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Using a Ludic Simulation to Make Learning of Middle School Space Science Fun

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Abstract

In this paper, we describe a ludic simulation designed for middle school space science and examine its use to support students' learning and motivation. The participants were 383 sixth graders and 447 seventh graders. The findings of this study showed that sixth- and seventh-graders perceived the simulation as having substantial ludic characteristics and educational value. The results indicated that having a playful experience is important for this age group and that participating in a ludic simulation can help motivate students to learn school subjects. Results also indicated that incorporating *ludus* into the learning experience can improve students' attitudes toward the subject matter. Implications of policy, research, and practice with regard to using ludic simulations to support classroom-based learning were discussed.

Keywords: ludic simulation, middle school science, motivation, learning, attitude,

The use of digital simulations and games to support learning has garnered significant interest in recent years. Simulations are routinely applied in a variety of fields to address diverse learning objectives, but increasing interest in games within popular culture has led many to consider the effects that playful or ludic simulations can have on learning. For instance, about 60% of children and adolescents reported playing digital games daily during 2009, an increase from 52% in 2004 and 38% in 1999 (Rideout, Foehr, & Roberts, 2010). With such an explosion of interest in the ludic value of digital media, we echo the question that the editors of this special issue posed: “What does it mean to have a simulation that could be called ludic?”

The purpose of this paper is to describe a ludic simulation designed for middle school space science and to highlight previous and emergent research findings that can help us better understand the value of ludic simulations in education. To this end, we will proceed by first presenting a brief overview of previous research studies conducted on the simulation and then explore some intricacies of students’ ludic experiences within it. In so doing, we will directly address issues relevant for this special issue and hope to provide valuable insights to educators interested in the topic.

Theoretical Framework

Considerations of the pedagogical value of *ludus*, or play, feature prominently within constructivist metatheory, having been of interest to both cognitive constructivists (Piaget, 1951) and social constructivists (Vygotsky, 1978), and the topic has seen renewed attention in recent years (cf. Singer, Golinkoff, & Hirsh-Pasek, 2006). At early stages of development, children engage with the world and people around them through playful interactions that allow them to learn by imitation, symbolic interaction, and cognitive representation, thereby constructing

experiential knowledge about the world (Piaget, 1951). As a result, play for children is “an engaging and deliberate activity to which they devote great effort and commitment” (Rieber, 1996, p. 44), and out of such play, children can develop deep and important understandings. Current research in a variety of fields suggests that “play is an important mediator for learning and socialization throughout life” (Rieber, 1996, p. 44; see also Csikszentmihalyi & Bennett, 1971).

With the introduction of digital technologies, researchers were empowered to think about play in new and innovative ways, and digital games as a method of play have become commonplace amongst consumers on computers, game consoles, and mobile devices. In 2009, for instance, it was reported that 42 percent of U.S. homes had a game console (Ivan, 2009), and the emergence of Internet-based social networking technologies and new content distribution platforms such as Valve Corporation’s Steam (2003) and Apple’s App Store (2008) have enabled the growth of new popular methods of digital gaming like massively multiplayer online games (MOOG’s), casual games, mobile games, and social gaming.

This rapid growth and the prevalence of digital games in our culture have led many to consider the questions we might answer and the problems we might solve through play. McGonigal (2011), for instance, argues that games in today’s society “are fulfilling *genuine human needs* that the real world is currently unable to satisfy” and that games, if properly harnessed, have the potential to address real-world problems. Current gamification or ludification movements agree with this stance and hold that a “new ludic system” is arising in conjunction with a variety of ludic social phenomena (e.g., the video game industry, theme parks, etc.). Ortoleva (2012) explains that this “new ludic system would not exist without thinking machines, to which we owe a great variety of playful practices, from video games to

casual games, to those peculiar games that are social networking websites,” and in the words of Fuchs (2012), “we have a society with a ‘high lusory attitude’ … in using these ludic interfaces [e.g., digital games], we increasingly turn work, war, sport and health into gamified processes.” Focusing on specific problems in education, Squire (2003) has argued that digital games can “elicit powerful emotional reactions in their players, such as fear, power, aggression, wonder, or joy” (p. 2) and that designers of educational products have much to learn from game developers with regard to designing “interface, aesthetic, and interactivity” (p. 11) to support learning, and Gee (2003) has further argued that good commercial games incorporate “learning principles that … are all strongly supported by contemporary research in cognitive science” (p. 1). Regarding the educational value of games, Gee even goes so far as to argue that “games may be better sites for preparing workers for modern workplaces than traditional schools” (p. 3).

From these perspectives, games and the play that people engage in through them have the potential for serving important and transformative roles in education and society, and many have attempted to harness this predicted power of games for educational pursuits (e.g., Barab, Pettyjohn, Gresalfi, Volk, & Solomou, 2012; Barab, Thomas, Dodge, Carteaux, & Tuzun, 2005; Clark, Dede, Ketelhut, & Nelson, 2006; Nelson, 2007; Nelson, Ketelhut, Clarke, Bowman, & Dede, 2005; Ketelhut, 2007; Zech et al., 1994). Throughout these endeavors, however, there has been a great deal of confusion and lack of clarity with regard to what types of games might have the most impact for education, what aspects of games are valuable, and what we even mean when we use the word “game.” As a result, in modern vernacular, the terms *computer*, *digital*, and *video game* are used inclusively to refer to a variety of types of programs that do a variety of things. Although a clear, universal definition of *games* has yet to emerge, researchers continue to consider the diverse range of games and game-like environments in an inclusive manner to

better understand their potential impact on teaching and learning. However, some clarification is needed in the field if we are to understand the value of games and their components in an analytic manner.

Lindley (2003) attempts to capture some of the complexity of “what is a game” by offering a “high level framework for game analysis and design.” According to Lindley’s framework, games can be classified in accordance with how heavily they emphasize four factors: gambling (or chance), ludology (or playfulness), simulation (or representation of a system), and narratology (or story). Lindley places these four factors in a three-dimensional tetrahedron (see Figure 1) and explains that different genres of games may be effectively mapped to different locations within the tetrahedron. Lindley’s framework is important for game and educational researchers, because it empowers us to talk about games in ways that are more intentional, meaningful, and directed while simultaneously allowing us to escape the confines of restrictive game definitions.

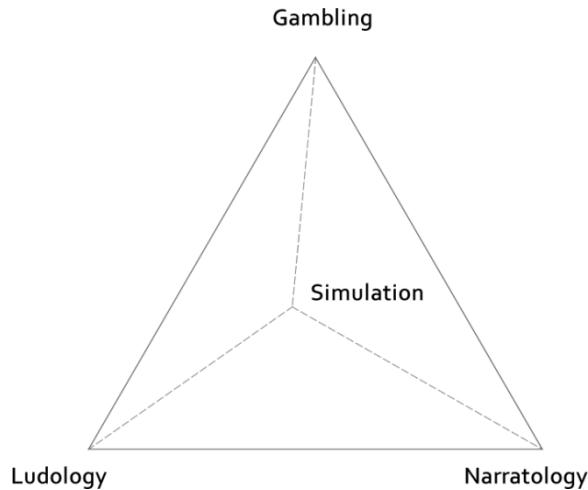


Figure 1. Lindley’s (2003) three-dimensional classification model for game analysis and design (p. 2).

Within education in particular, Lindley’s framework is valuable, because it allows us to focus upon certain aspects of games that are educationally valuable for a given context (e.g. play,

real-world fidelity, etc.) without having to address other elements that may not be as relevant (e.g. chance, etc.). This framework also gives us flexibility to talk about a diversity of educational media that in cultural vernacular might be called “games” without fitting a strict definition of the word.

Within this tetrahedron, simulations are of particular interest to educators for their emphasis on skill development. In Lindley’s words: “Simulations … are not interesting as games or stories, but for understanding how a particular system functions in different circumstances” (p. 1). For this reason, simulations have been used in a variety of fields to support educational goals, and many popular commercial games could be considered simulations, since they provide representations of systems that can be tweaked and manipulated by players. For example, *Flight Sim X* (2006) simulates airplane flight, *Garry’s Mod* (2004) simulates laws of physics, *Grand Theft Auto* (2008) simulates many aspects of city and criminal life, and *Civilization* titles (1991) simulate aspects of economics, warfare, and diplomacy.

However, rather than being pure simulations, these commercial products incorporate other aspects of game design (e.g. ludology) to make the simulated experience motivational and meaningful to players. *Grand Theft Auto* ignores certain aspects of the criminal justice system, like authentic jail time, and allows players to freely explore the world and to interact with it, and *Civilization* provides players with animations, musical tracks, missions, a variety of scenarios, and even the ability to artificially introduce novel factors into a running scenario (like an attack helicopter in the Stone Age). By so doing, these *ludic simulations* offer an interesting and engaging blend of skill development and playfulness that would be lost in a simulation that did not incorporate ludic elements or a game that did not simulate interactive systems. Unlike true

simulations, which would replicate a system with absolute fidelity and realism, ludic simulations hold ludicity to be as important as fidelity or realism.

Up to this point, the term *ludic simulation* has not been frequently used in educational game research, though many research projects have utilized games and virtual environments that might be meaningfully classified in this manner (Angehrn, 2006; DeNeve & Heppner, 1997; Ketelhut, Dede, Clarke, Nelson, & Bowman, 2007; Kimmons, Liu, Kang, & Santana, 2012; Linser, Ree-Lindstad, & Vold, 2007; Roberts, 1976;). For example, much research involving the development and use of virtual worlds, multiuser virtual environments (MUVEs), and multimedia enhanced learning environments might be meaningfully discussed from the perspective of their ludicity and simulation properties, but have not been, largely due to divergent research emphases and lack of a common theoretical framework. However, current interest in ludic simulations reflects a larger ludification movement in society (Fuchs & Strouhal, 2008; Raessens, 2006), and current research into educational games should consider the ways in which ludic simulations can support learning by focusing on the value of *ludus* and simulation.

Research Context

This study focuses on a ludic simulation called *Alien Rescue*. *Alien Rescue* (AR) is a problem-based educational ludic simulation for sixth-grade space science (Liu, Horton, Olmanson, & Toprac, 2011; Liu, Williams, & Pedersen, 2002; see also <http://alienrescue.edb.utexas.edu>). The goal of AR is to engage students in solving a complex problem that requires them to use the tools, procedures, and knowledge of space science and to apply processes of scientific inquiry while learning about our solar system.

Acting in the role of a space scientist, the learner's goal is to find suitable homes within the solar system for six different alien species, each with different habitat requirements, who

have been displaced from their home planets. The experience challenges students to learn how scientists work, plan, and conduct scientific inquiry and to develop well-justified problem solutions. The inquiry process presents an authentic context in which students must exercise high-level thinking skills, such as goal setting, hypothesis generation, problem solving, self-regulation, evaluation of various possible solutions, and the presentation of evidence. AR is designed as a sixth grade science curriculum unit to be completed over the course of approximately fifteen 50-minute class sessions and aligns with National Science Education Standards and Texas Essential Knowledge and Skills (TEKS). To support students in this endeavor, AR's design centers on a collection of tools, each of which is intended to support various aspects of the learner's thinking and problem solving process.

AR engages learners in roleplaying, as they take on the role of a space scientist aboard the fictional *International Space Station Paloma*. Roleplaying directly engages learners in the problem context of the simulation and allows learners to participate in its narrative structure. Students are first situated in the narrative through a video introduction that features a variety of audio and video elements. In this opening video, a series of breaking news segments, delivered by professional news anchors, relays the news that aliens have entered Earth's orbit and have broadcasted a plea for help. Subsequent reports depict Earth's response to the plea and shifting public consensus, which lead to the eventual formation of a special United Nations task force to address the crisis. Through the introductory video, students are introduced to the goals and context of the simulation and are oriented to their role as scientists tasked with saving the alien species.

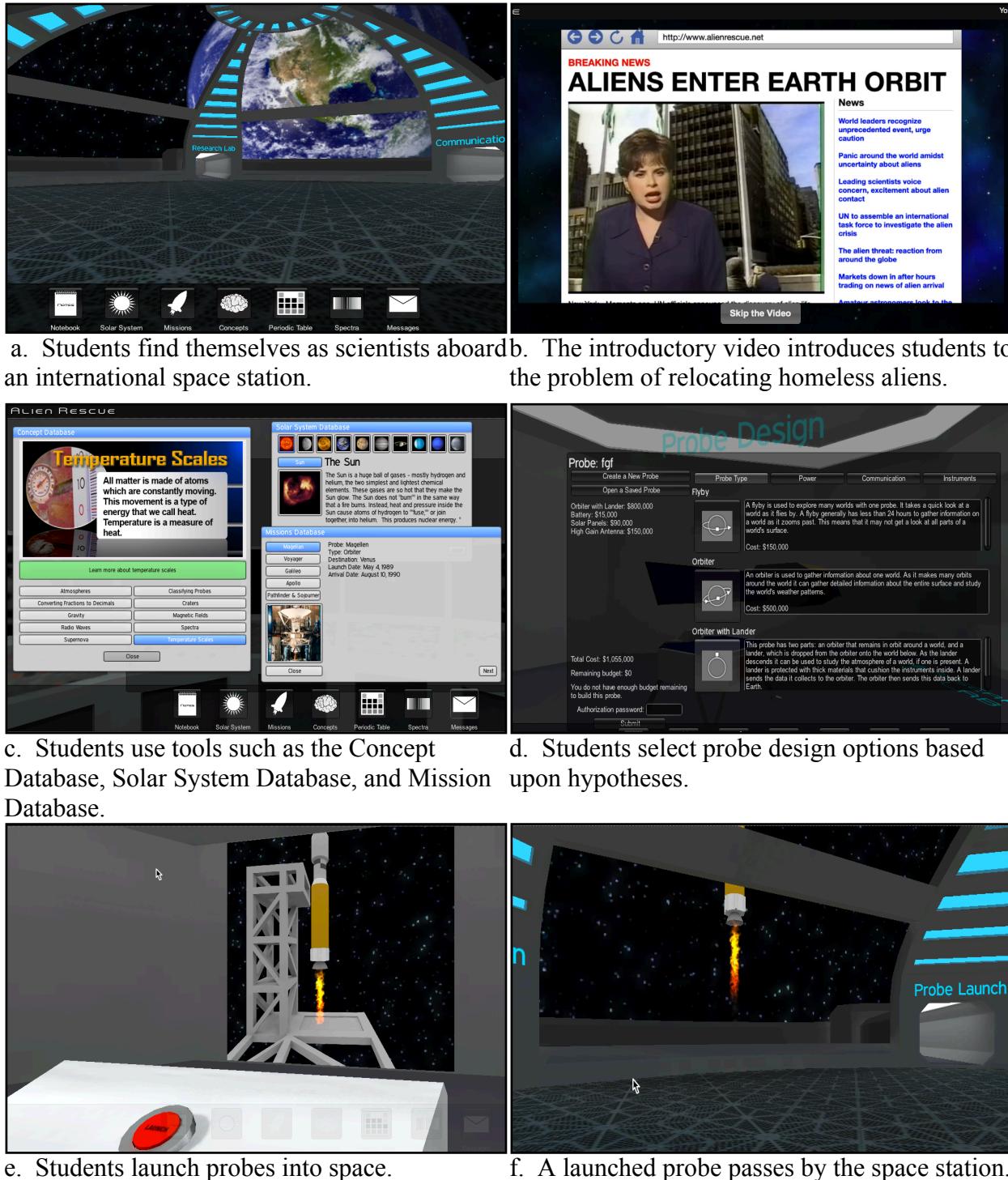


Figure 2: Screenshots of various tools provided in Alien Rescue to support the process of scientific inquiry.

After being situated in the problem context by the introductory video, students are free to roam the 3D environment of *ISS Paloma*, the primary setting of the simulation, through a first

person perspective. Paloma includes five independent rooms that are connected to one another via a central area. These rooms include the Research Lab, Probe Design Center, Probe Launch Center, Mission Control Center, and Communication Center, and each room provides access to a specific scientific tool. Additionally, a simulated augmented reality interface presents students with a toolbar that can be used to access persistent tools (e.g. Solar System Database, Concept Database, Notebook etc; see Figure 2) while navigating the space station. These tools are available for information gathering, data recording and analysis, experimentation, and reporting (See Figures 2 & 3) and are designed to support complex thinking and problem solving processes. A brief description of each major tool follows:

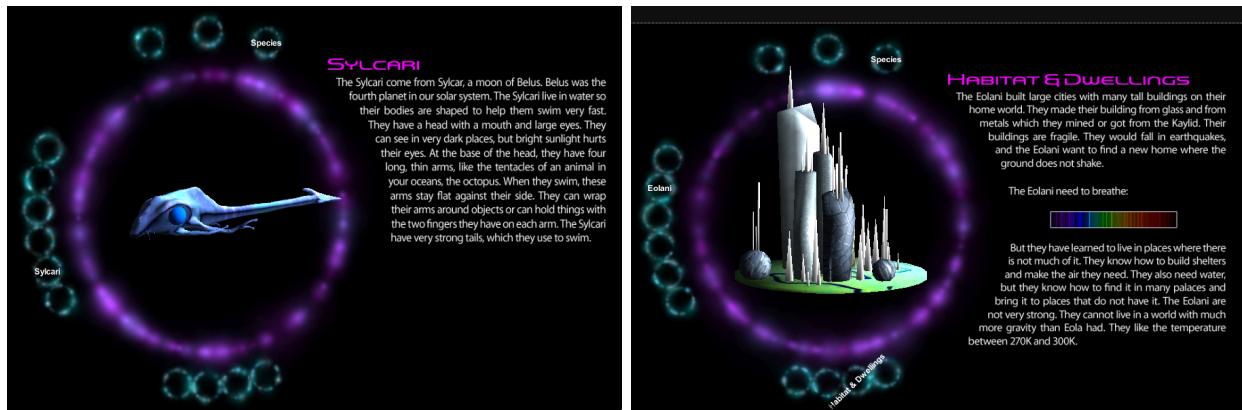
- The Alien Database, located in the Research Lab, provides information on the six alien species, their journey to our solar system, and their home planets.
- The Solar System Database provides students with information on the solar system and features high quality images and meaningfully designed hypertexts. Selected planets and their moons are presented with relevant images and text.
- The Mission Database provides information on past space missions, helping students understand processes of research in space science and providing exemplars of possible probe designs.
- The Concept Database provides just-in-time instruction on a variety of scientific concepts, such as gravity, temperature, and atmosphere, and is available to help students address knowledge gaps as they are encountered within the simulation. Each concept is presented in an interactive format that supports the acquisition of conceptual knowledge through animations, simulation, and informal knowledge checks.

- A Notebook tool allows students to record information during the simulation, subsequently reducing the cognitive load required to manage information while mirroring the tools and processes of practicing scientists.
- The Probe Design Center, Probe Launch Center, and Mission Control Center allow students to build, launch, and receive data from probes. Following their investigation of the solar system and the habitat requirements of the aliens and the formation of initial hypotheses around appropriate solutions, students are able to design and launch probes to gather additional information from a specific planet or moon. Their work in this phase can be used to confirm or disconfirm hypotheses or help address information gaps in order to further inform the students' work.

The Probe Design Center is of special emphasis, because it allows students to design their own probes by selecting a probe type and equipping it with the scientific instrumentation required to test a given hypothesis. The process of designing and launching probes simulates the actual process of scientific investigation in space science, and a budget system simulates a real-world constraint that requires students to be strategic in the configuration of their probes. An incorrectly designed probe can malfunction, thus wasting crucial funds. As a gamification element, the Probe Design Center aims to help students identify efficient methods of scientific investigation and recognize realistic constraints that impact scientific inquiry. After designing a probe, students have the opportunity to launch it from within the Probe Launch Center, a process that includes a simulated rocket launch. Data from each probe are available from the Mission Control Center and are presented using a variety of images. Invalid probe configurations and

randomization result in error messages, further supporting the authenticity of the simulation and encouraging students to refine their approach to designing probes.

Additionally, fantasy components are incorporated into the narrative of the simulation via the story of the distressed aliens, the shifts in public opinion, and the urgency of the situation, as depicted in the introductory video. The narrative of the video uses a familiar TV news format, while the incorporation of well-known international organizations, such as the UN, enhances the realism of the scenario. Beyond the introductory narrative, the playful science fiction inspired interface of the Alien Database provides background information on the alien species alongside interactive 3D models of the aliens, their home planets, and their food sources, each of which was designed according to the principles of educational fantasy (Kim, 2009; see Figure 3). Although the alien narratives are fictional, they are presented in a realistic way that promotes the fantasy of the simulation, thereby encouraging students to respond to the aliens with empathy and emotion (Toprac, 2011).



- a. One of the alien species, called the Sylcari, is depicted in the Alien Database.
b. Information on alien habitats and dwellings are provided.

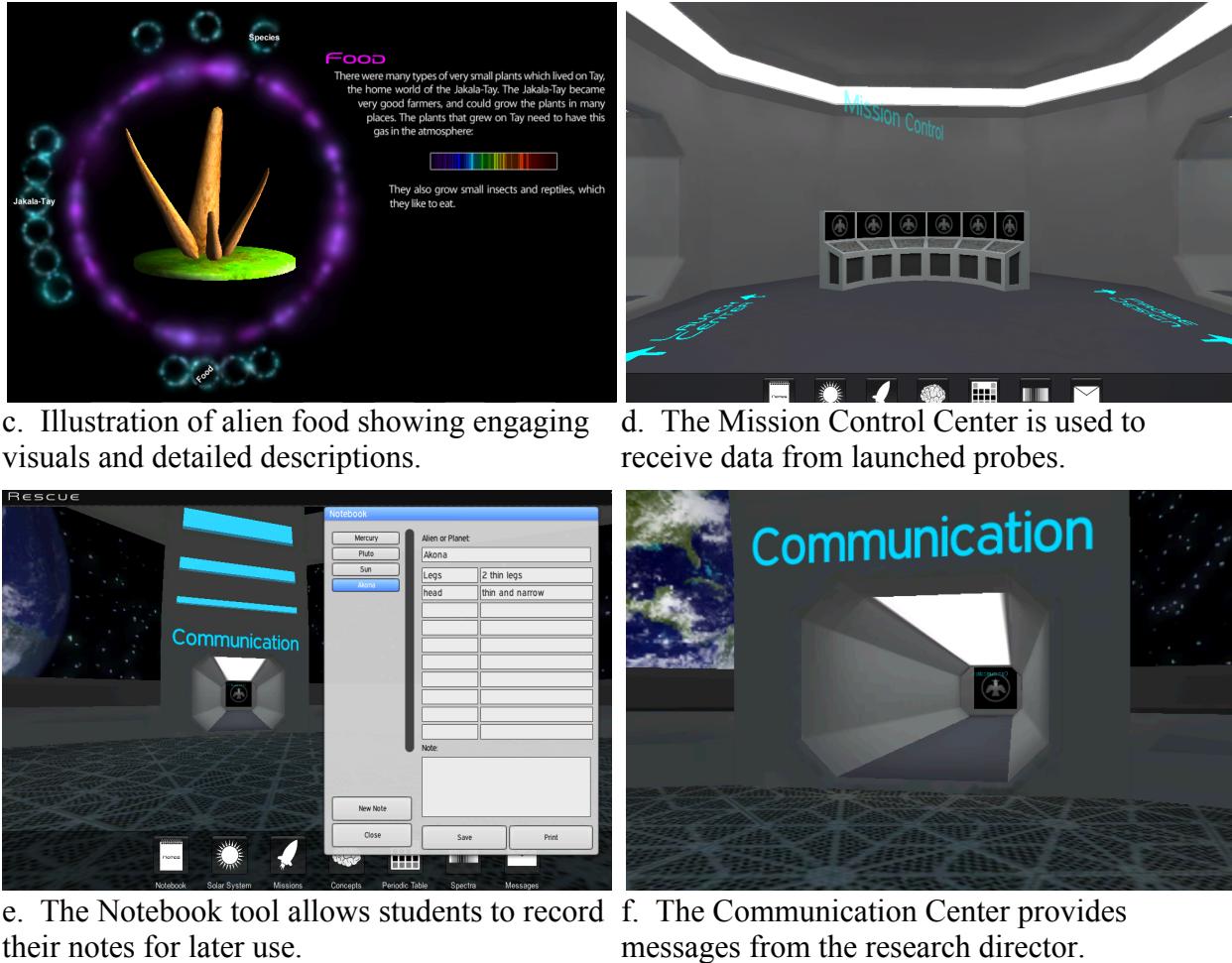


Figure 3. Screenshots of some tools, including the Alien Database, Probe Launch Center, and Communication Center.

Previous Research

As designers and developers of this ludic simulation, we are interested in determining if its use has an impact on student learning. Two recent research studies investigating this topic were conducted (Kimmons, Liu, Kang, & Santana, 2012; Liu, Horton, Olmanson, & Toprac, 2011).

In the first study, we examined the effects of AR on learning and the relationship between learning and motivation (Liu, Horton, Olmanson, & Toprac, 2011) among sixth graders ($n=220$). ANOVA results indicated significant increases in students' scientific knowledge following use

of the simulation, as measured by a domain-specific science knowledge test. This finding was supported qualitatively through student responses to open-ended questions in which they described specific concepts learned. In investigating the relationship between learning and motivation, the study found a significant positive correlation between student knowledge scores and overall motivation. Of particular importance to this current study, qualitative analysis of student open-ended responses indicated significant use of the word “fun” as a descriptor of the simulation.

In the second study, we further examined the relationship between learning and attitudes (Kimmons, Liu, Kang, & Santana, 2012) among participating sixth graders ($n=478$). Results using ANOVAs and regression analyses showed that use of the simulation had a significant effect on student achievement, female students averaged higher science knowledge gain scores than male students, and students with a better attitude toward the simulation had a significantly higher post-test achievement score. Qualitative analyses supported these findings.

Findings from our previous research have indicated that sixth graders’ science knowledge improved after using the simulation and students with more positive attitudes toward the simulation had higher achievement scores. These two studies employed a mixed-methods design, using both quantitative and qualitative data. When students were asked to respond to open-ended questions such as “How would you describe *Alien Rescue* to a friend?” or “What do you think of *Alien Rescue*?,” responses included ludic explanations like the following: “freaking awesome!!!” “soooooooooooooo FUN!!!!!!!!!!!!!!” Throughout these studies, students often referred to this ludic simulation as a game and expressed that it was fun to use.

This leads us to consider the following: What aspects of AR do students consider to be fun and why? The current study continued this line of inquiry and built upon our previous research by further examining the ludic aspect of the simulation from two perspectives. First, we asked participating sixth graders from two schools (in different school districts) to provide their thoughts on the simulation. In the first study described above, our participants were from ‘regular education’ (RegEd) classes, and in the second study, participants included talented and gifted (TAG), RegEd, and students with limited English proficiency or learning disabilities. In this follow-up study, we again included sixth graders from all ability groups in the analysis, because we wanted to further investigate sixth graders’ experiences using the simulation. Second, we surveyed a group of seventh graders from four schools (different from the two sixth-grade participating schools), who had used the simulation in the previous year, in an attempt to find out how they compared their use of AR to other science activities they had experienced. Our rationale was that if the students truly enjoyed the simulation, then they probably would remember it one year later and that the experience of these participants should allow us to further investigate the topic. To direct our inquiry, we asked the following research questions:

- What do middle school students think of *Alien Rescue* as a tool to learn science?
- Is AR fun for them to use it? If so, in what way? If not, why not?
- What features do middle school students consider fun?

Method

Participants, Setting, and Data Sources

Sixth Graders. Sixth graders ($n = 383$) from two public middle schools in a mid-sized southwestern city in the United States participated in this follow-up study (see their demographic information in Figure 4). These sixth graders used AR as their curriculum for space science in

place of regular textbooks for three weeks in their daily 50-minute science classes. Each student had his or her own computer for use but also worked in a small group, which is a recommended instructional strategy for implementing AR. After they completed AR, students were asked to respond to the following open-ended questions:

1. How would you describe *Alien Rescue* to a friend? Or what do you think of *Alien Rescue*?
2. What did you learn from *Alien Rescue*?
3. What did you like about *Alien Rescue*? Or what is your favorite part of *Alien Rescue*? Why?
4. What did you dislike about *Alien Rescue*? What is your least favorite part of *Alien Rescue*? Why?

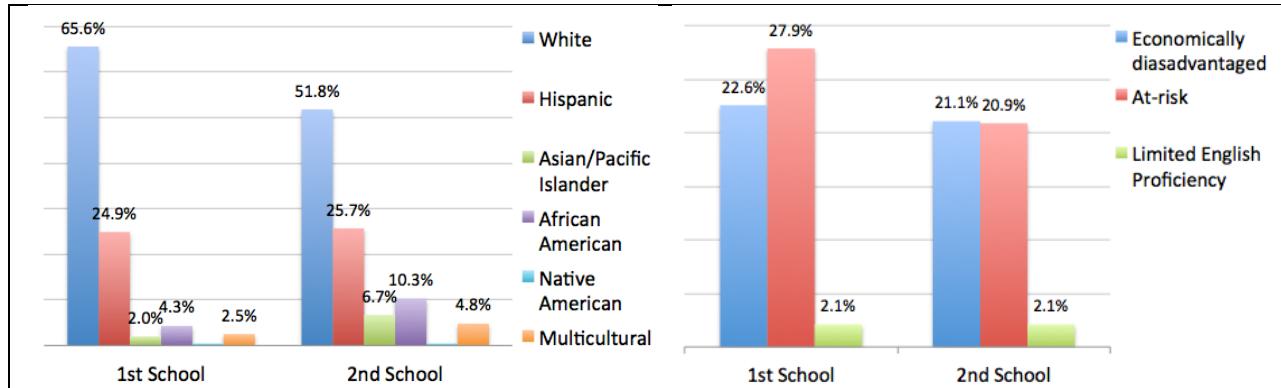


Figure 4: Demographics of two six-grade participating schools

Seventh Graders. Seventh graders ($n = 447$) from four different public schools (see demographic information in Figure 5) were given a survey one year after they used AR. Survey questions included: “Of all the activities you have done in science since 6th grade, what would you like to have a chance to do again?,” “Do you remember *Alien Rescue*? ” and “List 3 or more things you remember about *Alien Rescue*. ” Several Likert scale questions were also utilized and will be presented below.

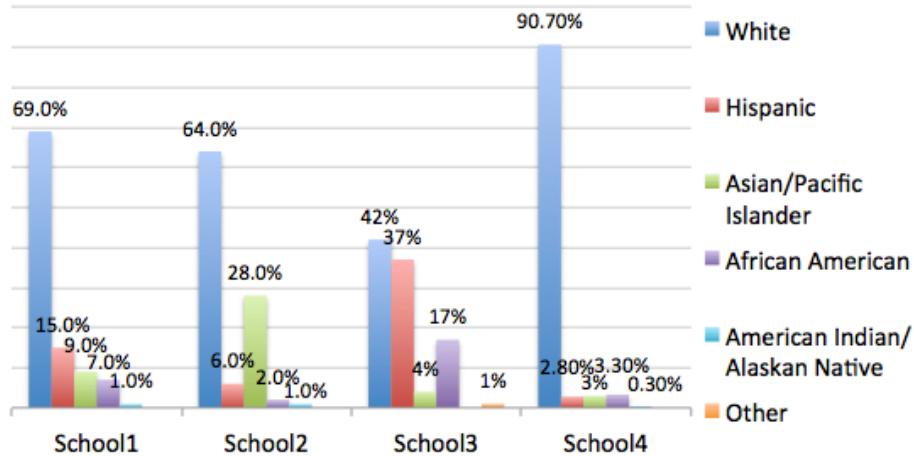


Figure 5: Demographics of four seventh-grade participating schools

Analysis

Students' responses were first cleaned, removing meaningless words or sentences and empty responses, leaving a total of 358 responses from sixth graders (female=46%; male =53%) and 439 from seventh graders (female=53.7%; male =46.3%). Not all students responded to all questions and the *n* in each table below reflects the actual response rate for each question. To analyze the open-ended responses, we followed the constant comparative method of analysis practice (Lincoln & Guba, 1985; Strauss & Corbin, 1990). In examining sixth graders' responses to the first question, our intent was to learn how the students described their experience in using the simulation. Before creating a frequency count of the words the students used, we removed words such as "to," "the," "a," "an," "that," and "and" to increase the prominence of relevant adjectives, nouns, and verbs. The reference to the program name, "*Alien Rescue*" or "program" or "I think" as the start of the sentence were also removed. Typos were eliminated or replaced with correct spelling, and variations and misspelled words, such as alieb/alien/aliens, gets/got/get, and probes/probe, were combined. For example, in this statement "I think alien rescue was a lot of fun. I learned a lot. And I got to help aliens," "I think," "alien rescue," "was," and "a" were removed. After the data were cleaned, a word cloud was generated

using wordle.net from students' responses to question one, which was produced by coupling word frequency with font size (the bigger the font size, the higher the frequency).

Sixth graders' responses for questions two to four were read and chunked from a line-by-line analysis of the data. Relevant information was extracted through a systematic and iterative examination of the raw data. These extracted units were coded to describe what the students said about their experience through "focused coding" (Charmaz, 2006). As the codes were compared with each other, similar codes were combined, different ones were separated, and various categories emerged at the next level (Creswell, 2005). Such analyses continued until an "emergence of regularities" (Lincoln & Guba, 1985) was reached. We then examined and re-examined the codes, categories, and emergent themes in light of our research questions. Two researchers were involved in the process of coding, checking, and verifying the codes, categories, and themes until 100% inter-rater reliability was reached on their interpretations.

The quantitative data in the seventh graders' responses of the survey questions were analyzed descriptively. Their responses to the open-ended questions were analyzed following the same practice as described above.

Findings

Sixth Graders' Responses

For the question: "How would you describe *Alien Rescue* to a friend?" Or "What do you think of *Alien Rescue*?" a total of 1,072 words were extracted out of the 358 statements. Words used by the students to describe their experience included: fun, learn, solar-system, aliens, find, helpful, home, information, interesting, probe, game, computer, and so on (see Table 1). The word "fun" has the highest frequency.

Table 1

Word Cloud of students' responses to "How would you describe Alien Rescue to a friend?" Or "What do you think of Alien Rescue?"

Word Cloud	Word	Frequency (%)
	fun	183 (17%)
	learn	108 (10%)
	solar-system	93 (8.7%)
	aliens	74 (6.9%)
	find	46 (4.3%)
	helpful	41 (3.8%)
	home	38 (2.7%)
	information	30 (2.5%)
	interesting	29 (2.7%)
	probe	27 (2.5%)
	game	24 (2.2%)
	computer	20 (1.9%)

Note. Word count below 20 is not listed.

We then further examined 183 statements in which the word “fun” is positively used.

Students’ responses ranged from simple answers such as “fun” and “very fun” to more elaborate statements such as “it was really FUN and could help a lot of people! especially for the people who would like to go to space someday,” “it is very FUN. it help[ed] you learn. i want to do it again,” “i think was really FUN and enjoyable. i think was a good source to learn more about space.” Reasons cited by the students ranged from more generic statements such as “a FUN way to learn,” “it was very very FUN!!!!!!!!!!,” to more specific statements indicating the aspects of the program they considered fun. For example, students stated, “I think was very FUN and interesting. It was cool to see the alien and launch probe and get to learn about planet,” “Its FUN. You can work with a group. Its a problem solving game,” “It was FUN to do because you get to figure out what alien which to what planet and their needs,” and “A FUN activity that get you to enjoy science and not just read out of the textbook. You get to help aliens find home in

our solar system. But you also learn A LOT!!!" Table 2 provides the main reasons students considered AR to be a fun experience.

Table 2

Main Reasons Revealed in Student Statements in Which the Word 'Fun' Was used Positively

Why Students Considered Fun	Sample Quotes
a fun way to learn about solar system, space science, science	i think it is FUN. and that it is a good learn[ing] activity. that it was cool to learn about alien, planet and moon. It is FUN an. It is a perfect way to learn. it is the best way to learn about the solar-system
An educational or a learning experience	I would describe as FUN. It can help you learn and has surprises on the way. I would say while most of it was awesome, I would describe alien [rescue] to a friend to be really FUN. It is informational and valuable to a student's education. I would also say that it is creative.
a game	[It] was a FUN learn experience. The type of game like this should be more widely used among school districts. This was a healthy way for kids to learn about the planet. A FUN computer game that you go around to different plants try to find home for alien in our solar-system.
Learn to collaborate, work in groups	its FUN and help us learn. teaches teamwork. super FUN. I think that it was FUN because we had partners that we chose on our own and it was very delightful to be on the computers with a person we trust and know and we could communicate. Except i would like to do it more often.
Get to help aliens, learn about aliens, design/launch probes	i think [it] was FUN because we could buy things. because we could roam around the space station and see what the space station looks like. finally i think was FUN because we could send probe around the galaxy and see what the world look like. I think that [it] is very educational and is cool how you get to help alien. I like when you get you send probe to moon and planet. I think alien rescue was FUN over all.
Fun but challenging	its FUN learning about different planet and i love a challenge and this was a big one

FUN and challenging, a worthwhile goal

Problem solving, scientific process it is a FUN activity that lets you interact and make your own probe. It is also educational because you can learn about different planet. You also have a budget, just like in real life.

[It] is a FUN way to study planet. It also can tell you a lot of information about planet. You also get to learn about alien and figure out where each alien goes.

Feel good, want to do again I think that was a very FUN interesting thing to do. It was one of my favorite projects all year. I hope to do something like this again this year.

It was very nice. it was enjoyable and i think i did a good job. it was FUN.

So what have students learned from using AR? Out of a total 515 coding units, approximately 51% of the responses were related to learning knowledge about our solar system (the planets, moons, and their characteristics) and about 16% were about learning the scientific instruments (creating and launching probes and various instruments needed for each type of probe). Other concepts or processes students stated they had learned include 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. Below are a few sample statements:

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 *Alien Rescue* was a neat game that could help us learn about the solar system. (Student 1)

I learned mostly about magnetic fields, gravity, elements and the solar system. I also learned how the different instruments work for probes. (Student 2)

From alien Rescue how to really research and find information using tools and problem solving hard questions. (Student 3)

Of various aspects the students liked the most, the top five were probe-related (33.84%), alien-related (22.28%), exploring the 3D environment (9.86%), learning about the solar system (9.52%), and problem solving or doing research (8.67%). Other aspects the students liked included: working with peers and managing the budget. 2% of the responses indicated that they did not like anything (see Table 3).

Table 3

Student Responses to “What did you like about Alien Rescue?” Or “What is your favorite part of Alien Rescue?”

Category	%	Sample Quotes
Probes related	33.84%	<p>Launching probes because we got design our own probe and try to see if our ideas would work.</p> <p>My favorite part was probe launching. I loved how the probes would send back info so quickly. It really boggles my mind how a probe could go off so quickly and give back so much information!!!!!!!!!!!!!!</p>
Aliens related	22.28%	<p>My favorite parts were learning about the aliens. They have very different needs than humans. I also liked the time when you sent the aliens to the specific planet.</p> <p>Getting to learn about the aliens because I liked to look at the different pictures that the alien had. That included the habitat and the food. :)</p>
Exploring 3D environment	9.86%	<p>Exploring Paloma. It was cool to see all the different rooms. Also looking at the aliens.... Great job an designer(s) part!! It was a cool 3D environment, and I enjoyed exploring it.</p> <p>The Pictures because they actually showed what they look like. I also liked how you got to see the probe go into space.</p>
Learning about Solar system	9.52%	<p>I thought being able to look at all the planets gave me a new view on them.</p> <p>When we did research on the planets. Because we learned a lot of</p>

		new things.
Problem solving/Research	8.67%	<p>Figuring out what type of aliens some planets have and what they do, and what they eat and breath to live on that planet.</p> <p>My favorite part was doing the research. I liked this best because it gave me an opportunity to learn about different worlds and moons.</p>
Working in groups	3.06%	<p>I love Alien Rescue because we got to work with friends and think on our own about how to get answers versus reading in a textbook to get answers.</p> <p>Working with collaborations because it would have been difficult if we were working alone.</p>
Managing budget	2.04%	<p>That there is a budget. Also that you get to send probes into space. I liked these because it gives people challenges.</p> <p>Our favorite part of Alien rescue was building the probes. Because you can tell how much money is an average probe.</p>
Game	2.04%	<p>It is fun and creative. I like it because no one never wants to play a game that's boring and just learn from it.</p> <p>It was a very kid-like gaming world, which made me feel free to do whatever I needed to win the game. This game is very fun and I liked being able to learn about the world we live in. It's very entertaining.</p>
Other (including a sense of accomplishment, multimedia features, computer-based etc.)	6.63%	<p>Getting to the end because I felt happy and confident. It gave me a reason to be happy with myself. The reason is because at first I did not understand what to do.</p> <p>The video the aliens sent. Because everybody thought it was real.</p> <p>I enjoyed how they added extra stuff like a note pad, the table of elements and other tools because it was very useful.</p>
Nothing	2.04%	Nothing

Note. Total units= 588.

Students were also asked to tell us what they did not like. Out of a total 413 coding units, their top responses included: doing research (21.55%), limited budget (9.44%), not interactive enough (8.47%), too difficult (8.47%), note-taking (6.54%), and probe-related frustrations (6.54%). Other responses included that the simulation was boring, making mistakes, filling out

worksheets (given by the teachers), and not having enough time to work out the problems.

12.11% responded that there was nothing that they disliked. Sample quotes are:

The researching was confusing because it didn't say what you were looking at.

(Research)

I didn't like losing money to send probes. I didn't like being denied when I asked for more money. (Limited budget)

The aliens should have been on the ship and you could talk to the aliens about what they needed. (Not interactive enough)

My least favorite part about Alien Rescue was placing the aliens because that took the longest and it took a lot of the work and time. (Too difficult)

My least favorite part had to write down all the info that you had to gather. It took a long time to find and write the info down. (Note-taking)

Designing probes because they would get destroyed. They would not come back with information. (Probe related)

Failing probes because I just spent all that money on a probe that failed me. (Making mistakes)

Seventh Graders' Responses

We first asked the seventh graders to name a science activity they would like to do again as shown in the question "Of all the activities you have done in science since sixth grade, what would you like to have a chance to do again?" We purposefully did not mention AR as our interest was to find out what the students would tell us. Students' responses ranged from "marble," "roller coaster," "*Alien Rescue*," "lab" to "I don't remember," or "I don't know" to "not go back to 6th grade," or "taking a different class." The top three choices of the activities

they would like to do again were AR (15%), lab (8%), and roller coaster (6%). They were then presented the question: “Do you remember *Alien Rescue*?” 93.1% responded yes and 6.9% said no. For those who responded positively, they were asked to rate on a scale of 1-5 the following statements:

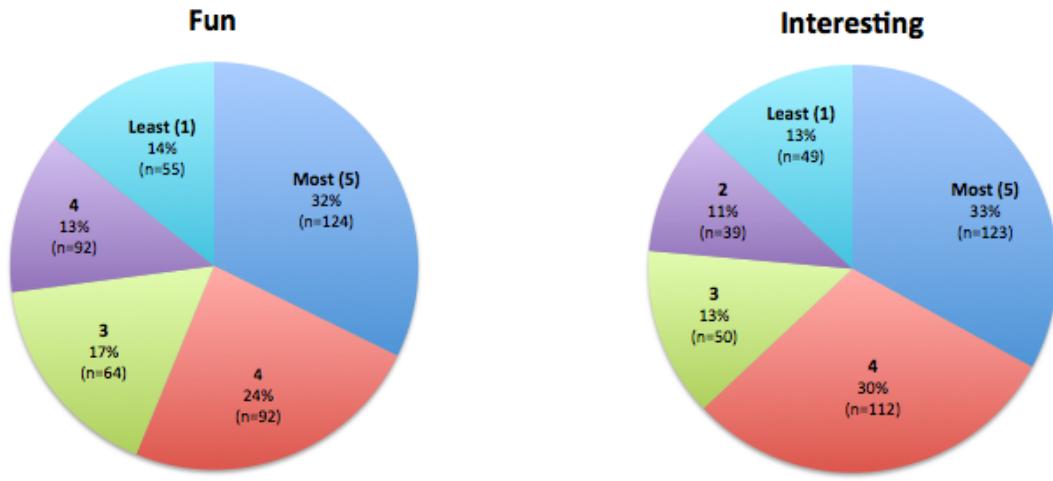


Figure 6. 7th Graders’ Responses on the question about “Compared to other Science activities you have done since 6th grade, Alien Rescue was”

Table 4

Seventh Graders’ Responses to Several Likert Scale Questions

	Very True (5)	(4)	(3)	(2)	Not True At All (1)
I enjoyed doing <i>Alien Rescue</i> very much.	28.1% (n=110)	22.2% (n =87)	22.2% (n =87)	12% (n =47)	15.6% (n =61)
<i>Alien Rescue</i> was fun to do.	34.5% (n =135)	20.7% (n =81)	17.9% (n =70)	12.3% (n =48)	14.6% (n =57)
I would describe <i>Alien Rescue</i> as very interesting.	27.9% (n =109)	23.3% (n =91)	20.3% (n =79)	11% (n =43)	17.4% (n =68)
<i>Alien Rescue</i> was enjoyable.	30.5% (n=117)	21.9% (n=84)	19% (n=73)	10.2% (n=39)	18.5% (n=71)

In answering “I wish there were more activities like *Alien Rescue* and why?” 38% ($n = 149$) of the students responded “strongly agree,” 19.6% ($n = 77$) responded “agree,” 15.1% ($n = 59$) responded “somewhat,” 9.9% ($n = 39$) responded “disagree,” and 17.3% ($n = 68$) responded “strongly disagree.” We further examined those responses of strongly agree and strongly

disagree to understand students' rationale. The reasons the students strongly agreed included because it was "fun," "cool, entertaining or interactive," "educational or learning about solar system or problem solving," and "using computers." The reasons the students strongly disagreed included because it was "boring or not fun," "[activity] took too long," "confusing," "not helpful or educational." Below are a few sample responses:

In alien Rescue you got to play a game that helped you with science. (Positive response)

Because we get to move around and figure things out. It's also like a puzzle.
(Positive response)

Because we learned things while we were having fun playing games. (Positive response)

Well because it wasn't fun and it was a lot of work. (Negative response)

Because it was confusing and i didn't like it. (Negative response)

Seventh graders were also asked to list 3 or more things they remembered about AR. Of a total of 888 coding units, what the students remembered the most are various aspects about helping aliens (30%), designing and launching probes (14%), learning about planets in our solar system (14%), exploring the 3D space station (8%), and doing research (5%). Other items students mentioned they remembered include: managing time and a budget, a challenging/difficult project, various multimedia features (i.e. graphics, video), working in groups, and nothing (2%).

Discussion and Implications

The Role of Fun in Learning

With multiple data sources, it is clear that the sixth graders generally considered their use of AR to be a fun experience. The word “fun” has the highest frequency in their responses to an open-ended question as shown in the word cloud in Table 1. Seventh graders’ responses confirmed this finding in that over 50% of the seventh graders rated their experience as a 4 or 5 (toward the positive end) on several Likert scale questions asking if using the ludic simulation was fun or enjoyable (see Figure 6 and Table 4). This finding is consistent with our previous studies (Kimmons, et al.; Liu, et al.) and supports the idea of gamified processes as described by Fuchs (2012) and the manner through which ludic simulations support a sense of playfulness, as suggested by Ortoleva (2012).

Both sixth- and seventh-graders indicated that they learned both the content (i.e. our solar system, various science concepts and scientific instruments) and thinking skills such as problem solving and researching. Students also learned about working in groups, managing a budget, and how to engage in problem solving. One student responded that AR “taught us useful skills such as time management, working in a group, computer skills, working independently too.” Our qualitative data analysis supports previous quantitative findings on the positive relationship between use of the ludic simulation and student learning. The finding that students had fun while learning supports the literature emphasizing the value of play and playfulness (Barab, Thomas, Dodge, Carteaux, & Tuzun, 2005; Garris, Ahlers, & Driskell, 2002; Rieber, 1996; Squire, 2003; Toprac, 2011), and illustrates the possibility of creating playful and fun interactions for purposeful and intentional contexts such as school learning. That is, our findings support the idea that games can be contexts in which significant learning can occur, as suggested by Gee (2003).

Many students expressed their desire to use AR again: "It was FUN. You should do this every 6 weeks! Thanks!," and "It did teach me a lot of things I did not know! I would probably LOVE to do it again." Without indicating project or activity names, AR was the top choice for seventh graders across all the activities completed within their sixth grade science course. One year later, over 90% of students remembered the simulation. Nearly 60% of the seventh graders agreed or strongly agreed that they wish there were more activities like AR. Such findings provided a clear indication that these middle school students would like to use this type of program in the future. Perhaps the most encouraging finding is that some students expressed self-confidence and motivation toward learning science as shown in such statements as:

It was FUN. I learn a lot and now I am going to do this [be a scientist] when I get older.

I did very well and I see that I am good at space science.

Ample research has shown that motivation and self-efficacy play important roles in influencing learning and achievement (Ames, 1990; Bandura, 1986, 1997; Lane & Lane, 2001; Lepper, Iyengar, & Corpus, 2005; Schunk, 1995). However, research has also shown a general reduction in students' interest in science beginning at the sixth grade level (Osborne, Simon, & Collins, 2003). Our finding that students' use of AR was shown to have a positive influence on attitude towards science should provide an additional impetus for educational designers and researchers to explore, design, and research technology enriched ludic simulations to support learning.

Attributes of a Fun Experience

Of particular interest to this study are those aspects of the ludic simulation that middle school students considered fun or enjoyable. The findings centered on two aspects (i.e. probe-related and alien-related) and features related to these two.

In solving the central problem of finding relocation sites for the aliens, the students must engage in a series of problem-solving steps including gathering information from the databases (e.g. Solar System Database, Mission Database, Alien Database). However, the information in those databases is intentionally incomplete and therefore students must use the Probe Design Center, Probe Launch Center, and Mission Control Center to design and launch probes to gather more information and test their hypothesis. In designing each probe, students must select appropriate tools. These probe related tools simulate the tools scientists use and the inquiry process they typically apply in their work. Students are given opportunities to experiment and establish for themselves a suitable problem-solving path. The design intention of AR is to provide an authentic learning context where students can apply various thinking skills to find a solution. Students' responses related to the probe tools specifically demonstrated the importance of realism and the role of being a scientist:

Making probes were fun. I felt like an astronaut!

Sending probes was cool, because you got to pick what probe you wanted to send and all the stuff for it. You kind got the feeling of being one of those people that work for NASA and other places.

This sense of realism is a significant motivating factor for these young scientists.

While the probe related tools were designed to provide a sense of fidelity and realism, the design of Alien Database is intended to create a sense of imagination and fantasy. The essential information about the aliens (i.e. their body, food, habitat, communication symbols, and their home planets) is presented through rich, colorful, and interactive 3D. Each species has its own distinct look and feel. The results suggest that this visual and playful interface elicits a strong sense of fantasy among these students aged 11-13; the aliens are one of the top features students

liked about AR. In addition, the fantasy element is also embedded in the narrative of the simulation as presented by the introductory video. This approach of blending more realistic representation with fictional and imaginative elements apparently prompted strong empathy from this age group, a finding consistent with Squire's (2003) belief that games can evoke strong emotional responses in the player. Among those features that students indicated as their favorites (see Table 3), 22.28% are alien related, the second highest. Of this category, 42% are about helping or saving aliens, as shown in sample quotes:

Finding homes for the aliens, because when you find one you just feel so excited.

Sending an alien to their planet because it just makes you feel good to know that you worked hard for that moment.

In addition, the narrative of the young scientists tasked with saving the aliens is situated in an open-ended problem-based context where there are multiple built-in challenges. Once the students are presented with the central problem, there are no instructions within the simulation that direct their work. Students are encouraged to explore and discover in a self-directed way while negotiating one of many possible solution paths. There are also six different species, each of which can have more than one solution. Some habitats are more optimal than others, requiring students to weigh a diverse range of possibilities and develop well-articulated justifications. Additionally, the budgetary constraints present in designing and launching probes prompt students to make careful decisions so as not to be wasteful. While this problem-solving process is challenging, it represents an authentic level of real-world complexity and provides another motivational element that promotes joy and self-confidence in these students: "It was very FUN and help me learn more about science. Thank you for making this. I love it so much. :)"

In addition, working in groups is shown to be a feature many students liked. Group work encourages collaboration within and between the groups, as well as competition, a feature the students considered entertaining and enjoyable.

The findings validate the design of the simulation and highlight several attributes that made AR a fun learning experience for these middle school students: exploratory, interactive, immersive, playful, media-rich, roleplay, engaging narrative, and a challenging problem scenario. Addressing the three factors in Lindley's tetrahedron (2003), AR places equal importance on simulation and ludology and delivers a playful experience in an intentional problem-based narrative. With these attributes, it is also necessary to point out designs of technology enhanced environments must be solidly grounded in learning principles and designed with social responsibilities.

Students' responses also indicated three aspects that they did not like: they perceived it as too difficult, wanted to see more interactive features, and experienced some technical glitches. As discussed above, this problem-based ludic simulation presents a complex problem over a period of 15 days. For some sixth graders, this self-directed approach is difficult and time-consuming, highlighting the need to implement additional technology-based scaffolds to support students in acquiring the expertise necessary to fully engage with the problem.

Summary and Implications for Policy, Research, and Practice

In summary, the findings of this study confirmed our previous research and provided further evidence to show that sixth- and seventh-graders perceived AR as having substantial ludic characteristics and educational value. The results indicated that having a playful experience is important for this age group and that participating in a ludic simulation can help motivate students to learn school subjects. Results also indicated that incorporating *ludus* into

the learning experience can improve students' attitudes toward the subject matter, which is a valuable finding for STEM-related fields in particular, due to current low interest and poor performance in these fields in the US.

Given the results of our research on the potential impact of ludic simulations in supporting classroom-based learning, there are a number of issues to consider related to policy, research, and practice. In particular, we are interested in exploring potential pathways for further conceptualizing ludic simulations as a legitimate form of instructional practice, better understanding how students learn through ludic learning experiences, and supporting the development of new pedagogies that guide the use of ludic simulations in teaching and learning.

School policies governing the availability of technology resources, access to technology support, curricular alignment, and the use of game-like learning environments within classroom all converge to influence the extent and manner in which ludic simulations are diffused into educational contexts. Ongoing research is essential in evaluating the efficacy of ludic simulations to advance learning within and across multiple disciplines, promoting increased interest and adoption of these simulations within schools, and facilitating necessary shifts in policy that acknowledge the role of ludic simulations in supporting curricular objectives and help ensure student access to these learning environments.

Our research further highlights the need for more research on the use of ludic simulations, particularly as they relate to more established areas of instructional practice, including their role in supporting inquiry and problem-based learning and their effectiveness in facilitating productive collaborative learning experiences among students. Further research on instructional design methodologies related to the design and development of ludic simulations will promote development of strategies to support students in achieving learning outcomes

through play. Our research revealed several attributes are of critical importance in designing ludic simulations for middle school students. Just as the name denotes, ludic simulations rely upon a blend of reality and fantasy, and fun in Alien Rescue was achieved by striking a balance between the fidelity of a realistic simulation and the fantasy of imaginative narratives and interactions. Future research into ludic simulations should continue to seek to understand this balance and how to optimally support learning and engagement through effective juxtaposition of realism and fantasy via game mechanics, narrative, and other game elements. Our research has also shown that making the ludic simulation too complex can lead to student confusion and frustration, so future research should also seek to identify appropriate levels of game complexity for different groups of learners. In addition, the creation of robust assessment and evaluation methodologies around ludic simulations will allow researchers and practitioners alike to evaluate student success within these learning environments and understand the specific ways through which ludic simulations can support learning.

Finally, additional research is required in order to identify the types of instructional strategies and methods that will enable teachers to facilitate student learning within game-like learning environments. Our work borrows significantly from research on constructivist learning environments and the application of instructional approaches -- such as problem-based learning - - that historically have not explicitly considered the ludic characteristics of student learning experiences. While the existing body of research undoubtedly provides a substantial basis for the design and application of ludic simulations, there also exists a space for new pedagogies and strategies to be developed that guide the effective application of these simulations.

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