aspect; a narrative story can provide the structure to propel successive learning and drive interests. Also, the language choice of Java may be too difficult for beginners learning to program (Radenski, 2006).

*Scratch* programming is effective but does not allow for practical programming as in SOS. *Scratch* does not present problems to solve; rather it is an environment for them to explore programming. Similarly, *Hack'n'Slash* does not include practical programming or social aspects and only focuses on entertainment value. While they are effective for their original purpose, these games are not appropriate for the current research's specific target Audience and objective.

## REQUIREMENTS DEVELOPMENT

Previous work provided requirements for effective games in education (Gee, 2003; Prensky, 2007). Gee (2003) created an extensive list of 36 learning principles which are used in most games. For the scope of this project, it was necessary to develop requirements which are more specific to the current task's target audience. Requirements for this audience focused on including protagonist's portrayal, narrative, induced uncertainty, mechanics, social aspects, and overall enjoyment. These are discussed further in the following section.

### Description of Requirements

*Protagonist.* One of the primary reasons why females do not enjoy playing video games to the same extent as males is the portrayal of their gender (Martin et al, 2009). Thus, it is important to design a game with female characters whose representation is not hypersexualized (Grimes, 2003).This provides young female players with a relatable character.

*Narrative.* The story is important because it can encourage repeated play. A story that is interesting can engage students and incorporate the concept of flow (Rollings & Adams, 2003).

*Uncertainty.* Uncertainty provides motivation and can increase interest (Ozcelik, Cagiltay, and Ozcelik, 2013). It mimics real life, as the solution to a problem is not always immediately clear. . A game needs to be difficult but not overwhelming. Uncertainty also allows for exploration and experimentation with previously acquired competencies (Iacovides, Aczel, Scanlon, Taylor, & Woods, 2012).

*Mechanics.* This refers to how coding is accomplished. Game skills should be transferrable to the real world. Maloney et al., (2008; p. 371) argues that "*systems can make programming more accessible for novices by simplifying the mechanics of programming, by providing support for learners, and by providing students with the motivation to program.*" Thus, applications for learning programming should strive to teach in a way where concepts can be comprehended through mastery of the system, and are applicable in realistic contexts.

*Social.* This social requirement relates to peer influences and promotes interaction. When a student is first learning to program, it can be frustrating as many are quickly discouraged (Williams & Upchurch, 2001). Social interaction can decrease frustration through one-to-one peer interactions by alleviating discouragement. A previous study found that students aged 9-13, who worked together at a computer solving puzzles were more successful and motivated to play a game longer compared to a single player (Inkpen, Booth, Klawe & Upitis, 1995).

*Fun*. While the purpose is not solely to entertain, entertainment value is important as it leads to more time spent playing the game (Billieux, Deleuze, Griffiths, & Kuss, 2015). This increases the potential for concept retention.

## SORCERESS OF SEASONS (SOS)

The six requirements were utilized to design the game *Sorceress of Seasons*, which teaches concepts of Python programming. Several concepts serve as the subject matter for the preliminary levels.

### Game Process

Players are introduced to Python through a tutorial video. They then play through the game using a command window to enter in Python code, which alters or engages one of the abilities inside the game. For example, changing the color of the teleport block indicates the distance and direction a player is transported (see Figure 1).

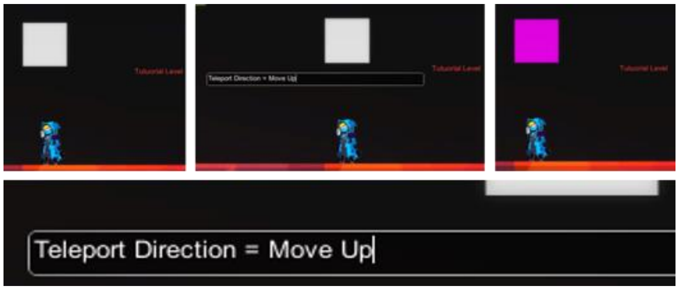


**Figure 1: Teleport Block Storyboard and Command Window**

As players progress, they learn new concepts they acquire new in-game abilities such as the teleport block, programmable ammo coins, and programmable walls. These tools are necessary for completing in-game puzzles which manipulate uncertainty. They require the player to demonstrate critical thinking skills as they apply the tools in order to progress. Several hints are given but it is up to the player to solve the problems, as they explore the environment.

## METHODS

### Objective

The evaluation's purpose is to determine how the game's requirements affected middle school student's attitudes and interest towards STEM or CS career fields.

### Hypotheses

There were two hypotheses in this evaluation:

- Interest in STEM fields will increase after playing an educational game that was designed based on gender-inclusive requirements.
- The game requirements will have a higher influence on females' STEM attitudes than males'.

### Participants

Fifteen students (eight male, seven female) participated in the study. Age ranged from 10 to 14 years old and all were middle school students from a school located in a medium-sized, Midwestern city. Eight students (four male, four female) were fifth graders, three (two male, one female) were 6$^{th}$ graders, three (one male, two female) were in 7$^{th}$ grade, with one male student was an 8$^{th}$ grader. Seven students (4 male & 3 female) indicated that they had previously programmed.

### Experimental Metrics

The metrics of the evaluation were responses to questions deigned to assess the utility of requirements and changes in STEM attitudes (see Table 1). Changes in responses to these questions pre and post-game assess the effectiveness of the requirements as implemented in *SOS*.

**Table 1: Experimental Questions**

| Topics | Pre-Experiment Questions | Post-Game Questions |
|---|---|---|
| Protagonist | The gender of the protagonist does not matter to me.<br>It is important to have a female protagonist in a game.<br>It is important to have a male protagonist in a game. | Your character's gender affected your level of interest in the game. |
| Narrative | I enjoy a game that has an interesting story/narrative.<br>I enjoy a game with a developed story. | The game's story made you want to play the game. |
| Uncertainty | I like games that have puzzles.<br>I like games that are challenging. | The game had puzzles which were fun to figure out.<br>The game was too difficult to understand. |
| Mechanics | n/a | You would've like more hints or help within the game. |
| Social | I like games in which I can interact with friends or other players. | You would have liked to play with your friends. |
| Fun | The best games make me want to play for long periods of time. | The game was enjoyable.<br>You were interested in playing the game for the allotted time. |
| STEM Attitudes | n/a | Opinions about CS and related careers changed.<br>More likely to choose a CS related career. |

### Experimental Procedure

After confirming parental consent, students were invited to participate in the child assent process. The students began the 60 minute session 1 of the study by completing a pre-experimental survey. Next, students practiced filling out a NASA Task Load Index Survey (TLX). Then, they watched a 15 minute game tutorial video, completed a 10 minute tutorial level and finally, completed a 10 minute post tutorial quiz; this completed session 1. Session 2 occurred one week later with students completing a three minute game refresher. Next, they had 30 minutes of game play. Then, students completed a three minute TLX survey. Finally, they completed a 20 minute Post-Game Survey.

### Limitations and Assumptions

Access to students was determined by parents and the school which resulted in using a two session format which allowed for flexibility. However, the gap between the Session 1 and Session 2 may have affected the results of the Post-Game Survey. Also, some students indicated having previous exposure to programming. The results do not reflect a diverse sample size since the study was conducted at a single school.

### Data Analysis

Student's t-tests were used to check for significance between genders in the pre-experiment and post-game survey questions that asked about the influence of the requirements. In all cases, significance of data was determined by alpha values under 0.1. Values ranging from 0.05 to 0.1 were categorized as marginally significant while values below 0.05 were categorized as being significant.

# RESULTS

## Comparison of Career Attitudes

Female students had a higher response (M= 3.5, SE = 0) of opinions changing about CS and related fields than males (M= 3.25, SE = 0.37) (see Figure 2**Error! Reference source not found.Error! Reference source not found.**). Females (M= 4.17, SE= 0.08) also indicated that they were more likely to choose a CS related career field which was greater than males (M = 3.38, SE = 0.41). The differences were not significance.

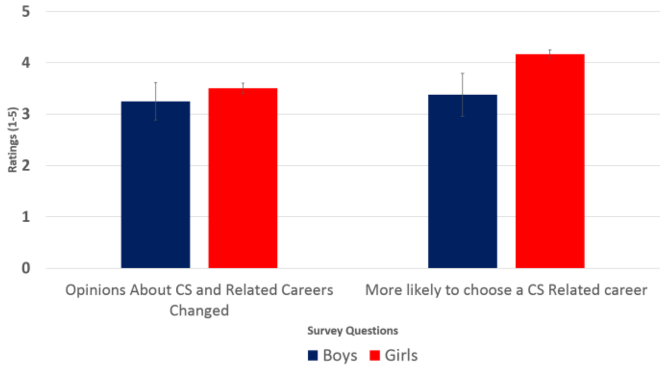


**Figure 2: Post-Game Gender STEM & CS Attitudes**

## Pre-Experiment Importance of Requirements

**Error! Reference source not found.** Figure 3 provides a gender comparison for the pre-experiment questions on the influences of requirements. There were no significant differences found for any of the question.

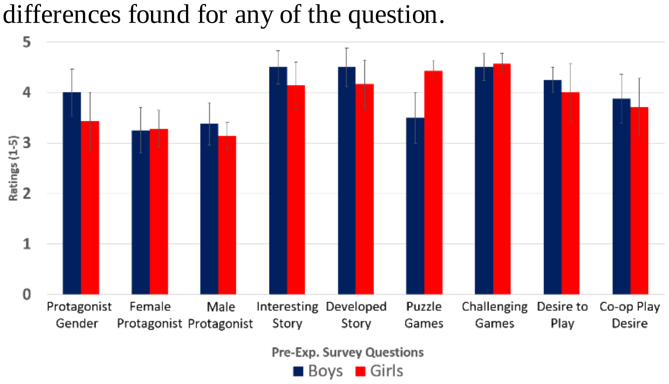


**Figure 3: Pre-Experiment Importance of Requirements**

*Gender Requirement*. Students across both genders had similar views reporting a high interest. Males averages 4.0 (SE= 0.46) while females averaged 3.42 (SE= 0.57), suggesting that the gender of the main character mattered to both males and females rated the importance of a female protagonist similarly (males: M=3.25, SE=0.45; females: M=3.28, SE=0.35). However, males placed a slightly higher importance for having a male character (M= 3.37, SE=0.41) than females (M=3.14, SE=0.26).

*Narrative Requirement.* Both gender averages were high for the story requirement with males posting a higher average than females in both categories. For interesting story males had an average of 4.5 (SE= 0.32) while females averaged 4.14 (SE =0.26). For a developed story, males averaged a 4.5 (SE= 0.37) while females had an average of 4.16 (SE= 0.47).

*Uncertainty Requirement.* Females post a higher average of 4.42 (SE= 0.2) for favoring games which had puzzles while males were 3.5 (SE= 0.5). Both males (M= 4.5, SE= 0.26) and females (M= 4.57, SE= 0.2) posted relatively high preference with challenging games.

*Social Requirement.* Males (M= 3.88, SE= 0.47) and females (M= 3.71, SE= 0.57) scores showed relatively the same preference for playing games with friends.

*Fun Experience Requirement.* Both males (M= 4.25 SE=0.25) and females (M= 4 SE= 0.57) tended to agree with wanting games to encourage long periods of play. They also indicated liking games which they could play with friends (males: M= 3.88, SE= 0.48 and females: M=3.71, SE= 0.57).

## Post-Game Influence of Requirements

**Error! Reference source not found.** provides a gender comparison for the Post-Game Influence of the requirements.

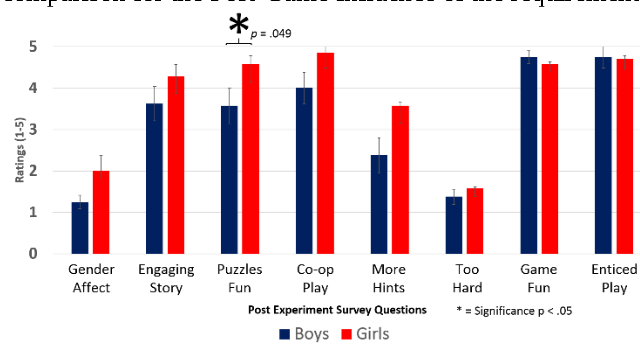


**Figure 4: Post-Game Influence of Requirements**

For the puzzles question, females' scores were significantly ($t$ (11.96) = -2.18, $p$ = .049) higher than males. The other findings were not statistically significantly. For the protagonist, students indicated that characters gender did not affect their levels of interest with low scores. They also did not find the game too hard. Meanwhile, students gave high scores for the importance of story, fun puzzles, cooperative play, desire to play SOS, and deeming it enjoyable.

# DISCUSSION & CONCLUSION

The first hypothesis was partially supported as the game was shown to have a positive effect on students' interest and attitudes towards programming. Based on the average ratings to post-experiment questions, students indicated that their opinions about CS and related careers had changed after playing *SOS* and they were more likely to choose a CS career. While a larger increase was reported for females than males, the difference was not statistically significant, given the low numbers of participants. The phrasing of the questions, and the fact that they were only asked at the end of the session may have encouraged some participants to answer more positively due to expectation bias. Future studies should measure attitudes before and after the game for a more direct comparison. The second hypothesis was not supported as there was no statistical difference between males and females. However, female students did report a higher response to the influence of a majority of the game requirements than males, although most differences did not rise to the level of significance. This is important as it may show how curriculum can be improved for female STEM students.

The mechanics of programming in *SOS* are relatively simple as students could quickly grasp them in the tutorial and at the start of the second session. This simplicity is similar to the arcade style game *Hack'n'Slash* (Cobbett, 2014). Students showed understanding with concepts but the level of detail required to enter programming commands may have been too difficult for some students, leading to uncertainty. However, this complexity allows for problem solving which may not be achieved with programs like *Scratch* (Ozcelik, 2013).

Results of the study also support the inclusion of uncertainty as a majority of students reported to like the puzzles, find the game appropriately challenging and being motivated to play *SOS*. Its' puzzles or challenges were met with significantly high response from females which in part builds upon previous work from Esper et al (2014) that involves the development of challenges or puzzles. This suggests how uncertainty was incorporated in the game was successful. Furthermore the requirement of engagement throughout the activity was clear through students' feedback. A majority of participants were disappointed at gameplay's end as they wanted to continue playing. This is important as one of the goals of the game was to engage female students.

In the study, social interactions within the game were limited to players talking about their achievements and unlocking abilities. All students indicated that they would have liked to have played the game with their friends. This follows previous work which indicates the benefits of teamwork within GBL and for female students (Stewart-Gardiner et al., 2013; Inkpen et al., 1995). This also suggests the effectiveness of GBL for programming.

Results of the study are encouraging for improving STEM interest for both male and female students. Supplementary descriptive data can be acquired through incorporating new *SOS* features and surveying materials. Further exploration of curriculum may be of benefit for future iterations. Follow up work needs to validate these results with a larger sample size. In addition, schools from different districts should be included for diversity.

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