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Designing Science Learning with Game-Based Approaches

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Abstract

Given the growing popularity of digital games as a form of entertainment, educators are interested in exploring using digital games as a tool to facilitate learning. In this paper, we examine game-based learning by describing a learning environment that combines game elements, play, and authenticity in the real-world for the purpose of engaging students' learning of science and enhancing student motivation. We discuss the design of the environment and present research conducted. Our findings demonstrate that the design of an engaging, interactive environment using a games-based approach can help students have fun while learning.

Keywords: game-based learning, middle school science, interactive learning environments

Digital games as a form of entertainment continues to grow its popularity in the U.S and abroad. In the U.S. 38% of K-12 students reported playing video games daily in 1999, a number that increased to 60% in 2009 (Rideout, Foehr, & Roberts, 2010). In Singapore, 83% of children and adolescents played video games at least occasionally in 2011 (Gentile et al., 2011). Moreover, more than half of junior high school students play online games in Taiwan (Tarng & Tsai, 2010), and 82% of children in the UK reported that they played video games at least once every two weeks (“Video games,” 2006). Digital games are thus becoming an increasingly ubiquitous form of how people spend their leisure time. Concomitantly, interest in exploring the use of digital games to support learning is also growing. However, despite this growth, as indicated in the call of this issue, research “in this area is still in its infancy and further research needs to be done to better inform practice, design and integration” (Sadera, Li, Song, & Liu, personal communication, August 26, 2012).

In this paper, we will examine game-based learning by describing a learning environment, *Alien Rescue*, that combines game elements, play, and authenticity in the real-world for the purpose of engaging students’ learning of science and enhancing student motivation. This game-like environment uses play to organize meaningful player experiences. It further situates this experience through the perspective of scientific inquiry in ways that help students learn the language of science through role-play in a science fiction fantasy setting. We will discuss the design of the environment and present research conducted. Our goal is to provide research evidences and explore the theory, design, and research behind a science-learning environment that is informed by a game-based learning approach.

Literature Review

What is a game? What does it mean to learn by playing games? Although there are number of ways in which games support learning, there is little agreement as to the definition of a game. Games resist definitions, as Wittgenstein (2009) famously pointed out, while terms such as *games*, *computer games*, and *video games* are often used interchangeably (Garris, Ahlers, & Driskell, 2002; O’Neil, Wainess, & Baker, 2005). From James Gee’s perspective, we can look at games as compelling tools for “deep learning” if they succeed at creating “virtual experiences centered on problem solving [that] recruit learning and mastery as a form of pleasure” (Gee, 2008, p. 36).

Games and game-like environments can provide students with opportunities for experiential, authentic learning. Gee (2003) provided a framework to understand how commercial games can foster learning in ways that are grounded within principles such as situated meaning, multimodal literacies, active learning, and knowledge transfer. Games expose players to context-sensitive dialogue and in the process, “pu[t] language into the context of dialogue, experience, images and actions,” (Gee, 2008, p. 36) a process that Gee describes as creating situated meaning. According to Gee (2008), games are able to promote the acquisition of situated meaning by embedding knowledge within specific contexts and by relating the language used in them to “actual experiences, actions, functions, and problem solving” (p. 36). Gee’s work is situated within a literacy framework that explores games as “New Literacies”—that is, a “multiplicity of literacy (literacies) [that requires us] to think beyond print” (Gee, 2003, p. 14). Mills (2010) extends this further, describing a “digital turn” in our perspective on literacies to include “literacy practices in digital environments across a variety of social contexts” (p. 246) which include educational spaces. Games thereby represent knowledge in

the form of game assets, visual representations, and interactions that form what Gee (2003) describes as a “semiotic domain” that presents “any set of practices that recruits one or more modalities...to communicate distinctive types of meanings” (p. 18). Semiotic domains can be construed as game environments, each of which embodies what Gee describes as a “design grammar” (p. 99). In doing so, these environments embody Squire’s (2006) notion of a “designed experience” (p. 19) through which players construct their own understanding of the game space.

According to Squire (2006), designed experiences enable players to “learn through a grammar of doing and being” (p. 19-20) while enabling them to participate in “ideological worlds” that offer spaces for inquiry. Squire found that disadvantaged minority middle-school students who played *Civilization* (1991) (a complex “geographic-materialist” strategy game) turned their game play experience into a historical simulation through which they inquired into historical differences between European and African American colonization practices. Similarly, Egenfeldt-Nielsen (2011) studied the effects of student gameplay of *Europa Universalis* (another strategy game, similar to *Civilization*) on learning of history, as measured by retention and motivation. According to Egenfeldt-Nielsen, teacher involvement was integral to helping students connect historical concepts to lessons learned through play. This connection is especially crucial if there is a cognitive dissonance between the game’s historical framework and a student’s knowledge of history (Egenfeldt-Nielsen, 2011).

Games such as *Civilization* and *Europa Universalis* thus present opportunities for learning both as an outcome of game play and as a platform for critical inquiry into sociocultural issues. However, games can also help students develop critical media literacies around the design and play of games (Squire, 2005). Additionally, by studying the discourse in forums

within *World of Warcraft* (a massively multiplayer online game, or MMO), Steinkuehler and Duncan (2008) found that students demonstrated a range of scientific literacies through collaborative and scientific discourse. This process led students to develop “scientific habits of mind” (p. 535) by socially constructing knowledge, using systems-based reasoning and by using feedback and counterarguments in their discourse.

Games designed to support curriculum are also used to create spaces for immersive, experiential learning. *Quest Atlantis (QA)* is a 3D multiuser virtual environment (MUVE) in which students must play within a quest-based system to solve problems and save an endangered world (Barab, Thomas, Dodge, Carteaux, & Tuzun, 2005). *QA* is designed to create a space that encourages players to become immersed within a rich context for game play that involves student role play in which students “must apply conceptual understandings to make sense of and, ultimately, transform the context” (Barab et al., 2005, p. 97) of their game play experience.

Alien Rescue (AR), the game-like environment under investigation, incorporates a variety of game-like strategies to foster play. *AR* positions learners as novice scientists tasked with the problem to find new homes for several alien species and in doing so provides a meaningful, “designed experience” within a fantasy-based context that provides a space for scientific inquiry. *AR* thereby uses authentic scientific problem-solving strategies as a design grammar in an immersive, 3D environment to situate problem solving and promote ludic play (Liu, Horton, Kang, Kimmons, & Lee, 2013).

We are interested in investigating the efficacy of this game-like environment as a learning tool and its impact on students’ learning. The overall research goal that guides this line of research is to examine the effect of this game-like environment on students’ learning. We

present the findings of three studies that used *Alien Rescue* with sixth graders, the targeted audience.

Description of the Research Context

All three studies used the same environment, *Alien Rescue* (<http://alienrescue.edb.utexas.edu>), which engages sixth-grade students by challenging them to solve a complex problem. Students must use the tools, procedures, and knowledge of space science to learn about our solar system and apply processes of scientific inquiry. It is designed as a space science curriculum unit for approximately 15, 50-minute class sessions and is aligned with both National Science Standards and Texas Essential Knowledge and Skills (TEKS).

The design of *Alien Rescue* for this age group is grounded by the creation of a learning environment that is rich in what Malone and Lepper (1987) described as a “Heuristi[c] for designing intrinsically motivating instructional environments” (p. 248). Malone and Lepper recommended that game environments incorporate four elements that help keep players motivated: challenge, curiosity, control, and fantasy. *Alien Rescue* incorporates various game attributes such as challenge, control, fantasy, interaction, communication, mystery, role-play, representation, goals, sensory stimuli, adaptation, and 3D, as suggested by Malone and Lepper and other researchers (Garris et al., 2002; Wilson et al., 2009) in game-based learning.

The program begins with the narrative of the central problem. Each of six alien species, each displaced from a distant galaxy, needs to find a new home because their homes have been destroyed. Students learn this narrative by watching a video that is presented through a television news format. The video then situates students in the role of young scientists who are asked to join a United Nations rescue operation. After students view the video, they begin to work as space scientists aboard a fictional space station. Once they emerge in the station, they

are free to explore the 3D environment and examine five separate rooms contained in the station: the Alien Database or Research Lab, Probe Design Center, Probe Launch Center, Mission Control Center, and the Communication Center. In addition, students are given a set of persistent tools through a toolbar that is placed at the bottom of the screen. This toolbar enables them to use tools such as the Solar System Database, Concept Database, Notebook, Periodic Table and Spectra (see Figure 1). These interactive multimedia tools are designed to help students (a) share cognitive load, (b) support cognitive processes, (c) support cognitive activities that would otherwise be out of reach, and (d) support hypothesis generation and testing, using Lajoie's (1993) four conceptual categories (see Table 1).

Table 1

Descriptions of Cognitive Tools Provided in Alien Rescue

Tool Categories	Tool Functions
Tools sharing cognitive load	
Alien Database	Provides information via 3D imagery and text, on the aliens' home planet, their journey, species characteristics, and habitat requirements.
Solar System Database	Provides information on selected planets and moons within our solar system. Data is intentionally incomplete to support the ill-structured nature of the problem-solving environment and foster the need for hypothesis testing.
Missions Database	Provides information on past NASA missions, including detailed descriptions of probes used on these missions.
Concepts Database	Provides instructional modules on selected scientific concepts using interactive animations and simulations designed to facilitate conceptual understanding.
Spectral Database	Provides information to help students interpret spectra found in the Alien Database.
Periodic Table	Provides an interactive periodic table of the elements.
Spanish/English Glossary	Provides Spanish translations of selected English words found within the program.
Tools supporting cognitive process	

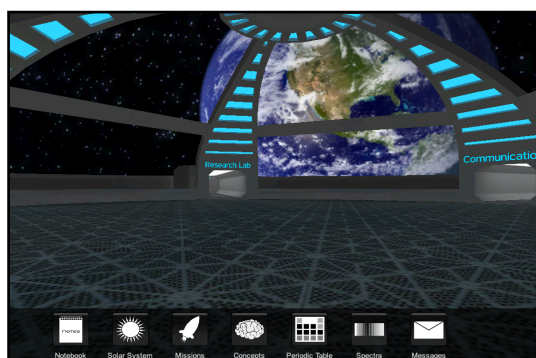
Notebook	Provides a notebook to store student notes about their research findings.
Notebook Comparison Tool	Helps students to compare information from multiple notebook entries so that students can detect similarities and differences among the information in the entries.

Tools supporting otherwise out-of-reach activities

Probe Design Center	Provides information on real scientific equipment used in both past and future probe missions. Students construct probes by deciding probe type, communication, power source, and instruments.
Probe Launch Center	Provides an interface for launching probes. Students check designed probes and choose which probe(s) they want to launch according to the budget.

Tools supporting hypothesis testing

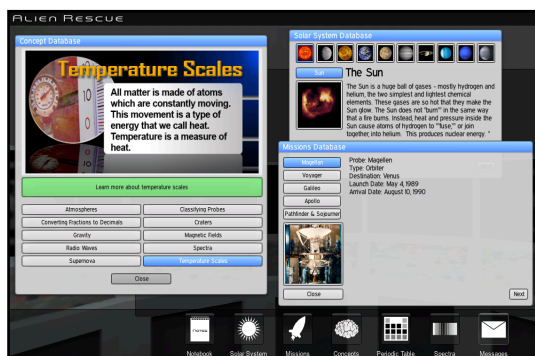
Mission Status Center	Displays the data collected by the probes. Students analyze and interpret this data in order to develop a solution. Equipment malfunction can occur, and poor planning may lead to mission failure and budget waste.
Message Tool	Provides students with ability to send and receive text messages received from the Interstellar Relocation Commission Director as well as the aliens. The Message Tool also includes the Solution Form.
Solution Form	Provides students with a way to submit their solution for each alien species. Students must also use the form to provide a rationale for their choice of alien habitat. Teachers can review and critique these solutions.



a. Students find themselves as scientists aboard an international space station.



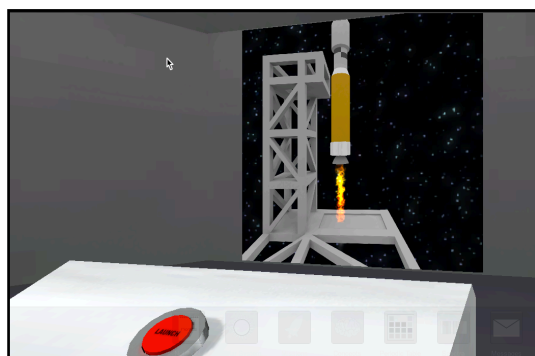
b. The introductory video introduces students to the problem of relocating homeless aliens.



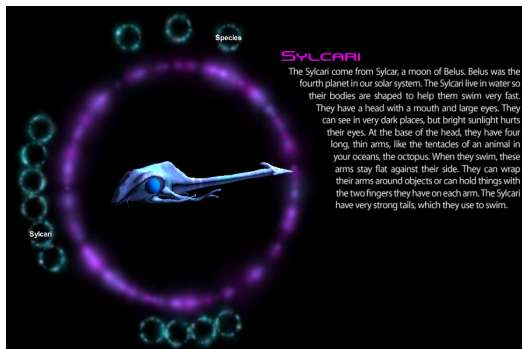
c. Students use tools such as the Concept Database, Solar System Database, and Mission Database.



d. Students select probe design options based upon hypotheses.



e. Students launch probes into space.



f. One of the alien species, called the Sylcari, is depicted in the Alien Database.

Figure 1: Screenshots of tools in *Alien Rescue* to support scientific inquiry.

Previous Research Findings

Summaries of two previous studies examining *Alien Rescue* and students' learning are reported below.

Study 1

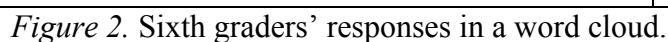
The goal of this first study was to examine sixth graders' science learning, their motivation, and the relationship between students' motivation and their learning of science after using *Alien Rescue* (Liu, Horton, Olmanson, & Toprac, 2011). A total of 220 sixth graders participated in the study. The analysis of the results showed that students significantly increased their science knowledge from pretest to posttest after using the program ($F(1,142) = 320.94, p < .01, ES = .69$), they were motivated and enjoyed the experience, and a significant positive

relationship was found between students' motivation scores and their science knowledge posttest scores ($F(2, 129) = 23.17, p < .01$). The average gain score in the science knowledge test from pretest to posttest was 30.31 out of 100 with $M_{\text{male}} = 28.02$ and $M_{\text{female}} = 31.85$. Although this difference between male and female was not statistically significant, it showed female students, on average, had 3.83 higher gain points.

Study 2

In the second study (Kimmons, Liu, Kang, & Santana, 2012), we further examined the relationship between sixth graders' science learning and their attitudes with a different student population ($n=478$). The findings indicated that students' science knowledge increased significantly from pretest to posttest by 30 points (out of 100, $t(478) = -31.28, p < .01$). Moreover, female students, on average, had higher gain scores than male students by 3 points. This finding indicated that program use had a significant effect on student achievement. In addition, student attitude towards the learning environment was associated with achievement ($F(2, 467) = 3.35, p < .05$). Students with better attitudes also had significantly higher posttest achievement scores ($M_{\text{lowAttitude}} = 85$, and $M_{\text{highAttitude}} = 88, p < .05$). Attitude appeared to be a stronger contributing factor than other variables (e.g. gender, teacher) to achievement scores ($\beta = .05, t(384) = 5.8, p < .01$), with the exception of the pretest score.

In both these studies, qualitative data were also included. The analysis of student open-ended responses indicated students often used the word “fun” to describe their experience with *AR*. A few of typical comments from the sixth graders include: The program was “freaking awesome!!!” “so unique,” “soooooooooo cool!!!!” and “sooooooooooooooooooooooooooooo FUN!!!!!!!!!!!!!!!!!!!!” Figure 2 presents a word cloud of students' responses to the question “how do you describe *AR* to a friend” in Study 1 or “what do you think of *AR*?” in Study 2.



To further this line of inquiry, we recently collected data from sixth graders in two different schools. We asked the following research question: “What is the effect of this game-like environment on sixth graders’ science learning and what do they learn by using the environment?”

All sixth grade students from two public middle schools in a mid-sized southwestern city in the U.S. participated in this study (see Table 2). The participating population included talented and gifted (TAG) students, regular education students (RegEd), English as a Second language (ESL)/English Language Learners (ELL) students, and students with special needs. These sixth graders used *AR* in their daily 50-minute science classes as their curriculum for space science for three weeks. All students had their own computer to use but also worked in small groups; a recommended instructional strategy for implementing *AR*. Five sixth-grade science teachers taught these intact classes. These teachers had received training previously on how to use the environment and this was their second year using the environment in place of regular textbooks as their space science unit.

Table 2

Demographics of the Participating Schools

Student Ethnicities	School 1 (<i>n</i> =130 approx.)	School 2 (<i>n</i> =300 approx.)
White	65.6%	51.8%
African American	4.3%	10.3%
Hispanic American	24.9%	25.7%
Asian/Pacific Islander	2.0%	6.9%
Native American	0.5%	0.5%
Multiracial	2.5%	4.8%
Economically disadvantaged	22.6%	21.1%
At-risk	27.9%	20.9%
Limited English Proficient	2.1%	2.1%

Data Sources and Analysis

A mixed-methods design was employed with two data sources: 1) science knowledge test and 2) open-ended question responses. Students' learning of science was measured by their understanding of the various scientific concepts introduced in *AR*. The tests reflect what the designers and subject matter experts consider to be important knowledge for the students to acquire after completing the curriculum. It includes both factual knowledge and application questions, and was used in previous studies with similar samples using the same learning environment (Kimmons et al., 2012; Liu et al., 2011). Two slightly different versions of the science knowledge test were used. One test included 20 items ($r = .87$) for School 1 and the other included 18 items ($r = .72$) for School 2 (The science teachers in School 2 made a slight modification to the test provided by the researchers to fit their curriculum unit.) This test was administered before and after the implementation of *Alien Rescue* to measure any change. After

the students completed *AR*, they were asked to respond to the following open-ended questions: “What did you learn from *Alien Rescue*?” and “Tell us how much you liked *Alien Rescue* as compared to other science activities? Why.”

An ANOVA with repeated measures was conducted with gender as a between-subjects independent variable and time of testing (pretest and posttest) as the repeated measure within-subject variable for each participating school. The dependent variable was students’ science knowledge test scores. Responses to open-ended questions were analyzed using a constant comparative method of analysis (Lincoln & Guba, 1985; Strauss & Corbin, 1990) and a multi-level coding scheme by Miles and Huberman (1994). We first cleaned responses, eliminating blanks responses or those without meaning. We then consolidated all responses from both schools in one spreadsheet. Next, we read each response and chunked the data line-by-line. Relevant information was extracted through a systematic and iterative examination of the raw data. A list of codes describing the data emerged. We then compared the codes so that similar codes were combined, different ones were separated, and categories emerged at the next level (Creswell, 2009). This iterative analysis continued until it became apparent the emerged codes and themes represented the data adequately and no new codes emerged to support our research question. Two researchers were involved in the process of coding, checking, and verifying codes, categories, and themes until a 100% inter-rater reliability was reached.

Findings

Results from quantitative data. For School 1, the two-factor mixed ANOVA with repeated measure indicated that there was a main effect for the time of testing: $F(1,112) = 153.02, p < .01, ES = .58$. The correct responses in the science knowledge test increased significantly from pretest to posttest for both male and female students; and the average gain

score from pretest to posttest was 24.29 with $M_{\text{male}} = 23.34$ and $M_{\text{female}} = 25.78$. There was not a significant two-way interaction between gender and time of testing (see Table 3). There was also not a gender main effect: $F(1,112) = 1.21, p = .27, ES = .01$; however, it is worth noting that female students had 2.44 higher gain in points than their male counterparts.

For School 2, the two-factor mixed ANOVA with repeated measures indicated that there was a main effect for the time of testing: $F(1, 255) = 132.62, p < .01, ES = .34$; and for gender: $F(1, 255) = 9.72, p < .01, ES = .04$. The correct responses in the science knowledge test increased significantly from pretest to posttest for both male and female students (see Table 3); and the average gain score from pretest to posttest was 13.31 with $M_{\text{male}} = 12.28$ and $M_{\text{female}} = 14.46$. It is worth noting female students had 2.18 higher gain in points than their male counterparts. There was not a significant two-way interaction between gender and time of testing.

Table 3

Students' Science Knowledge Test Scores

Science Knowledge Score (% on 0-100 scale)	Boys		Girls		Total	
	<i>n</i>	<i>M (SD)</i>	<i>n</i>	<i>M (SD)</i>	<i>n</i>	<i>M (SD)</i>
School 1	69		45		114	
Pretest		57.17% (22.61)		52.11% (13.76)		55.18% (21.69)
Posttest		80.51%* (18.55)		77.89%* (22.55)		79.47%* (20.17)
School 2	134		123		257	
Pretest		49.54% (21.81)		41.82% (19.7)		45.85% (21.15)
Posttest		61.82%* (19.18)		56.28%* (16.28)		59.17%* (18.03)

*Significantly different from the pretest, $p < .01$. Only those who completed both pre- and posttests were reported.

Results from qualitative data. Sixth graders were asked to describe the specific information and skills they learned from working in *AR*. The analysis of this qualitative data in their open-ended responses resulted in a total of 515 units. These units were tallied given the codes describing the data. The emergent themes and representative quotes are presented in Table 4. The students stated they learned about our solar system (the planets, moons, and their characteristics) (51%); the scientific instruments (creating and launching probes and various instruments needed for each type of probe) (16%); alien species (8%); scientific concepts such as magnetic fields, gravity, and temperature scales (7%); problem solving (4%); conducting research (4%); managing a budget (2%); and working with others (2%). “Nothing” comprised about 4% of the responses.

Table 4

Student Responses to “What did you learn from Alien Rescue?”

Categories	% (total units=515)	Sample Quotes
Solar System related	50.87%	<p>I learned many different facts about the moons and planets in our solar system that I haven’t known before, and some were quite interesting. I enjoy learning about outer space, therefore I thought that <i>Alien Rescue</i> was a neat game that could help us learn about the solar system.</p> <p>I learned a lot of the moons of our different planets. I also learned what living things need to survive, like an atmosphere, solids or gasses and all that different stuff. I learned a lot of different characters about the different planets in our solar system.</p> <p>I have learned a LOT of information about our solar system, and become more analytical.</p>

Scientific Instruments related	15.73%	<p>Different moons from planets. How magnetic field works. I also learned how the different instruments work for probes.</p> <p><i>Alien Rescue</i> made me familiar with scientific tools/equipment to measure information from an area.</p> <p>I learned a lot about the different instruments that were used on the probes we made. For example, I never knew that the different types of cameras were specifically meant to find certain pieces of information. If I had not known that I would be sending a wide angle camera to find something very specific.</p>
Aliens related	7.77%	<p>The many kinds of alien names. I also learned what they eat and what kind of elements so they can breath on a planet.</p> <p>That different aliens need different kinds of atmospheres and different kinds of environments.....It's so cool.</p> <p>I learned that aliens need certain things to breath in the air so they can live. I also learned that some aliens need to live on a place where they can dig under ground and build there homes. I also learned a little bit about planets.</p>
Scientific Concepts related	7.18%	<p>I learned mostly about magnetic fields, gravity, elements and the solar system.</p> <p>Each planet, moons, surface, atmosphere, magnetic field, elements, gravity, and temperature.</p> <p>I learned about a new temperature scale called "Kelvin."</p>
Problem Solving	4.08%	<p>I learned about how to use information to solve problems.</p> <p>I learned a lot about planets and how to design probes, eliminate choices, and go for the best possible answer.</p> <p>From <i>Alien Rescue</i> how to really research and find information using tools and solve problems.</p>
Doing Research	3.88%	<p>I've also learned what I call "matching skills". Such as having to match the aliens' specific needs to a planet or moon that provides those needs.</p>

		How to match up my facts to what I already know. I also learned about the solar system characteristics. I learned different things about the planets I didn't know.
		There is a lot of research that is in this process.
Managing budget	2.33%	<p>I learned more about the make-up of planets and materials on them. I also learned about the different tools. Also that probes cost a lot.</p> <p>I learned about different instruments that gather information about other worlds. I learned that \$10,000,000 doesn't go very far when you are researching other worlds. Lastly, I learned how to read a barometer.</p> <p>That if we need to send aliens to different worlds it would require extreme funds and research. That we need to be prepared for something like this at any moment.</p>
Working in groups	1.94%	<p>It taught me to work with my group and find informative facts. It taught me more information about the planets in our solar system.</p> <p>I also learned that you have to trust people to help you find information instead trying to do the work all by yourself.</p> <p><i>Alien Rescue</i> helped with my skills with working together with my group.</p>
Other (including fun, note-taking)	1.94%	<p>I also learned that science can be fun. I love science. About the weird aliens that will some day come to our solar system and our planets.</p> <p>I learned how to take good notes.</p> <p>I learned that taking notes and looking over them can be very important when it comes to solving problems like this one.</p>
Nothing	4.27%	Nothing

Note: Students' responses often reflected more than one coding unit. In providing sample quotes in the table, quotes were placed in the primary code to show sample responses.

The sixth graders at School 1 were also asked “Tell us how much you liked *Alien Rescue* as compared with other science activities [on a scale of 1-5]? Why?,” 37% ($n = 44$) of the students responded “very much,” 32.8% ($n = 39$) responded “much,” 16.8% ($n = 20$) responded “somewhat,” 9.2% ($n = 11$) responded “not much,” and 4.2% ($n = 5$) responded “not at all.” That is, close to 70% of the sixth graders liked *Alien Rescue* as compared to other science activities. The top four reasons for their rating are: “fun” 25% ($n = 36$), “learn” 15.3% ($n = 22$), “game” 7.6% ($n = 11$), and “group work” or “collaboration” 6.9% ($n = 10$). Sample responses include:

- It was a fun way to explore astronomy.
- I like *Alien Rescue* much more than other science activities because we’re not just sitting at our desk doing work that must be done on our own, it’s a fun activity that ties in with what we’re learning.
- *Alien Rescue* was better than other activities because I liked learning about the different things. *Alien Rescue* gave us a chance to work independently on a project by ourselves. I also liked that we could work with different people. Collaboration caused us to debate and come up with more correct answers than if we were working by ourselves.
- Because *Alien Rescue* you can learn what scientist really do and how they learn about all the planets.
- It was interactive. *Alien Rescue* was also like a video game and I really like things like that.
- I liked *Alien Rescue* more than other science activities because it was a group project, we got to do it on the computer, and it was like a video game.

Other responses included: “I liked doing *Alien Rescue* more than other activities because you get to do hands on activities. I find it more interesting than reading out of the book. It would prepare me to be an astronaut!” and “*Alien Rescue* is educational, but at the same time interactive and fun, like a video game. You are also much more independent in *Alien Rescue*.”

Discussion

Students’ Learning as Supported by Game-Based Approaches

Sixth graders often referred to *Alien Rescue* as a game. However, did they learn as a result of playing *AR*? Results from quantitative and qualitative data of the present study clearly indicate that sixth graders have acquired significantly more science concepts after playing *Alien Rescue* and they were able to articulate what they learned. In addition to content knowledge about our solar system and scientific concepts, the students learned about the processes of using scientific instruments, conducting research, managing a budget, and applying important problem solving skills. In addition, they acquired interpersonal skills by working with other students, skills that are crucial for what the Partners for 21st Century Skills (n.d.) characterize as “21st century readiness.” The findings of our present study support the findings from our previous research in which students demonstrated a gain in science knowledge after they used the program. Moreover, the findings from this series of three studies suggest that playing *Alien Rescue* can encourage positive learning outcomes, and are thus consistent with findings from other game-based learning research (Barab et al., 2005; Egenfeldt-Nielsen, 2011; Ketelhut 2007; Squire, 2006). Notably, in all three studies female students had a slightly higher gain score than their male counterparts. In our two previous studies, we also found a positive relationship between students’ learning and their attitude and motivation. Additionally, female students in Study 2 had fewer negative comments than male students in describing their experiences with

AR. These findings are encouraging, given the documented research showing a decline in students' motivation to learn science during the middle school years (Eccles & Wigfield, 2002; Lepper, Iyengar, & Corpus, 2005; Osborne, Simon, & Collins, 2003).

Learning Through an Authentic, Experiential, and Playful Experience

Games are appealing because they are fun to play. For middle school students, the process of having fun can engage them in deeply meaningful ways (Gee, 2003). In investigating sixth graders' experiences with *Alien Rescue*, a recurring theme is that they had fun while learning. This theme is consistent with our intention to deliver a playful experience in an intentional problem-based narrative in *AR*. Our prior research indicates that *AR* has created an authentic, playful, and experiential learning experience for middle school students (Liu et al., 2013).

Authenticity is achieved by placing students in the role of young scientists and charging them with the task of saving distressed aliens. This central problem is presented through a compelling introductory video to create a sense of urgency (see Figure 1 [b]). As scientists, the students are challenged to find new homes for the aliens by engaging in the process of scientific inquiry: identifying the problem, researching, forming hypotheses, testing and validating their hypotheses, and justifying their rationales. Thus, the problem-solving process requires students to think and act like scientists and communicate with each other, thereby demonstrating scientific literacy. In addition, students use a variety of media-rich tools designed to assist learning (see Figure 1 [c], [d], [e] & Table 1). Learning therefore occurs as a result of solving a complex problem. Such processes encourage and support active learning and multimodal literacies development (Gee, 2003, 2008). It is necessary to point out that although various tools are available for students to use, they must decide which tools to use, when, and why. There are six

different types of alien species for students to rescue and each species has its own unique characteristics. Moreover, there is not one single correct answer to the central problem. Some answers are more optimal than others. It is therefore up to the students to present evidence and justify their problem solution with a rationale. These complications present a challenge to sixth graders that encourages them to control their own learning path.

In *Alien Rescue*, real-world scientific inquiry is coupled with a more playful experience and delivered through a 3D immersive, discovery, and sensory-stimuli-rich approach (see Figure 1 [a]). *Alien Rescue* thus presents a game-like, problem-based learning (PBL) environment that promotes a ludic approach to support learning. When students enter the program, they are not given explicit instructions on how to begin problem solving. They must explore and discover the available tools, understand their functions and determine when to use which tool at the time. This design evokes uncertainty, mystery, and curiosity, important game attributes (Malone & Lepper, 1987; Wilson et al., 2009). As discussed in the study by Liu and her colleagues (2013), two aspects of the program are notably important in creating a fun experience: (a) the use of the Alien Database and (b) the Probe Design and Launch tools. The Alien Database presents information about each of the six alien species, including details about their physique, nutritional needs, and habitats. This detail is packaged into an interactive 3D tool that is designed to help establish a sense of fantasy (see Figure 1 [f]). For sixth graders, the task of helping the alien species is an engaging and enjoyable part of the process. This fantasy-based approach is important to help motivate students and develop a sense of helping others as shown in this study. Of the responses in the category of learning about alien species (see Table 3), 35% of the units are about helping aliens as shown in such responses as “I liked that I can help the species find a new and right world that works,” and “That there really could be aliens out there. Also that we

need to help them if they every come for our help.” The theme of “saving aliens” was also found to resonate more with girls than boys (Kimmons et al., 2012).

Interactive elements such as the Probe Design and Launch Tools and Alien Database (see Figure 1 [d], [e], [f]) foster experiential learning that is authentic, fun, and collaborative. As one teacher commented on her experience in using *AR*, “The interactive graphics, databases, and discovery learning format provided my students with innumerable hours of higher-order thinking opportunities. The program required them to collaborate with their classmates, plan probe missions, and learn about the needs of alien species.” In *AR*, these interactive elements combined with a problem-based learning approach provide what Bogost (2008) describes as a “possibility spac[e]” that “represent[s] processes in the material world” (p. 121).

Notably, the ethically conscious game, *Fate of the World (FOTW)* purposefully crafts a possibility space in which learners act to solve environmental problems, while *Quest Atlantis (QA)* provides a space in which learners must act as agents of social change in a troubled world. Similarly, *AR* positions learners as scientists on board a space station, who are being asked to help six alien species that have come seeking help (Liu et al., 2011). Thus, *FOTW*, *QA*, and *AR* all challenge students to tackle socially important problems that provide rich contexts for play, situated in fictional game-like settings. In *AR*, students must also acquire a working literacy of the scientific method through a discovery-based approach in which they must apply the scientific method to research, form hypotheses about possible alien habitats, launch probes to collect data, and validate their working hypotheses. This student experience is highly collaborative and situated in a classroom context. Thus, the peer-based process students adopt when playing *AR* help them acquire scientific literacies that in some ways parallel the process the students used to acquire “scientific habits of mind” in Steinkuehler and Duncan’s study (2008, p. 530).

Limitations

The research design of these three studies incorporated pre- and post-testing and both quantitative and qualitative data. While quantitative and qualitative data allow for triangulation and make the research more rigorous, some lingering questions researchers may have include how this game-like environment compares to other environments and how students' learning after using *AR* compares to that of others who do not use *AR*. In the real-world setting, doing comparison studies is a challenge, because as we found out once a school adopts *AR* as its space curriculum unit, all sixth graders are involved. That is, ethically it is difficult to divide sixth-grade classes into two halves in a school or with the same teacher such that half will use *AR* and the other half will not, for our research purpose. However, we are working on this issue and have recently collected data with two close comparable groups. We hope to report the findings soon.

In conclusion, this paper examined the effect of a game-like environment on sixth graders' science learning. Our research demonstrates that the design of an engaging, interactive environment using a games-based approach can help students have fun while learning. By encouraging exploration, providing interactivity and opportunities for play using media-rich assets and role-play situated in a challenging problem-based scenario, it is possible to offer a fun experience for middle school students that cultivates learning.

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