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ATTITUDE, ACHIEVEMENT, AND GENDER IN A MIDDLE SCHOOL SCIENCE-BASED LUDIC SIMULATION FOR LEARNING

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ABSTRACT

This study examined the learning experiences of 478 middle school science students using a problem-based ludic simulation over a 3-week period to learn space science. Findings from both quantitative and qualitative data revealed that use of the simulation supported student learning and that knowledge gains helped reduce gender-based achievement gaps between boys and girls in the subject matter. Student attitude was additionally linked to learning success while using the simulation. These findings suggest that student engagement and self-recognition of progress and learning are important design factors when developing problem-based learning experiences.

INTRODUCTION

There has been much interest in recent years in using computer-based simulations and games to support learning (DeNeve & Heppner, 1997; Gee, 2003; Polanco, Calderón, & Delgado, 2004; Rieber, 1996; Roussou, 2004; Squire, 2003). Many in the constructivist and socio-constructivist camps of instructional design, led by

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an understanding of the value of Piaget's play (Piaget & Inhelder, 1972) and Csikszentmihalyi's flow (Csikszentmihalyi & Bennett, 1971), have come to look upon certain types of interactive media with great interest for the purpose of more fully engaging students in the process of learning (Rieber, 1996). As examples of such interactive media, it is believed that computer-based simulations and games can be used to support constructivist and socio-constructivist learning, because they can be utilized to allow learners to experiment, problem solve, and role-play in settings that safely, inexpensively, and authentically replicate real-world scenarios in engaging ways. The purpose of this study is to examine the effects of a computer-based space science simulation created to enhance middle school student learning through playful role-play, experimentation, and problem-based scenarios.

RESEARCH FRAMEWORK

Problem-Based Learning

Constructivism holds the belief that learning processes are complicated, contextual, and situated, and it places much emphasis on using engaging methods of instruction (Hung, Looi, & Koh, 2004). As a result, constructivism underscores the importance of grounding learning in real-world situations so as to foster what some have called authentic learning situations (Herrington & Oliver, 2000). Problem-based learning (PBL) represents a constructivist attempt at situating students within learning environments that are complex and contextually realistic, and is commonly seen as a valuable student-centered pedagogical approach (Savery, 2006).

In PBL, learning is contextualized in the form of problem scenarios that are engaging, authentic, and complex. Educators, particularly in the medical field, have long recognized the importance of connecting learning objectives with real-world problems in an authentic, complex manner, instead of delivering instruction in decontextualized, amorphous chunks (Schmidt, Van Der Molen, Te Winkel, & Wijnen, 2009). In so doing, those implementing PBL instruction anticipate that learners will both engage more fully with the subject matter at hand, facilitating deep understanding and the ability to use acquired information in new scenarios, and develop important reasoning skills (e.g., critical thinking, problem solving, prioritization, etc.) in the process (Gallagher & Stepien, 1996; Hmelo & Ferrari, 1997). Problem-based learning relies upon hooking students with an engaging problem statement and giving them the tools necessary to construct a solution to the problem. In so doing, learners are expected to take charge of their own learning, plan for how they will gain necessary information for solving the problem, and effectively execute those plans (Barrows, 2002). Those who develop PBL scenarios often leave problems loosely structured in order to reflect the ill-defined nature of real-world problems and to allow for the development of meta-cognitive skills in the learner, whereby the learner is at liberty to direct their own learning process (Dabbagh & Blijid, 2010; Strobel & Van Barneveld, 2009).

In such student-driven learning processes, issues of learner self-direction, attitude, and willingness to explore arise as questions of pedagogical effectiveness switch focus from the behaviors of the teacher to the behaviors of students. It seems obvious, for instance, that learner self-directedness would be a very important skill to develop for utilizing an instructional system that requires exploration to solve problems, whereas such a skill would not be so important for filling out a worksheet by referencing textbook entries. Thus, we should recognize that certain pedagogical approaches bring with them certain assumptions about what successful student participation looks like and that student success with PBL systems, thereby, may be influenced by student attitudes.

Simulations and Games

As a corollary to PBL, computer-based simulations have been used in a variety of fields from aviation and nursing to climatology and economics for the purposes of: (a) training individuals to succeed in dangerous, risky, or foreign environments (e.g., combat fighter pilots); and (b) predicting outcomes within complex systems (e.g., global climate change). As designers build simulated environments that support the acquisition of targeted learning objectives, students can be empowered to experiment with variables and observe instant outcomes, thereby allowing them to learn, often by trial and error, how to successfully make decisions within real-world systems. Thus, in their purest form, simulations may be seen as "technical drawings" of real-life situations that allow participants to explore, experiment, and observe results (Crawford, 1984, p. 8) and are typically useful insofar as they maintain a high level of fidelity to the real world.

In recent years, there has been an explosion of interest in digital (or video) games as more and more people from all demographics have begun playing games on electronic devices. This explosion of interest has led many to consider the educational value of digital games (Gee, 2003), especially given their observed ability to engage a wide variety of audiences in sustained, voluntary action (McGonigal, 2011). Though computer-based simulations may be defined as electronic representations of real-world environments and scenarios, finding a simple definition of digital games may be much more complicated. Some, for instance, have argued that games require a foundational story, while others have argued to the contrary (Aarseth, 1997; Eskelinen, 2001; Kimmons, 2010). Discussions of game theory have arisen as a topic in a variety of disciplines, and all of these disciplines have employed unique (sometimes conflicting) definitions of what constitutes a game. At the heart of all of these definitions, however, McGonigal (2011) has identified five elements of games that seem to be (fairly) common across theorists:

1. games have a goal;
2. games provide established rules that must be followed;
3. games utilize feedback systems to help players recognize progression toward goals;
4. games are fun; and
5. games are voluntary.

Considering these elements, it seems clear that simulations and games are not mutually exclusive entities (i.e., there is nothing in the definition of a game that precludes it from also being a simulation), but it is also interesting that many popular media products that are marketed as games actually may align more with simulations than with McGonigal's definition. For instance, it has been argued that the popular products in the Grand Theft Auto franchise, which emphasize self-directed exploration and somewhat high-fidelity representations of street crime with very little in the way of strict goals, are more like simulations than games (Dormans, 2006). Very different from older games like Pac-Man or Pong, these emerging products are designed as a type of hybrid environment that seeks to make the user's experience as real as possible while simultaneously making it as fun as possible. Such resulting "ludic simulations" (Aarseth, 1997; Frasca, 2003; Juul, 2005), which attempt to balance realism with fun, capitalize upon the best of both worlds for engaging audiences: providing a realistic environment that invites exploration and experimentation that is nonetheless structured to exaggerate or over-emphasize certain elements of the real environment that players may desire to explore (e.g., becoming a vigilante and chasing a crime boss), while purposefully neglecting or downplaying others that may not seem to be as enjoyable for the player (e.g., serving jail time in a high-fidelity manner).

From a Piagetian perspective, the value of *ludus*, or play, in knowledge development cannot be overstated (Singer, Golinkoff, & Hirsh-Pasek, 2006), and the potential for ludic simulations and similar technologies within education seems to be an important area of exploration insofar as they may have the power to combine the potential educational benefits of simulations with the potential engagement benefits provided by games. Squire (2003) argues that students in traditional classrooms are not actively engaged in their own learning and that the value of rich media like ludic simulations lies in their ability to draw students back into their own educational experiences.

Previous projects involving ludic simulations and related technologies (e.g., multi-user virtual environments (MUVEs), serious games, etc.) have yielded promising results. A few of examples include: *The Adventures of Jasper Woodbury* project by the Cognition and Technology Group at Vanderbilt (CTGV, 1993, 1994) utilized video anchored instruction to enhance middle-school student mathematical problem solving skills (Zech, Vye, Bransford, Swink, Mayfield-Stewart, Goldman, et al., 1994); *Biologica* was developed to guide model-based learning in high school science (Buckley, Gobert, Horwitz, & O'Dwyer, 2010); *Quest Atlantis* and *Atlantis Remixed* are MUVE environments of educational adventures through quests for 9- to 16-year-olds on a variety of subjects to be used in as well as outside classrooms (Barab, Pettyjohn, Gresalfi, Volk, & Solomou, 2012; Barab, Thomas, Dodge, Carteaux, & Tuzun, 2005); and *River City* was also a MUVE project to teach problem solving and scientific inquiry skills to middle-school students (Clarke, Dede, Ketelhut, & Nelson, 2006; Ketelhut, 2007; Nelson, 2007; Nelson, Ketelhut, Clarke, Bowman, & Dede, 2005). Though many educational media projects have high hopes with regard to improving student engagement, questions remain by critics as to the value of many of such tools and approaches (Oppenheimer, 2004). There is a need for further empirical evidence supporting the use of such rich, engaging media in educational pursuits in a variety of contexts and content areas.

Situating the Study

In this study, we examine the effects of a PBL-driven ludic simulation for 6th-grade space science on student learning. Consistent with constructivist beliefs and PBL premises, in this ludic simulation, 6th-graders are faced with an engaging and complex problem. They are given the opportunity to role-play as scientists in a media-rich, three-dimensional environment and to use various tools to construct their own understanding of the solar system as they formulate solutions for the central problem. Through this study, we seek to understand three research questions related to the use of this PBL-based ludic simulation for learning:

1. How does student use of the ludic simulation impact learning?
2. How does student attitude toward the simulation impact learning?
3. Does the simulation work to counteract or to perpetuate STEM learning disparities between boys and girls?

The first question lies at the heart of our design-based research (DBR) approach and attempts to determine if the tool under development is effective in achieving its educational objectives. Unlike traditional, laboratory-based approaches to researching learning technologies, design-based research emphasizes the importance of developing usable knowledge in realistic contexts (Design-Based Research Collective, 2003). Thus, rather than creating controlled experiments with random samples in unrealistic environments, researchers in this study sought to create and use a tool in real contexts to improve student learning and, by framing this intervention within a larger research framework, sought to produce generalizable knowledge from the experience regarding the utilization of ludic simulations to support learning. As a result, student learning was of central importance in this study and was measured to determine to what extent student use of the ludic simulation helped them master targeted content.

The second research question grows out of an interest in constructivist, student-driven learning situations. If constructivist beliefs about internal influences of the learner are true (i.e., learner attitudes, moods, beliefs, and so forth influence learning), then it would be assumed that student achievement is connected to attitude and that the effectiveness of a learning simulation may be partially determined by students' beliefs, moods, and attitudes toward that simulation. As a result, it seems possible that if certain students find the PBL simulation more appealing than others find it to be, then the first students might learn more as a result of the experience. This study sought to compare the experiences of a variety of students based upon their attitudes toward the simulation in order to determine if this was a contributing factor.

Third, given national disparities between boys and girls in science, technology, engineering, and mathematics (STEM) achievement, it seems pertinent to consider whether ludic simulations can perpetuate gender gaps or if they can be used to counteract them. It has been argued, for instance, that the types of media (including games) that boys and girls choose to engage with are very different (Leonard, 2006; Lever, 1976), and so, it behooves designers who are utilizing game-like environments to consider how their learning products may impact the learning of boys and girls differently. By considering differences in achievement in the ludic simulation based on gender, this study sought to determine how participation with the ludic simulation impacted boys and girls differently, and by exploring these three questions, we hope to gain more in-depth understanding in how to leverage rich media tools such as PBL ludic simulations to support learning of diverse students who may have conflicting attitudes toward game-like environments and varying levels of historical achievement in STEM learning situations.

METHOD

Sample

Participants were 6th graders (N = 478) from two public middle schools in a mid-sized southwestern city in the United States. 52% were female (n = 250) and 48% were male (n = 228). Demographic information of students at the first school reveals that approximately 6.2% are African American, 13.8% are Hispanic, 15.3% are Asian/Pacific Islander, 0.3% are Native American, and 64.6% are White. Of these students, 12% are economically disadvantaged, 13.2% are at-risk, and 1.4% are identified as Limited English Proficient. Demographic information of students at the second school reveals that approximately 6.1% are African American, 19.1% are Hispanic, 8.3% are Asian/Pacific Islander, 0.3% are Native American, and 66.2% are White. Of these students, 13.8% are economically disadvantaged, 13.9% are at-risk, and 1.2% are identified as Limited English Proficient. Missing data were excluded from the analyses. Sixth graders were chosen as the research sample because they were the targeted audience of the ludic simulation used in this study. The two schools decided to adopt the ludic simulation as their curriculum on space science in place of the regular textbooks. All sixth-graders in the two participating schools were included in the study. Between the two schools, the study included the science classes of seven teachers, each of whom had an average of four classes throughout the day.

The Ludic Simulation

The ludic simulation used in this study was *Alien Rescue*: a problem-based learning environment designed as a sixth grade space science curriculum (Liu, Williams, & Pederson, 2002). Its design is guided by current educational theories and research on problem-based learning. Students, role-playing as scientists, are asked to participate in a rescue operation to find suitable relocation sites within our solar system for six different species of aliens who have been displaced from their home planets. Through inquiry-based activities, students practice a variety of 21st century critical thinking skills such as problem-solving, self-directed, decision-making, and collaboration skills.

Students are introduced to the central problem through a news video: fleeing their destroyed solar system, a ship containing six alien species has entered orbit around Earth, and the aliens have requested that Earth scientists (i.e., the students) help them to find suitable homes. Students are informed by the aliens that each species has necessary habitat requirements essential to support themselves and that if these requirements are not met, the species will die. To solve this problem, students travel to a virtual space station laboratory orbiting the Earth and engage in a variety of problem-solving activities. The major activities that students engage in include:

1. discovering the unique physiological needs of each alien species;
2. studying provided information about our solar system;
3. effectively constructing experiments to fill in knowledge gaps; and
4. proposing the best planet for each alien species to inhabit.

As with any authentic problem, the answers are not clear-cut, and there is intended to be no single correct answer for a given species. Rather, students are expected to carefully weigh a variety of informational variables against one another and to use their best judgment to decide on a habitat and support it with documenting evidence. The learning objectives of *Alien Rescue* are aligned with Texas Essential Knowledge and Skills Guidelines 2010 and national science standards.

To assist students' problem-solving, a variety of multimedia enriched cognitive tools are provided, including a database of information on our solar system, a database on the alien characteristics, a database on probe missions carried out by NASA, a probe design tool, a mission status tool, tutorials on science concepts, and adaptive note-taking tool (Liu, Horton, Toprac, & Yuen, 2011b). With all these cognitive tools at their fingertips, students can concentrate on solving the problem and teachers can make best use of their time to facilitate the learning process. In addition, a comprehensive teachers' manual is provided, detailing pedagogical approach, lesson plans, science content, and assessment. Teachers can adapt and adjust according to their students' levels and curricula needs.

Similar to other projects mentioned above, it incorporates inquiry-based activities and using technology to deliver an immersive learning environment. Unlike other projects, *Alien Rescue* is designed to be a curriculum unit on 6th-grade space science for approximately 15, 50-minute sessions, not merely supplementing the curriculum. It is intended for classroom use, with students interacting with the tool as well as peers in groups. Its design and development is guided by DBR with iterative improvement based upon classroom implementations (Reeves, Herrington, & Oliver, 2005) and has progressed from older technologies to the current web version created in Unity game engine. More information about this ludic simulation can be found at http://alienrescue.edb.utexas.edu. The goal of this study is not to tie specific learning gains to specific design features of the simulation, as explored in other research on the program, but to consider the learning environment as a whole from the perspectives of student attitude and gender.

Instruments

Science Knowledge Test

Achievement in this study was measured by students' understanding of the various scientific concepts introduced in the simulation. A 20-item test was administered (Cronbach's alpha for the instrument by this sample was .78 for the pretest and .77 for the posttest). The content of the test reflects what the designers and subject matter experts consider to be important knowledge for students to acquire after completing the simulation and was used in previous studies with similar samples using the same learning environment (Liu, Bera, Corliss, Svinicki, & Beth, 2004; Liu, Horton, Olmanson, & Toprac, 2011a). Since raw pre and posttest scores were on a 20-point scale, all scores were converted to percentages on a 0-100% scale and normalized as z-scores for analysis. The science knowledge test was administered before and after students used *Alien Rescue* in order to measure any change resulting from using the simulation.

Attitude Questionnaire

The attitude measure consisted of a five-question Likert-scale survey developed for this simulation and used in previous research (Liu, 2004) with a Cronbach's alpha reliability index of .91. Sample items include "I would describe *Alien Rescue* as interesting" and "*Alien Rescue* was enjoyable to use." Responses were in the form of a Likert scale and included the options of [1] "Disagree Strongly,"

[2] "Disagree," [3] "Neutral," [4] "Agree," and [5] "Agree Strongly." The attitude questionnaire was administered after the completion of the 3-week curriculum.

Open-Ended Questions

To more fully understand students' beliefs about the simulation, they were also asked to provide written responses to the following four open-ended questions:

1. What do you think of *Alien Rescue*?
2. In what way do you think *Alien Rescue* helps you learn science?
3. What is your favorite part of *Alien Rescue*? Why?
4. What is your least favorite part of *Alien Rescue*? Why?

The open-ended questions were administered after the completion of the 3-week curriculum.

Analysis of Data

Attitude Groups

Students were grouped by their scores on the attitude questionnaire into high, medium, and low attitude groups based upon the scored value of answers a student gave in the attitude questionnaire. Responses were coded from [1] (for "Disagree Strongly") to [5] (for "Agree Strongly"), summed up, and converted to a percentage (ranging from 20% to 100%). Descriptive statistics of the data set revealed a normally distributed curve (M = 70%, SD = .2). As a result, student attitude scores were organized into three roughly equal groups, wherein the n for the low to high groups was equal to 167 (for scores below 13), 158 (for scores from 13 to 15), and 169 (for scores above 15). ANOVAs and regression analyses were conducted as relevant to each research question and are explained in detail in the following.

Open-Ended Questions

Guidelines established by Miles and Huberman (1994) were used to analyze the responses to the open-ended questions. Two researchers worked together to code 50% of the all responses and to discuss emergent codes. Once a list of codes was agreed upon, the two researchers independently coded the remaining 50% of the responses and then reviewed the analysis by the other researcher. During the analysis, the constant comparative method was employed as outlined by Strauss and Corbin (1998). Patterns from the data were extracted, and data were sorted into categories and subcategories according to common themes and shared relationships. The researchers discussed discrepancies until a consensus was reached on categories, themes, and interpretations.

RESULTS

Overall Achievement as Revealed in Pretest and Posttest Scores

Descriptive statistics of student scores revealed that students had an average gain score of 32 points as a result of using the simulation (see Table 1). A paired samples *t*-test comparing pre and posttest scores for each student revealed a significant effect, $t(478) = -31.28$, $p < .01$, indicating that students performed significantly better on the posttest than on the pretest. In order to understand whether this occurrence was attributable to any different teaching techniques possibly utilized by the seven teachers, a two-way repeated measure ANOVA was conducted with each student's teacher as the between-subjects factor. Within-subjects effects revealed that student achievement remained significant between tests with a high effect size, $F(1, 471) = 1346.8$, $p < .01$, $\eta^2 = .74$, and that a significant, though very small, interaction effect existed between teacher and testing instance, $F(6, 471) = 4.58$, $p < .01$, $\eta^2 = .06$. Between-subjects effects revealed that a student's teacher had a significant impact on student achievement from pre to posttest, but that this effect also had a low effect size, $F(6, 445) = 3.309$, $p < .01$, $\eta^2 = .04$. As a result, the findings indicate that using the simulation had a significant and large main effect on student achievement and that though a student's teacher had an impact on his or her achievement, the effect size of that influence is very small.

Effects by Gender

Descriptive statistics of student scores revealed that boys outperformed girls on both the pretest and the posttest but that girls had a higher gain score (33 points) than boys (30 points; see Table 2). A two-way repeated measures ANOVA was conducted with student gender as the between-subjects factor in order to consider the impact gender has on achievement. Within-subjects effects revealed that student achievement remained significant between tests with a high effect size, $F(1, 452) = 1499.86$, $p < .01$, $\eta^2 = .76$, and that a significant, though small,

Table 1. Overall Achievement on Pretests and Posttests

Test	*N*	*M*	(*SD*)
Pretest score	452	54%	(19.1)
Posttest score	452	86%*	(14.5)

*Significantly different from the pretest score, $p < .01$.

interaction effect existed between gender and testing instance, $F(1, 452) = 4.917$, $p < .01$, $\eta^2 = .01$. Between-subjects effects revealed that student gender had a significant impact on student achievement from pre to posttest, but that this effect had a low effect size, $F(1, 452) = 19.69$, $p < .01$, $\eta^2 = .04$. As a result, the findings suggest that the simulation had a significant impact on student achievement with a large effect size, and that though gender played a factor in student achievement, the effect size contributable to gender is small and favors girls (as evidenced in the gain score).

Effects By Attitude

Student attitude scores were assigned numeric values and were averaged for each student in order to account for overall attitude toward the simulation. A one-way ANOVA of posttest scores by attitude groups revealed a significant effect, $F(2, 467) = 3.35$, $p < .05$, and post hoc testing using the Bonferroni procedure revealed a 4-point difference between students in the low attitude group and the high attitude group, $p < .05$ (see Table 3 and Figure 1).

Factors Contributing to the Posttest Score

To measure the relationship between posttest score and such factors as pretest score, attitude group, and gender, a step-wise regression analysis was performed using posttest score as the dependent variable and pretest score, attitude group,

Table 2. Achievement Scores by Gender

Gender	*n*	Pretest *M* (*SD*)	Posttest *M* (*SD*)
Female	250	51% (17.5)	84% (15.4)
Male	228	58% (20.0)	88% (13.2)

Note: Mean gain score for girls is 33 points, while mean gain score for boys is 30 points.

Table 3. Achievement Scores by Attitude Groups

Attitude groups	*n*	Pretest *M* (*SD*)	Posttest *M* (*SD*)
Low	134	55% (20.6)	85% (14.6)
Medium	129	53% (18.4)	85% (14.3)
High	124	55% (19.5)	88%* (12.6)

Note: Significantly different from the low attitude group, $p < .05$.

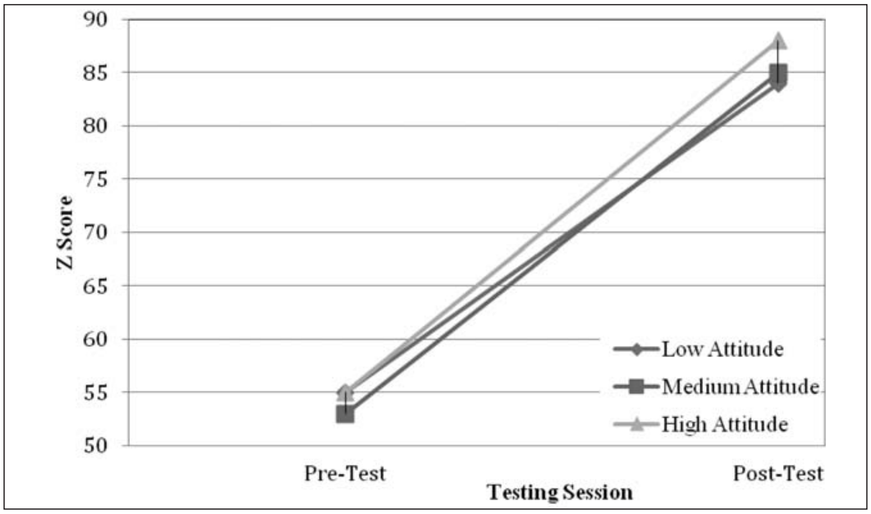

Figure 1. Attitude effects on student achievement.

and gender as independent variables (see Table 4). Of these factors, only pretest score and attitude were significant. A parsimonious view of the results indicates that pretest score significantly predicted posttest score, $\beta = .55$, $t(384) = 12.52$, $p < .01$, and that attitude also significantly predicted posttest score, $\beta = .05$, $t(384) = 5.8$, $p < .01$. Pretest scores and attitude combined also explained a significant proportion of variance in posttest scores, $R^2 = .30$, $F(2, 384) = 82.92$, $p < .01$.

Qualitative Findings

Students' responses to the question "What do you think of *Alien Rescue*?" were put into a word cloud displaying the frequency of student word use (see Table 5). The bigger the font size, the higher the frequency of the word appearing in student responses. Words used by students to describe their experience included the following: fun, like a game, cool, awesome, interesting, learning experience, and challenging.

In analyzing the responses to this question, we treated responses from each student as one unit. If the response is positive or negative, we labeled it as positive or negative. If the response contained both positive and negative comments, we labeled it as both. Of all the responses to this question, positive comments comprised 66% of all responses, negative comprised 10 %, and 24% were a combination of both positive and negative statements (see Table 6). This reveals that two-thirds of all student feedback on using the tool was positive and that 90% of all student feedback was at least somewhat positive.

Table 4. Posttest Regression Analysis Model

Variable	*B*	*SE B*	β
Step 1 Pretest score	.39	.03	.55*
Step 2 Attitude	.05	.01	.25*

*$p < .05$.
Note: Gender was not a significant predictor of posttest score.

Table 5. Word Cloud of Students' Responses to
"What do you think of *Alien Rescue*?"

Word cloud	Word	Frequency
	think	350
	fun	313
	learn	207
	like	117
	planets	113
	really	95
	way	95
	do	82
	cool	76
	very	71
	good	66
	have	64
	system	61
	solar	60

Note: Words such as: to, the, a, an, that . . . were removed to increase the prominence of relevant adjectives, nouns, and verbs. Word count below 60 is not listed.

In terms of what students recognized they had learned, Table 7 provides a summary of students' responses to the question "In what way do you think *Alien Rescue* helps you learn science?" In analyzing the responses to this question, we treated each sentence as one unit as each sentence typically reflected what students said they learned or did not learn. There were a total of 815 individual response units. Student responses indicated that the top three knowledge components acquired from using the simulation included knowledge about the

Table 6. Sample Student Responses to
"What do you think of *Alien Rescue*?"

Attitude	Total	Girls	Boys	Sample comments
Positive	66%	53%	47%	I think *Alien Rescue* is a very good, educational program. I learned a lot about the solar system from it. I also had a lot of fun doing it.
				I thought it was interesting because you were learning but at the same time it felt like you were actually in the game.
				it was really fun and challenging. it makes you work as a team better and think harder. I really thought it was awesome.
				I think *Alien Rescue* was a learning experience in a creative way. I also thought it was quite hard to find a planet for my aliens.
				I think that *Alien Rescue* is a great way to learn about are solar system. It is also a good way to study our planets. I think that you can have a lot of fun.
				it was cool and it was a fun game i liked how we had to find homes for the aliens.
				Alien Rescue was a good learning experience in science. It was fun and you can actually interact with the program like a video game. It has life lessons and helps you with problem solving skills.
				I think it is a great idea for kids to research and find the homes of aliens cause it makes you feel important. I loved *Alien Rescue*!!!!!!!
				it was really fun and challenging. it makes you work as a team better and think harder. I really thought is was awesome.

Negative	10%	39%	61%	I don't really like *Alien Rescue.* Its kind of boring and we are learning about aliens that aren't even real. The funnest part of *Alien Rescue* was finding a home for the aliens.
				I didn't really like it. I though it could have been more easy and more interactive.
				it was ok. it wasn't really that fun and it was really hard. :(
Both	24%	60%	40%	*Alien Rescue* was a generally fun way to learn about our solar system. It could have been better. However, it was much too easy to mess around.
				it is very fun but at times boring.
				It is a really fun game. During the game you use your brain a lot. It could be boring sometimes because you have to keep writing notes.
				I think *Alien Rescue* was okay. I think this because the research was a little boring. I still learned a lot from *Alien Rescue.*

Table 7. Student Responses to
"In what way do you think *Alien Rescue* helps you learn science?"

Codes primary	Secondary (in connection to primary)	% out of 815 comments	Sample comments
Solar system		46.13%	I think that *Alien Rescue* helped me learn more about space, planets, moons, and sending probes. I probably learned more about space from this program, than I would have learned out of a book.
			Alien Rescue helped me learn science by making me look at the solar system a difference way. I was a lot more into it because i have never done this before.
			I think that *Alien Rescue* teaches about science by teaching us about the planets. We also learned what moons belong to what planet and about their characteristics.
Scientific instruments		13.00%	It taught us about the instruments scientists use to learn about a planet.
			Alien Rescue helps us learn science by learning about different scientific tools such as magnetometers, etc.
			Alien Rescue helps me have fun while learning, which helps a lot. The information is easy to read, and easy to find. The probes help a lot also, the information is also easy to read and understand.
			It helped me learn more about science instruments not planets.
			Sending a probe helps us learn about science.

Scientific concepts		9.69%	Astronomy is a part of science and there was a lot of astronomy in *Alien Rescue*. I also learned how to use spectrograms. The periodic table was used a lot also. *Alien Rescue* helps learn about to earth and atmospheres. Also about planets and all magnetic fields and what goes on with aliens! The concepts database helped me learn about things like magnetic fields and atmosphere of planets. You learn about gravity, radio waves, spectrograms, atmospheres, craters, and other physical features and non-physical features. You learn what these things do for a planet and if we would be able to survive there.
Research	Solar system Scientific concepts Scientific instruments	9.45%	It helps u learn how to research better so when a project that comes and you need to look up info you will known how to do it. I think Alien *Rescue* helps you learn about the planets since you have to do research on the planets to see which one is best suited for each alien. I think that *Alien Rescue* helps you learn about science because it lets you explore and research all the planets and their moon(s). It help because it gets you into research. It helps because it can get you ready for future researching. It teaches about planets. It teaches how to send probes and do real research. It teaches about many instruments. It teaches you how to collect data and analyze it. It helps you to detail things more.

Table 7. (Cont'd.)

Codes primary	Secondary (in connection to primary)	% out of 815 comments	Sample comments
Problem solving	Solar system	6.99%	It teaches you about our solar system and helps you use logical reasoning. You have to use the process of elimination to find out which of the planets each alien goes to. You also have to design ways to get the information you need.
	Aliens		We learned to use the information they give us about the aliens and convert it into a planet that is right for the alien. *Alien Rescue* probably made most of us smarter.
			Like how it makes us read the stuff about the planet and we find out more things than we use to know, and you find out more stuff about the alien and what it needs and what it does not need.
			I think it helped me learn about Adaptations, and helped me understand how the Aliens had to live in a World that can sustain their existence.
Fun way	Scientific instruments	5.28%	It helps you learn about different scientific instruments, and it helps you learn more about the planets in a fun way. You can try different things and doing stuff with building the probes is fun.
	Solar system		I think it helps you learn about worlds in our solar system. Also it helps you learn about space. I think it is a good program to study planets in a fun way.
			This was a really good idea for learning about space b/c it was fun. the aliens were kind of cool.

			I think it is a really fun way of learning about space! It helped me understand the different tools and what they do. It was interesting.
			It's more fun to learn things and still have fun at the same time.
Aliens		3.19%	It just like learning about animals but they can fly and eat other things than normal creatures. Such as special plants real creatures on earth aren't picky eater they eat what ever.
			It helps us know about habitats and its characteristics.
Note taking	Solar system	1.1%	We did learn about the solar system by taking notes.
	Scientific concepts		It gives you a lot of information about the planets, and it helps you memorize it because you right it down in your notebook and you have to memorize it to find the correct home for your alien.
	Aliens		By showing you by having you write notes on the alien's and world's. also because it had facts about the aliens.
			I think *Alien Rescue* helped me learn science by giving me information about planets that I had to take notes on. I usually remember things more often when I have to write them down or take notes.

Table 7. (Cont'd.)

Codes primary	Secondary (in connection to primary)	% out of 815 comments	Sample comments
Collaboration		0.86%	Everyone always shares information about a certain planet and that makes you remember it.
			We also challenge our selves by working with a partner to solve a problem.
			I think it develops a characteristic of being able to work as a team.
			Learn to help others and learn about patient [patience] and more about science.
Nothing		2.25%	Nothing.
Other (including managing budget, 3D effects)		1.61%	I think getting to feel important and having an important job makes us concentrate harder, we don't want to make mistakes. It also helps us manage our money and learn wise spending.
			Alien Rescue teaches you in a 3D way about the planets and our solar system.
			It helped me learn science better because we saw pictures. You also weren't just reading books about the planets.

solar system (46.13%), scientific instruments (13%), and scientific concepts (9.69%). Students' responses also indicated they learned such important skills as researching (9.45%), problem solving (6.99%), note-taking (1.1%), and collaborating (.86%). Student responses to this question corroborated to their responses to the previous question that they acquired such knowledge and skills in a fun way. About 2% of the responses indicated they learned '"nothing."

In responding to the questions "What is your favorite part of *Alien Rescue*? Why?" and "What is your least favorite part of *Alien Rescue*? Why?" students told us what they liked and disliked about the experience and their reasoning behind these attitudes (see Table 8).

DISCUSSION

The findings of the study are now discussed with regard to the three research questions we intended to address.

Student Achievement

Results indicated that student understanding of the subject matter had increased significantly after using the PBL ludic simulation under investigation, as evidenced in growth from pretest to posttest subject matter scores. Students' responses to the open-ended questions indicated that the simulation helped them learn such knowledge and skills as problem-solving, research, scientific instruments, planets, note-taking, and collaboration. Students indicated that the interactive and role-playing features of the simulation made learning fun and engaging. Students said, "It is interactive. This makes people more interested in learning," "It helps me learn by immersing me in the problems N.A.S.A and other space exploration agencies face when exploring." "It kind of makes you feel like you are a scientist," "*Alien Rescue* teaches you in a 3D way things about the planets and our solar system," and "It helped me learn science because it's a game, but it is also teaching science at the same time, so it made science fun." Some also said that it helped them in memorizing important information through this visual way of learning. The outcomes of this research confirmed the findings of a previous study on *Alien Rescue* (Liu et al., 2011) with a larger and QA: 20011a or 2011b? different sample, and provided additional evidence through examining learning, attitude, and gender. The findings also support the literature indicating that interactive simulations have potential to benefit learning (Barab et al., 2005; Metcalf, Kamarainen, Grotzer, & Dede, 2011).

In this study, all participating teachers received training prior to using *Alien Rescue* in their classrooms, during which the pedagogy of student-centered PBL was discussed in detail. A 200-page teacher's manual, detailing suggested lesson plans for all 15 days of recommended classroom instruction, was also provided. One goal of *Alien Rescue* was to provide as many necessary tools as possible to

Table 8. Student Responses for Their Most and Least Favorite Parts of the Simulation

Part	Representative quotes
	Most Favorite
Creating probes	My favorite part was when we were able to send probes to these planets. I wanted to see what these planets look like and the different characteristics.
	my favorite part of *Alien Rescue* was sending probes. it was fun to design different probes and then learn about all the planets in the solar system.
Aliens	My favorite part of *Alien Rescue* was researching the aliens. We got to learn all of their characteristics and needs. Even thought aliens aren't real I think we all learned something from it.
	I really liked researching the aliens because I really liked to know what they need so I could find a perfect home for my aliens. I also like creating probes to send so i could see the plants and learn about them.
Finding homes for aliens	My favorite part of *Alien Rescue* was trying to find new homes for the all of the aliens. My partner and I had to find matches for the conditions on the alien's home planet. It was challenging, but I enjoyed it.
	My favorite part of *Alien Rescue* is the end where all the aliens are happy in their new homes. This makes me feel like I have accomplished something. It shows all the hard work that you have put into this.
Learning about planets	My favorite part was researching the aliens and planets. This is because I learned many new things like that Neptune's moon will eventually be torn apart by Neptune's gravity and become a new set of rings around Neptune.
	research because you get to learn about the planets

Making recommendations	I liked doing the recommendations because you have to look at ALL of the planets and moons and research aliens and find out the environment best suitable for this alien.
	Doing the recommendations is difficult because you have to read MANY paragraphs to get the perfect planet for the right alien. I also like that when you finally got the right planet all you had to do was look for information and write a paragraph summarizing why this alien is best suited with this planet.
	Least Favorite
Research	My least favorite part of *Alien Rescue* was research. This is so because it seemed like we weren't close to finishing. It also took a long time to finish the research.
	I did not like having to do research before making recommendations. I did not like having to work for three weeks this is because that was too much time for me and my partner.
	My least Favorite part would have to be research. That took a long time and I was getting restless. But the information was very helpful in the end.
	the research 'cause it was very boring and long
Specific features in the program	my least favorite part was having to keep on going between probe launch and probe status. This is because it was inconvenient. This was really frustrating because we only had so much time.
	I really didnt like the communication center, because i thought that it was going to be something cool but it was just saying thank you. I think that [you] should make it something cool.
	My least favorite part was that the game kept deleting my notes. I retyped the same notes 3 times before I finally just wrote them down on paper. You guys really should work on that.

Table 8. (Cont'd.)

Part	Representative quotes
	My least favorite part of *Alien Rescue* was the thank you message in the communication center. I liked the music, but the aliens just stood there and did nothing.
Partner	My least favorite part of *Alien Rescue* was my partner. I didn't like him because he is the most mean person I know. I don't have another reason.
	i think i would have to say having a partner. i think this because i am very independent and i like doing my own thing. i also didn't like that it went by so quickly. i feel like we didn't have enough time to finish.

students via the application (e.g., English-Spanish dictionary of terms, audio readings of the content, informational databases, etc.) in order to free teachers' time to provide individualized instruction to each student as needed. Each teacher, however, was given the opportunity to implement *Alien Rescue* differently given specific classroom needs and familiarity with problem-based pedagogical techniques. Results of the study showed that a teacher's use of the simulation, though statistically significant in its impact on learning, is weak ($\eta^2 = .04$), thereby suggesting that individual differences in teachers' use of *Alien Rescue* do not seem to exert a strong influence upon student overall achievement. This finding, that though teachers may have adapted the tool differently, student learning after using the simulation remains a constant, confirms the benefits of using technology-based ludic simulations as a tool for learning.

Attitude and Student Achievement

Based upon the ANOVA and regression analyses, student attitude has a significant impact on posttest achievement and is a stronger contributing factor than all other variables (e.g., gender, teacher) except for the pretest score. Qualitative analysis of open-ended questions provided more specific and detailed evidence to support these quantitative findings. A recurring theme from the students' responses is that the simulation made them think and that they had fun in learning to problem solve. Female students had fewer negative comments than male students. Though the process is challenging for many of these 6th graders as it involved many factors to consider in solving the central complex problem, they enjoyed the experience and acquired necessary content knowledge and inquiry skills as required by the curriculum goals. These findings support beliefs regarding the importance of engagement in student achievement and suggests that the ludic nature of the environment and students' self-awareness of knowledge growth, as evidenced by positive statements regarding the experience both from a fun perspective and a learning perspective as shown in the qualitative data, has an impact in improving learning. Sixth graders also shared with us the improvement of the simulation they wanted to see as shown in their comments on their least favorite parts.

Given these findings, it seems very important in the further development of *Alien Rescue* and other such simulations to capitalize upon elements that help students enjoy their experience and recognize the progression of their own learning. For *Alien Rescue*, more built-in guidance is needed in helping students conduct research as the research process in this PBL simulation is not easy for some 6th graders and more rich media enhanced elements can be built into the simulation for many technology savvy students. Some attempts at educational software development have attempted to trick students into learning (i.e., to learn content without realizing that they are learning). This view, however, is based upon an unsubstantiated assumption that students do not want to learn when, in fact, the case may be that students may find enjoyable success in learning if they are provided proper tools to support the process. The results of the study showed students used such words as "fun," "game," "cool," "learn," awesome," and "curiosity" frequently to describe why they found the environment motivational, suggesting that students were both aware of their own learning and had fun while they engaged in it. This finding implies that educational media, rather than trying to mask learning behind distracting media or to motivate students in inauthentic ways, should consider the structural value of ludic simulations to make learning exploratory and enjoyable.

Gender and Student Achievement

As is the case in many STEM-related studies, boys in this study tended to score better than girls on both pretest and posttest measures, reflecting a higher level of understanding of the subject matter both before and after using the simulation. However, consistent with previous research (Liu et al., 2011), this study did find QA: 20011a or 2011b? that learning through *Alien Rescue* was moderated by gender and that girls tended to improve more through using the simulation than did boys (33 percentage points vs. 30 percentage points) and that they showed more positive attitudes toward the simulation than did their male counterparts (as evidenced by differences in attitude statements). This 3% gain of girls on boys is promising in light of nationwide achievement gaps in STEM and suggests that gaps may be mediated by altering curricular decisions to support more egalitarian learning. Between-subjects effects of this study found that learning in the simulation was impacted by gender, but that this impact is fairly small ($\eta^2 = .04$) and favors girls. Perhaps the theme of "saving aliens" resonated more with girls than boys as such comments as "I like *Alien Rescue*. It is very fun. I liked getting to help different aliens find different homes," and "my favorite part was completing it and being able to see the aliens go to their new homes because it felt nice to help them" seemed to come more from girls than boys. The finding suggests that tools like *Alien Rescue* might play a positive role in reducing achievement gaps between boys and girls in STEM-related fields, and such finding should be further explored.

Limitations of the Study

This study, though it examined students' learning before and after the use of the PBL simulation, did not use a control group. The design of the ludic simulation under investigation is guided by the design-based research framework and is intended for use in authentic classroom settings as a curriculum unit rather than in controlled laboratories for research only. The feasibility of using a control group in such settings is questionable, as seen in this case. The two participating schools wanted all their 6th graders to use the simulation as their curriculum unit and, therefore, having a control group within the schools was not an option. In addition, having a meaningful control group would be difficult in this case, because the single independent variable (i.e., *Alien Rescue*) actually comprises a wide array of complex variables (e.g., multimedia, PBL, cognitive tools, etc.) and content objectives well beyond discrete space science curriculum items (e.g., critical thinking skills, collaboration, time management, etc.), such that it would be difficult to conceptualize what a control group would even look like. We grappled with such questions as: Would a control group use PBL a lot, a little, or not at all? Would it use multimedia? Would it use cognitive tools? Would it use an engaging story? Would it use computers? Would it employ an engaging narrative? Would it limit itself to fewer scientific concepts? Thus, given the richness of the ludic simulation and the authenticity of the setting, a control group seems unfeasible for measuring overall comparative success. Rather, the goal of *Alien Rescue*, and other similar design-based research initiatives, is to build upon prior research to iterate toward the most effective learning experience possible (Liu, Horton, Kimmons, Anderson, Lee, Rosenblum, et al., 2010).

CONCLUSION

The findings using both quantitative and qualitative data showed that 6th graders increased their understanding of the subject matter significantly after using the PBL ludic simulation under investigation, that student attitudes played a role in determining student achievement, and that the simulation had a small, though significant, effect in reducing a gender-based, STEM achievement gap. As current cultural trends underscore the importance and value of STEM learning, and as researchers and designers grapple with how to engage diverse students in learning STEM-related concepts, the results of this study highlight the potential benefits of ludic simulations and problem-based learning as boons for improving learning opportunities for all students. As educators rethink and continuously explore how STEM is taught, we need to recognize that sometimes gender gaps may reflect design biases and that the development of learning environments which engage both genders through compelling narratives, exploration, engaging technologies should be the designers' goal. Additionally, given growing interest in authentic and engaging learning, ludic simulations like *Alien Rescue* seem to offer a promising opportunity to improve student learning in part due to the positive attitudes that they can invoke in students in guiding them to become effective self-directed learners.

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