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Increasing Female Middle School Student Interest in STEM: Requirements for Game-Based Learning Applications*

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This exploratory work developed requirements to build games to increase female middle school students' interest in Science, Technology, Engineering, and Mathematics (STEM). In middle school, students typically begin to determine career interests. Female students have many barriers to full participation in STEM, including stereotypes, role socialization, interests, and attitudes which can influence confidence in areas such as mathematics. Game-Based approaches are designed to overcome barriers, allow experimentation with difficult concepts, and engage students. However, many games are designed for the "default" male user, leaving female preferences unaddressed or as secondary issue. Six requirements (Protagonist, Mechanics, Socialization, Fun, Uncertainty, and Story) were developed from relevant literature, surveys, and consultation with STEM outreach organizations. The requirements were developed to identify factors which may make a game engaging to a wider audience that include female middle school students. The requirements were used to develop SORCERESS OF SEASONS, a game designed to develop computational literacy in middle school students. An evaluation with 15 middle school students provided feedback on requirements, learning, and STEM interest. Both female and male middle school students showed an increase of basic computational knowledge comprehension, and increased interest in STEM careers, with females reporting a larger gain. The results suggest that the requirements may be helpful when developing games to increase student interest in STEM.

Keywords: game-based learning; STEM; programming; computational literacy; middle school education

1. Introduction

The number of STEM professionals must increase to keep pace with the growth of US high technology jobs [1]. The United States is expected to have 2 million STEM jobs go unfilled by 2025 due to a lack of highly skilled candidates [2]. While a third of all college graduates are from STEM degree programs, the number is insufficient to accommodate the demand. Despite efforts to raise female participation, the percentage within STEM fields remained approximately 24% from 2000–2009 [3]. Female participation in Computer Science (CS), Math, and Engineering decreased from 30% to 27% from 2000 to 2009 [3, 4]. As of 2015, 47% of the US workforce were women, but only 26% of STEM employees were women [5]. Women are the largest underutilized source of underrepresented populations [6]. If females were to enter STEM fields at rates equal to males, the predicted shortage of qualified engineering and science graduates would be filled [7].

Traditionally CS has been introduced during high school, with an approach that relies heavily on the instruction of formal computer languages that students often find cryptic [8], and which senior high school female students perceived as boring and irrelevant [9]. Female participation in particular is often depressed due to stereotypes, role socialization, interests, attitudes which can influence confidence in areas such as mathematics [10, 11], and a perception that it is not relevant to society [12]. The goal of this work is to apply the benefits of game-based learning approaches to overcome some of these barriers and increase female interest in CS.

Female and male students perform very similarly in fourth, eighth and twelfth grade math and science tests [13]. But by high school, significantly fewer female students sign up for Advanced Placement (AP) social studies, calculus, and science [14]. In 2014, only 20% of students enrolled in high school CS AP courses were women [15].

Middle school female students felt significantly less successful, and fewer females felt that mathematics was one of their best subjects, despite no difference in performance between males and females [16]. Many females discontinue STEM careers in college due to a lack of mathematical confidence instead of a lack of mathematical ability [17]. Barriers to female participation include students not initially finding CS interesting, having a lack of confidence in their ability to succeed in CS courses, and feeling uncomfortable in the currently male-dominated computer science culture [4].

Middle school is an important time in the development of student interests, competencies, confidence in their abilities [18]. During this time their

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interests begin to translate into career paths [19], and they start to make decisions about possible careers in the sciences [14]. Perceptions of STEM at an early age may influence career pursuits. More needs to be done to expand the pool of students interested in STEM by increasing diversity of participants and thought [20].

Previous studies have found that students may not understand exactly what a STEM profession consists of [10, 21]. Students who were exposed to STEM programming reported a higher interest in pursuing STEM fields or subjects that required problem solving compared to those who did not participate [21]. Furthermore, female students had a larger increase when compared with males.

One approach to addressing barriers is to leverage the power of games to inspire engagement with material and provide positive experiences in STEM. Since video game players make up approximately half of the US population, there is a large appeal for game-based content [22]. Approximately 155 million (42%) Americans play video games at least three hours per week [23]. The percentage of female gamers ranges from 41–45% [24]. However, there has been limited research in how the use of game programming with middle school students can enhance learning and engagement in STEM studies [25].

While many games are designed for entertainment, *serious games* is used to teach problem-solving or provide training, instead of strictly serving as entertainment [26]. Games and gamified applications have previously been used to change attitudes or perceptions [27]. Serious games have been created to increase knowledge and awareness of real-world issues such as climate change [28] or sustainability [29]. Game-based learning (GBL) is not a game, but rather an approach to learning. Specifically, game-based learning is the process and practice of student learning through the use of games. GBL pairs game play with defined learning outcomes [30].

To address the gender gap in STEM participation, a GBL approach was used with the goal of increasing female middle school students' interest in Science, Technology, Engineering, and Mathematics (STEM) careers in general, and CS in particular. A game aimed at middle school students was designed to support computational thinking skill development, an important skill to develop at an early age [31]. Game-based learning was used to create an engaging experience that also functions as a Computational Literacy Game (or CLG) [32]. A CLG is a game or program which is used to teach computational skills to students such as programming logic [12]. Computational literacy (also referred to as computational thinking) can be described as utilizing fundamental CS concepts to solve problems [33]. There has been a growing consideration that attaining computational literacy in younger students is an important way to develop the skills and familiarity with computational principles, design thinking, and procedural logic that are useful regardless of the fields in which students eventually study [31].

However, while games for learning exist, they do not explicitly address the preferences and needs of female middle school students. Therefore, requirements have been developed to design games with the goal increasing female interest in STEM. The requirements serve as guidelines for game designers and educators to create STEM-related educational games that are engaging to both genders but specifically include features which address the preferences of female students. This includes aspects which engage the player such as the method in which learning is planned, how the experience feels, and how to best implement the content within the game experience [34]. While previous work has looked at how effective games might be in learning (e.g., [27]), explored how female students think about and solve problems while working on the computer (e.g., [27]), and theoretical perspectives behind game development (e.g., [35]), there has not been a systematic articulation of game requirements that might be used to facilitate interest in STEM using GBL. For games developed without female student preferences, proper content implementation, inclusion, and testing, the GBL approach may fail to be effective for the intended audience or produce the intended outcomes.

The remainder of the paper is organized as follows: (1) background and theory behind using games-based learning to engage middle school female students, (2) development of requirements specially targeted to making games appeal to female audiences, (3) description of a game, SORCERESS OF SEASONS (SOS), developed based on these requirements, (4) an evaluation conducted with middle school children to evaluate the students' learning, the effectiveness of the requirements, and changes in students' attitude about STEM, and (5) a discussion and future work.

2. Game-Based Learning to Engage Middle School Female Students

2.1 How Gaming Can Help

Games for learning can add to students' comprehension of new and challenging content [29] through mechanisms like achievement, peer interaction, and immersion [36–38]. Games can broaden knowledge acquisition for problem solving compared to traditional classroom instruction alone

[39]. Through gameplay, difficult content becomes more approachable for students, allowing them to engage with subjects which initially bring about anxiety or are not appealing [40–42]. Games for learning is a relatively new area which needs further exploration [43].

In GBL, the player dictates the speed at which new content is introduced through gameplay and allows ample time to practice and gain competency before moving to a more complex concept, building upon previously-learned knowledge. Additionally, games provide real-time feedback on progress towards the game's goals, and how well students are learning content.

GBL can engage students by providing unique and realistic experiences [10, 26] that mirror aspects of active learning through engaging students with subject material in successive stages depending on comprehension levels [44]. The game should allow the user to experience situations, learn concepts, practice skills, and develop familiarity with the subject matter. Through experience with the subject material, opinions about the subject material may change as they are able to build confidence in the subject, dispel stereotypes, and understand what they can accomplish in that area [26].

2.2 Female Game Preferences Not Addressed

GBL can leverage the engagement offered by interactive media to support learning methods. However, what works well for some students do not work well for others [45]. How serious games are designed can either make them more or less appealing to certain groups based on preferences. Accounting for context, learning style differences between people in general are greater than the learning style differences between males and females [46]. Thus GBL provides an additional method to provide differential instructional interventions.

In technology, gaming, and education, the preferences of females have not been adequately addressed [47, 48]. Preferences of both genders should be considered when developing any application to be widely used. Carr [49] listed preferences that females find to be useful within games as "control, music, good graphics, choice, variety, unpredictability, action, option to select from a range of characters, intriguing tasks/missions, and content relating to magic or adventure." Through the inclusion of these aspects, games may become more effective for female players. Most technology is based on perceived male preferences, thus gaming has traditionally been designed for the "default" male user [50, 22]. For example, a group of software designers were asked to develop software for 7th grade males, 7th grade females, and generic 7th grade students. While the resulting software designs for males and females were very different, the "generic" program was nearly identical with the program designed for males, and shared little of the features of the program designed for females [50].

There are two areas in technology design where gender is insufficiently addressed [51]. Gender as *superfluity* refers to leaving gender issues unaddressed due to the belief that differences between genders as unimportant. This causes many design decisions that ignore the needs of females. *Gender as lack* refers to splitting the importance of gender into two classes, with females being classified as the second gender and consequently with less important needs.

2.3 Gamified Applications to Increase Female Participation

Studies have previously applied GBL and related game-based approaches to higher education [38, 52, 53]. Previous games have targeted K-12 students to teach and practice STEM subjects such as CS. CODE SPELLS was created for students aged 9–10 and teaches Java programming via a spell book [54]. Spells represent code players use to alter and create spells. CODECOMBAT is a role-playing game for students in 6–12th grade. It teaches programming skills in multiple languages [55]. CODE HUNT focuses on players identifying missing code within a compiler. The game does not specifically teach programming fundamentals, but rather serves to sharpen skills by building upon previous knowledge. It was not designed for a specific target audience. CODIN GAME is a website containing several games teaching programming. Players use a turn-based system to enter code to make their character or environment perform a function [56]. Furthermore, Tsarava et al. [57] taught fundamental computational thinking concepts to students in grades 3–4 by gamifying real world activities, brainstorming how to apply concepts in computer environments, and building games using constructionist education methods [58]. Finally, HACK'N'SLASH is an arcade-style game focusing on puzzle solving. Players use programming metaphors to "hack" the game and reprogram object properties.

Several programs have targeted female middle school students. STORYTELLING ALICE was developed as part of research studies to explore the effect of adding story elements to the time spent programming, and is a programming environment where students learn basic concepts by creating animated movies and games [59]. The *Girls Create Games* program was designed to evaluate the effectiveness of pair programming, and taught pairs of female students in 6–8th grade to program their own games [60]. Experimenters evaluated the effects of social interactions on students learning.

3. Development of Requirements

3.1 Development Process

Requirements were developed and implemented through literature review, student surveys, discussions with STEM outreach organizations, and consultations with game design experts. These requirements were not intended to "feminize" specific games. To do so would be to simply create what is known as a *pink game*, which focus on traditional values of femininity [61]. Rather, the requirements developed here identified factors which may make a game engaging to a wider audience that includes female students.

The review of existing literature included topics such as learning, game development, game design, and principles of successful learning games. Undergraduate students from a large mid-western university were given an initial survey to gather a preliminary understanding on their attitude about games. A five-question survey was administered to 15 (4 male, 11 female) STEM majors from a freshman STEM course. Some students felt that games are "*time consuming*" and "*do not really teach anything.*" Some perceived the violence as a negative and that playing games "*isolates you.*" Others felt that the socialization potential for games was a positive. Discussions with the Society of Women Engineers (SWE), Women in Science and Engineering (WISE), and the local Science Center provided feedback on what motivates young females to study into STEM and what barriers or behaviors to avoid. Game design experts provided a clearer understanding of content, how content was to be taught, and how to assess content inside and outside of a game. Computer Science Teachers Association [62] standards for students in sixth through ninth grade were followed to ensure the curriculum was effective. From this review, requirements were developed in six areas: Inclusive Protagonist, Mechanics of Gameplay, Social Aspects, Fun, Uncertainty, and Narrative.

3.2 Inclusive Protagonist

Positive representations of females within games avoids discouraging females [63]. Female characters in video games are typically hypersexualized [64]. This can influence poor body image and can lead to poor self-esteem and pathogenic dieting in both genders [64, 63]. Male characters are typically portrayed as athletic, muscular, reckless, and hyper masculine. This can lead to compulsive bodybuilding and steroid use. While likely less of an issue in serious games, gender stereotypes in the portrayal of the protagonist can have negative effects on participants. It was important to design a game with relatable female characters who are not hypersexualized, who display independence, and who avoid stereotypical gender roles [65].

3.3 Mechanics of Gameplay

In avoiding missteps of other educational games, it is useful to consider why some games are more engaging than others [66]. Game mechanics, defined as the mechanical elements of gameplay for the purpose of play and fun, can determine the playability and usability of a game, as well as support the learning goals [67]. Providing an interactive approach, visual indication of task execution flow, and feedback enable student to master differing levels of complexity [68]. Mechanics of Gameplay consists of three areas: content authenticity, appropriate controls, and content implementation. Content should be presented in an authentic manner, and transferrable to the real world. For example, players should program within the game similarly to realistic contexts or jobs [69]. Games like CODE HUNT teach skills applicable to the real world. Locating code errors is a type of problem solving which employers of information science majors rated as an important skill for employees [70]. Games like HACK'N'SLASH and programming environments like SCRATCH teach aspects of programming, but do not include realistic programming. CODE HUNT and CODESPELLS include authentic learning and practice [34].

Today's students are highly familiar with computers, mobile phones, and video game consoles [71], but nevertheless game controls should be straightforward and not interfere with learning. A high level of interactivity enables a fruitful dialog between a student and the game [72]. How the content is implemented in the game should help players learn core concepts without inconsequential details. In computer science, Maloney et al., [73, 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.*" The method in which a skill or competency is taught should make it easy for a learner to apply the material in the real world. This suggests situated meanings, regime of competence, and scaffolding [44, 74]. Situated meanings refers to information in the appropriate setting, such as how the knowledge of programming syntax is meaningful when writing an if-statement. Regime of competence refers to approaching the limits of competence with a concept just before the student requires assistance. Scaffolding helps a learner gradually acquire knowledge with assistance until self-sufficient.

3.4 Social Aspect

Effective teamwork is an important aspect in engineering design [75]. When learning programming, students can become frustrated and discouraged [76]. One-to-one peer interactions can decrease frustration by alleviating discouragement. A study found that students aged 9–13 working together solving computer puzzles were more successful and motivated to play a game longer than single players [77]. Additionally, working in groups or pairs when learning CS has been shown to be beneficial for female students [27, 78]. Motivating aspects of online games includes socializing, building relationships within games, and teamwork [37].

The social factor addresses some barriers to female participation in STEM. External factors such as perceived teacher support and peer influence can often affect how female students develop attitudes about their abilities and STEM interest [79]. Social factors such as feelings of isolation, intimidation, and lower self-confidence in STEM domains, despite equal or higher achievement, contribute to a lack of females in the field [80]. Social interaction in gaming can serve as form of communication [47].

3.5 Fun

Users who played a game with engineering content reported higher levels of enjoyment and considerably more time spent playing the game than those in a standard lecture setting [41]. While the purpose of learning games is not to entertain, entertainment value can lead to more time spent playing the game [47], increasing the potential for concept retention. Enjoyment consists of engagement, challenge, flow, persistence, and mastery [81].

Players may require a stimulus to continue playing after the initial novelty of the game has abated. Challenge or competition can be a primary motivation for some male and female middle school students [47]. Olson [82] conducted a survey wherein female students indicated that competition was not as appealing to them as males. However, females who identified as gamers went against the trend, saying competition was appealing. Of the total students surveyed, 61% of females reported that they enjoyed competition with 28% citing competition as a major reason for playing video games.

3.6 Uncertainty

Uncertainty is the challenge or obstacle within a game for which players do not always immediately understand what to do. Students are assessed on their ability to solve new problems through applying previously learned knowledge [83. It mimics real life, as the solution to a problem is not always immediately clear. A game needs to be difficult but not overwhelming. A game that is too easy decreases motivation, as there is little to be gained from continuing to play. The challenge needs to be sufficient to provide an uncertain outcome, but not make the player doubt that they can accomplish the goal [84].

Uncertainty allows for exploration and experimentation with previously acquired competencies [83]. In a study of second year engineering students, constructive failure was critical in fostering student intrinsic motivation that promoted learning [85]. Several principles by Gee [44] are relevant such as practice, risk taking, and intuitive knowledge. Additionally, there is a focus on Active Critical Learning (ACL), mental activities which lead to learning something meaningful [44]. Players must be engaged in ACL as the game requires users to continuously assess and solve problems.

3.7 Narrative

The narrative is a story of connected events that can encourage repeated play. Story can be a series of problem solving episodes [86]. These episodes emphasize goals and the actions necessary to achieve them. A good story includes themes, plot, structure, and settings. An interesting story can engage students and incorporate the concept of flow [87], where students learn about their environment from the story and develop knowledge and abilities. Flow can be categorized by elements of challenge [88], where cycles of expertise facilitate user competency over time [44, 74]. Game flow plays a key role in enjoyment as an optimal form of challenge [81]. Aspects of a game should not seem jarring or out of place. Each challenge should appear to be the natural next phase.

3.8 Summary

Based on the six areas discussed, Table 1 lists a summary of the game requirements developed to increase female middle school students' interest in STEM.

4. Application of the Requirements: SORCERESS OF SEASONS

The design of SORCERESS OF SEASONS (SOS) was based on the requirements described above, and was created to be effective for all genders. The game was developed using a human-centered design process of iterative cycles of requirements development, design, implementation, and evaluation [89]. Each iteration increased the prototype fidelity from

Table 1. Game requirements

Requirement	Requirement Description
Inclusive Protagonist	Games should represent females in a way that is not stereotypical or offensive. Portray realistic body types and roles associated with strong, independent females. The game should not reinforce stereotypes. Protagonists should be relatable. The character should have traits or goals consistent with issues students may encounter, as well as personality traits of the target audience (e.g., overcoming challenges, interaction with peers).
Mechanics of Gameplay	Gameplay should allow users to learn subject matter in a way that makes material easy to understand. Content metaphors should be used, when applicable. These include game objects or features which are affected by the player's performance, or an action within the game which directly correlates with a real-world example. Educational jargon (vocabulary peculiar to a particular trade, profession, or group) should be limited. Content learned in the game should be authentic to its real-world use or context. Controls of the game should allow the user to play tile game without distractions such as poor usability or high initial familiarization time. Scaffolding and well-ordered problems early in the game can teach players how to play tile game. Games should include defined rules so that players can understand what actions they can and cannot take. A high level of interactivity can enable a fruitful dialog between a student and the game.
Social Aspect	Games should have a degree of socialization, whether it be through peer play or use of the game for comparison and conversation during or after gameplay. Discussion or paired gameplay to facilitate interaction should be included, if possible.
Fun or Enjoyable	Players should have fun when playing the game. The game should not be seen as work. Active learning environments where players are easily able to understand rules and goals should be provided. Games should include aesthetics favorable to the target audience. Game goals should be clear so that players understand what they are trying to accomplish. Games should provide immediate feedback so that players can determine their performance. This also allows them to determine how effectively their actions accomplish a game's goal.
Narrative Story	Games should incorporate story or narrative that inform the players of the goal. Successful stories have well-developed themes (that which informs), engaging plots (conflict or struggle), structure (beginning, middle, end), an interesting setting (place or time), and an attractive style. Stories should consist of problem-solving episodes or levels containing concepts which add to overall comprehension of the content. Successful narratives mirror a game's structure as players master abilities at each level. The subsequent level should assume the player understands the previous concepts and should expand upon it in the next skill -related level. Stories should serve as a form of motivation for players to learn the educational content within the game experience.
Uncertainty	Game should have an appropriate degree of difficulty based upon educational goals. The problem or material included within a game should be manageable and solvable by the target audience. Easier concepts should be easy in the game. Harder concepts should come later after students have developed the necessary sub-skills to understand them. Levels of difficulty should serve as motivation for completing the game. Players should be provided with problems or obstacles which require critical thinking about the subject matter. Practice should be provided so that players can comprehend material in a less stressful environment than that compared to traditional exam. Players should be given hints or help within tile game when they are initially learning a concept. As they progress through the game, provide fewer hints.

sketches, storyboards, and paper prototypes to a computer prototype developed in Unity 2D [90]. Formative evaluations were conducted in early iterations with middle school students to provide formative feedback on the design before the formal evaluation described in the next section was conducted.

4.1 Scope and Learning Goals

The game was designed to teach fundamental CS concepts to middle school students to support the development of computational literacy. The game environment was built around the concept of magic to build a narrative that was slightly counter-intuitive for students in a CS class. Magic has been used in engineering classes as a counter-intuitive way to address misconceptions and provide a way to breach expectations in an entertaining and non-threatening way [91]. Specifically the game taught concepts in the Python programming language. Python was originally designed as a language for teaching programming [92]. Each level of the game teaches a core CS concept: (1) variables, (2) lists, and (3) if-statements. Variables represent a single piece of information, and was the first concept chosen due to its simplicity, scalability, and as a cornerstone of programming. Lists expand to several pieces of information in a structured format. If-statements require multiple variables used logically to construct a valid conditional statement. After completing each level, students should understand the concept and apply it within the game to accomplish goals. After the third level, students should be able to draw connections between the three concepts, creating new examples in real world contexts.

The GBL theories of Instructionist and Constructivism were considered as they have approaches for engaging learners [35–58]. Instructionism is educational instructional content which decreases the difficulty of topic conceptualization for students. A criticism by Bruckman [93] is that this decrease of difficulty oversimplifies educational content, perpetuating an idea that the difficulty setting needs to be lowered. Constructivist theory is defined as "educational practices that are student-focused, meaning-based, process-oriented, interactive, and responsive to student interest" [94] (p. 2). The social nature of learning has to do with learning communities such as class rooms where students play educational games in a group context where they can interact with others [93]. For this project, Constructivist theory is more relevant as the priority is increasing interest in STEM fields with computational literacy gameplay [31].

4.2 Learning Concepts and Game Levels

Players are introduced to Python through a tutorial video. They then play the game and use a command window to enter code, which engages or alters one of the game abilities. As players learn new concepts, they acquire new in-game abilities such as teleport blocks, programmable ammo coins, and programmable walls. These are necessary for completing in-game puzzles which manipulate uncertainty. The player must demonstrate critical thinking skills as they apply the concepts in order to progress.

Level 1: Variables. Teleportation blocks introduce the player to the environment and provide a foundation to scaffold subsequent concepts. Students learn what a variable is and how to use it to choose a direction to teleport. Competency is developed through repetition as players use blocks to move through a maze by assigning data to the variable Teleport Direction (see Fig. 1).

Level 2: Lists. Players summon Ammo Coins using the concept of lists. Ammo Coins allow a player to select a specific type of energy to break through walls when their normal energy cannot. Players select the appropriate energy type from a list: Energy = [Red Energy, Blue Energy, Yellow Energy].

Level 3: If-Statements. Students must use variables to produce a valid if-statement. Participants are shown how an if-statement depends on specific conditions being met. Players encounter walls; to destroy the walls, they must program an if-statement, as their energy blasts will not break them unless they choose the correct type of energy (see Fig. 2). If a player was using a blue gun, they would write "If Walltype == red: setgun blue will break".

4.3 Realization of Requirements in Game Design

The six requirements were implemented throughout the game. The main protagonist and antagonist of the game are female. Characters are not hypersexualized, do not represent stereotypical roles, and perform tasks which could be associated with either gender. Narrative is included through the tutorial video and gameplay. Social aspects outside the game include peer interactions to help understand concept, and comparisons of performance after the game. The mechanics of gameplay are appropriate as the command window simulates the entering of realistic coding. Metaphors serve as hints but do

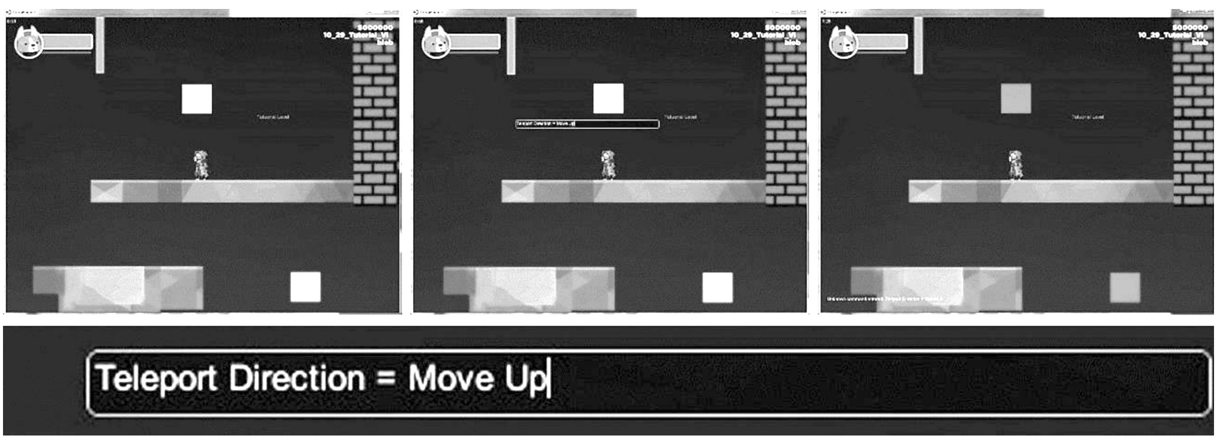

Fig. 1. Level 1, Teleport block story board and command window.

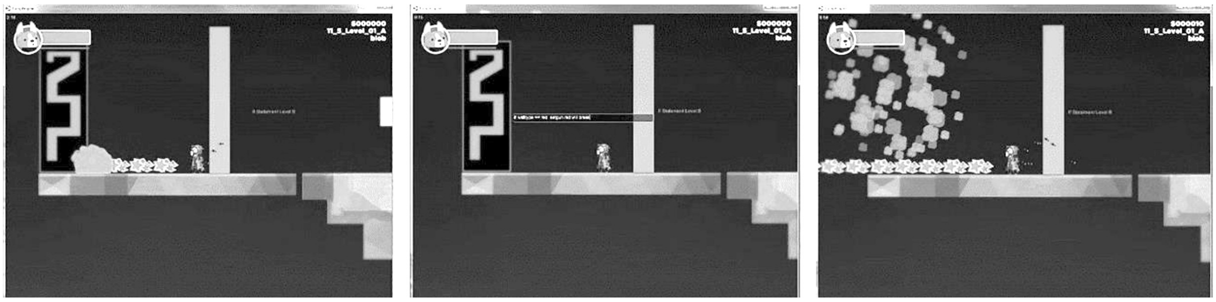

Fig. 2. Level 3, breaking programmable walls.

not diminish the experience of programming. The pacing of the game and possibility of in-game discovery provide an engaging experience. The game provides an environment for trial and error where students receive instant feedback on their actions within the game to immediately make adjustments. Game aesthetics were designed to result in an enjoyable experience. Finally, students solve puzzles in the game. Players are provided with hints, but they must ultimately apply lessons learned within the game to determine the information and actions necessary to solve them. The game facilitates the need for exploration and practice.

5. Exploratory Assessment Study

5.1 Study Design

An exploratory evaluation was conducted to determine the effectiveness of a game developed using the requirements to teach basic computer programming concepts, increase the interest of female middle school students in STEM, and create an engaging experience for both male and female middle school students. Evaluation of a serious games should demonstrate both a transfer of learning outcome (e.g., the "serious" component) and that the game was engaging (e.g., the gaming component) [67]. Specifically this study looked to gather feedback on elements directly impacted by the requirements. This research was approved by the Institutional Review Board.

After confirming informed parental consent, students provided assent. Fifteen students (eight male, seven female) ranged from 10–14 years old. Students were from a Midwestern middle school. Seven students (4 male, 3 female) indicated that they had previously programmed. Session 1 of the study included a pre-experimental survey, training on survey instruments, a game tutorial video, a programming tutorial, and a post tutorial quiz. Session 2 occurred one week later with students completing a game refresher followed by approximately 30 minutes of gameplay. Then, students completed a post-game survey.

Performance was determined by open-ended and multiple-choice problems. Questions were developed from examples a programming textbook for kids [95] and from validated *Assessing Women and Men in Engineering* surveys [96]. Design requirement effectiveness was assessed through pre-experimental and post-game surveys. Questions addressed specific requirements on a five-point Likert Scale (see Table 2). The post-game survey asked questions about participant opinions about CS and programming related careers. These questions were asked at the end of the experiment to avoid the question order effect, when the context of later questions perceived by participants is altered by initial questions, which influences the results of the survey [97]. If these questions were included at the start, participants would have known the measure being evaluated. Thus, students may have been influenced to provide desirable results. These questions were derived from the Friday Institute's validated survey instruments to assess the impact of K-12 STEM education outreach programs [98, 99].

5.2 Study Results

Given the small number of participants in this exploratory study, results are described in descriptive statistics, but no inferential statistical analyses was conducted.

Performance. There was an increase in performance from the pre-experiment (M = 16.0%, SE = 6.3%) to the post-game survey (M = 31.3%, SE = 6.2%). In the pre-experiment, males scored 19% (SE = 3%), while females scored 14% (SE = 6%). In the post-game survey, females scored 33% (SE = 12%) while males scored 30% (SE = 10%) (see Fig. 3).

Pre-Experiment Influence of Requirements. Fig. 4 presents a comparison between genders for each of the Pre-Experiment reported influences of requirements. Students of both genders had similar views, reporting a high importance to how the protagonist was portrayed. Males averaged 4.0 (SE = 0.46) while females averaged 3.42 (SE = 0.57). Both

Table 2. Requirements Evaluation Survey Questions

Requirement	Per-Experiment Survey	Post-Game Survey
Inclusive Protagonist	The gender of the protagonist does not matter. It is important to have a female protagonist in a game. It is important to have a male protagonist in a game.	Your character's gender effected your level of interest in the game.
Mechanics of Gameplay		You would have liked to have more hints or help within the game.
Narrative Story	I enjoy a game that has an interesting story/narrative. I enjoy a game with a developed plotline/story.	The game's story made you want to play the game.
Uncertainty	I like games that have puzzles. I like games that are challenging.	The game had puzzles that were fun to figure out. You found the game to be challenging but not too hard. The game was too difficult to understand.
Fun or Enjoyable	The best games make me want to play for long periods of time.	You were interested in playing the game for most of the allotted time. You were interested in playing the game for the allotted time. You would consider this game fun to play.
Social Aspect	I like games which I can interact with friend/other players.	You would have liked to play the game with friends. I would recommend this game to my friends.

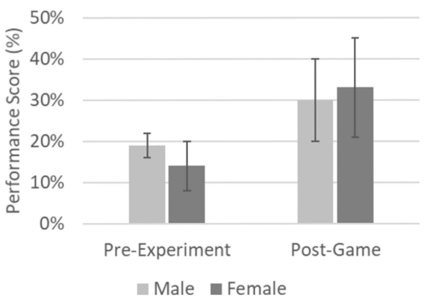

Fig. 3. Performance from pre-experiment and post-game surveys, across gender (n = 15). Error bars represent standard error.

gender averages were high for the narrative requirement with males posting a higher average than females. For interesting story, males had an average of 4.5 ($SE = 0.32$) while females averaged 4.14 ($SE = 0.26$). This pattern was consistent for a developed story, where males averaged a 4.5 ($SE = 0.37$) while females had an average of 4.16 ($SE = 0.47$). In the uncertainty requirement, females posted a higher average of 4.42 ($SE = 0.2$) for favoring games which had puzzles than males ($M = 3.5$, $SE = 0.5$). Both males and females posted relatively high preference for challenging games. Scores for males and females

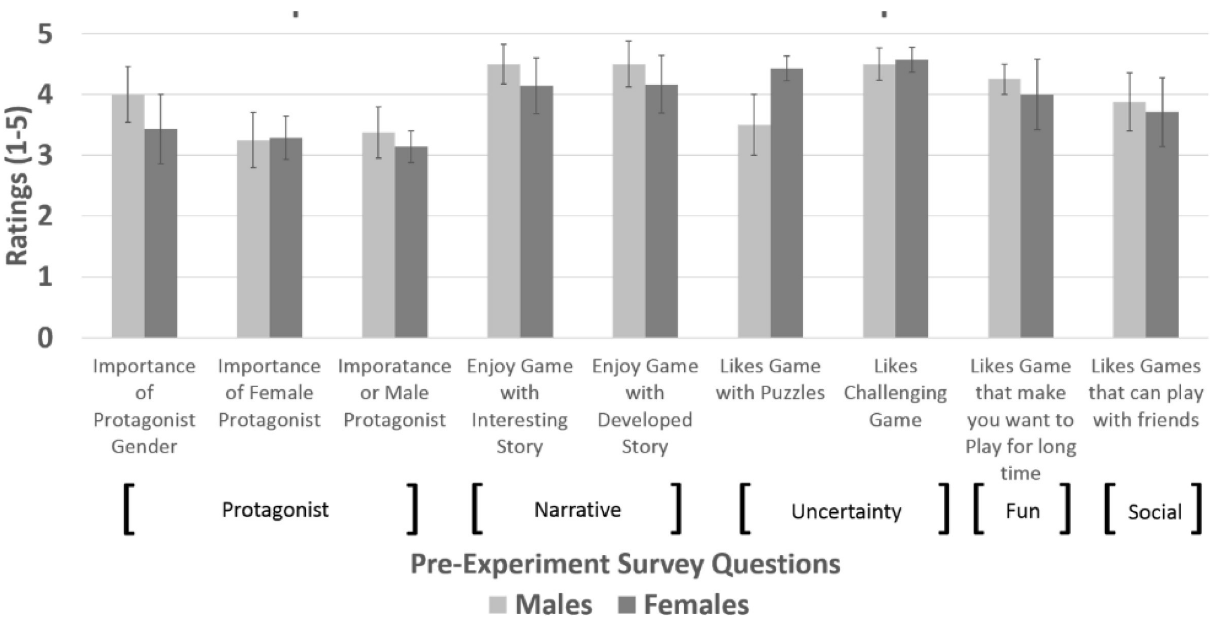

Fig. 4. Pre-Experimental influence of requirements (n = 15). Error bars represent standard error.

Fig. 5. Post-Game influence of requirements (n = 15). Error bars represent standard error.

showed relatively the same preference for playing games with friends. Both males and females tended to agree with wanting games to encourage long periods of play. They also indicated liking games which they could play with friends.

Post-Game Influence of Requirements. Survey results showed strong support by both genders for the requirements. For the puzzles question, females' scores were higher than males (see Fig. 5). Female students also rated higher the desire to play with friends, and for the hints question. For the protagonist, students indicated that character gender did not negatively affect their levels of interest. 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.

Comparison of Career STEM Attitudes. Female students ($M = 3.50$, $SE = 0.1$) had a larger change in opinions about CS and related careers than males ($M = 3.25$, $SE = 0.37$) after gameplay (Fig. 6). Females ($M = 4.17$, $SE = 0.08$) were more likely to choose a CS related career field than males ($M = 3.38$, $SE = 0.41$) after the experiment.

6. Discussion

Results from the pre-experimental survey show females reporting higher responses in the uncertainty related question for puzzles compared to males. Meanwhile, males reported higher responses in the first protagonist question. In the other categories for narrative, fun, and social requirements, differences were not large. The students were in general agreement with the utility of the requirements.

In the post-game survey, students reported that the protagonist's gender has little effect in their interest in playing SORCERESS OF SEASONS, which suggests that representation of the character was not negative, did not distract from playing, and the game did not display gender stereotypes which

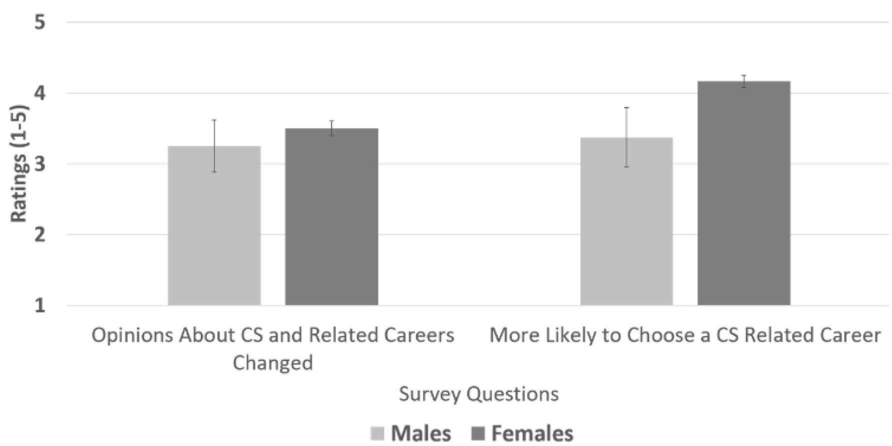

Fig. 6. Site a Post-Survey Attitudes Comparison.

would make students feel unrepresented in the game. Both male and female students reported that the game's story motivated them to play. Females responded with higher scores than males. This suggests the story was engaging, especially to female students. Students also responded that the game was fun and they were motivated to play the entire time. Students felt that the game was not too difficult. These results suggest that the requirements of protagonist, narrative, mechanics, and fun were well-received by students, and effectively implemented within SORCERESS OF SEASONS.

The comparison between genders revealed differences for uncertainty, social aspect, and mechanics of gameplay, where female ratings were higher than those of males. The desire to play with friends was also rated highly, with females rating higher than males. These results suggest that the inclusion of the uncertainty and social requirements were also well-received by students. However, the results from the hints question suggests that while mechanics were rated highly, more hints could have made mechanics better for gameplay.

Although scores improved after the tutorial and gameplay, they were still generally low. Low scores may be attributed to the short time of gameplay. Students demonstrated learning gains from the pre-experiment to the post-game surveys. While males scored higher in the Pre-Experiment, females scored higher in the post-tutorial and post-game phases, which demonstrates a larger learning gain. This suggests that the game was effective in teaching the subject matter and that both genders benefited from the game. Presumably, continued exposure to the game would improve scores, but further work is required to confirm these results. In future work, more concepts could be included like loops, if-then-statements, and dictionaries. These concepts further build upon the ones previously included.

7. Conclusion

This work developed requirements to build games to increase female middle school students' interest in Science, Technology, Engineering, and Mathematics (STEM). The six requirements were used to develop the game SORCERESS OF SEASONS. An evaluation demonstrated that while the requirements show promise, further work is necessary to provide a clearer understanding. The requirements and the resulting game were designed for middle schools students. While the requirements are likely to be applicable to older students, future work can look to determine if they are effective for students at higher education levels. Other areas of future work include expansion for social interaction between students by developing a multiplayer version. This is motivated by students indicating they would have liked to play with friends. It would also be interesting to see comparisons of performance between single and cooperative play.

Both males and females reported an increase in level of interest in STEM. Females reported a higher likelihood than males. While this result is encouraging, the results are limited by the fact that it was assessed immediately after a single game experience. A longitudinal study could assess effectiveness over time. Additionally, the participant population would need to be more reflective of the diversity of middle school students. Prolonged experience with a fully-featured game, in a class or instructional setting that was welcoming to both genders, would all be part of an intervention to realize the goal of increasing middle school interest in STEM. If more middle school female students would consider a career in STEM, the pipeline of STEM professionals would be bolstered by drawing on a wider pool of potential participants.

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