Creating a Multimedia Enhanced Problem-Based Learning Environment for Middle School Science: Voices from the Developers

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Abstract

This paper describes the design and development process used to create *Alien Rescue*, a multimedia-enhanced learning environment that supports problem-based learning (PBL) in middle school science. The goal of the project is to further our understandings of technology, pedagogy, and instructional theories as they relate to the application of PBL within middle school classrooms through the application of design-based research. A unique characteristic of the project is that it is developed entirely by a team of graduate learning technologies students, working under the direction and supervision of the faculty. Throughout the development process, graduate student developers learn steps and strategies for designing immersive learning environments, engage in technology development, and conduct research that informs future design iterations. Key features of the development model are described in detail and developers' reflections are shared. Recommendations for those interested in engaging similar endeavors are provided.

Keywords: problem-based learning, multimedia environment, middle school science, design and development, design-based research

Introduction and Background

The purpose of this paper is to describe and reflect on the process of creating an immersive multimedia enhanced problem-based learning (PBL) environment for middle school space science, known as *Alien Rescue*. We discuss our design and development model and its key characteristics to illustrate our approach to designing *Alien Rescue* as a platform for both learning and research. We hope that our experiences and the processes we have developed will help inform others who are involved in or interested in pursuing similar endeavors.

The goal of the *Alien Rescue* project (AR, http://alienrescue.edb.utexas.edu) is to challenge middle school students to solve a complex space science problem. This problem requires students to acquire domain knowledge in space science and use the tools and procedures of space science and scientific inquiry to learn about our solar system. Middle school students act as scientists by participating in a rescue operation to find suitable relocation sites for six displaced alien species within our solar system. Through inquiry-based activities, middle school students practice problem-solving, self-directed learning, and collaboration using multimedia enriched cognitive tools. AR is designed as a science curriculum unit spanning approximately fifteen 50-minute class sessions, and is aligned with the National Science Standards and Texas Essential Knowledge and Skills (TEKS). It is an open environment that encourages students to freely discover, explore, and experiment.

The design of *AR* is guided by the theoretical principles of problem-based learning (PBL). PBL is an instructional approach that exemplifies authentic learning and emphasizes problem-solving within richly contextualized settings. In PBL, students assume primary responsibility for their own learning while teachers provide facilitation; learning occurs in small groups in which collaboration is emphasized and encouraged (Barrows, 1996). This approach promotes student-centered learning and collaboration. Research suggests that PBL is an effective instructional approach to develop problem-solving and self-directed learning skills (Brush & Saye, 2000; Gallagher & Gallagher, 2013; Mergendoller, Maxwell, & Bellisimo, 2006). Despite its effectiveness, implementing PBL in K-12 classrooms can be a challenge (Ertmer & Simons, 2006; Hmelo-Silver, 2004; Savery, 2006). Complex student-centered learning environments such as PBL require appropriate scaffolds that support novices' learning and problem-solving processes (Pellegrino, 2004; Simons & Klein, 2007). A defining characteristic of AR is that it includes a collection of cognitive tools designed to support and scaffold complex problem solving within middle school classrooms.

AR is also designed to help address a significant challenge: our 21st century knowledge society needs a well-educated and skilled workforce, especially in the fields of science, technology, engineering, and mathematics (President's Council of Advisors on Science and Technology, 2010), yet, research has documented a decline in students' motivation to learn science, especially during the middle school years (Galton, 2009; Lepper, Iyengar, & Corpus, 2005; Osborne, Simon, & Collins, 2003; Vedder-Weiss & Fortus, 2011). A design goal for the project is to use immersive technologies as tools to motivate and engage middle school students to learn and apply science.

Numerous research studies have been conducted on the effects of *AR* on middle school students' learning and motivation (e.g., Liu, Horton, Kang, Kimmons, & Lee, 2013a; Liu, Horton, Olmanson, & Toprac, 2011), teachers' classroom implementation of the learning environment (e.g., Liu, Wivagg, Geurtz, Lee, & Chang, 2012), and the design and use of cognitive tools to support problem-solving (e.g., Liu, Yuen, Horton, Lee, Toprac, & Bogard, 2013b). The focus of this paper, however, is to describe the approach we have developed to position AR as a sustained and continuous technology development and research project and to present our experiences as designers and developers of a PBL environment.

The Development Model

A design-based research (DBR) framework guides our design and development model; *Alien Rescue* is designed to support both the research and development processes required to successfully apply DBR. This development model incorporates 1) research-based and research-driven inquiry, 2) iterative program design, 3) flexible design goals, 4) collaboration among students and faculty, 5) graduate student peer mentoring, 6) sensitivity to new technologies, and 7) student-centered learning. We discuss our development model and its associated characteristics below and also present illustrative examples and our own reflections, having performed the simultaneous roles of designer, developer, and researcher.

The *Alien Rescue* program has progressed from early versions (a prototype version 1 in 1998, version 2 created in *Macromedia Director* and delivered on CD-ROM in 2001, version 3 created using the *Torque Game Engine* in 2008) to the current web-based version, which was created using the *Unity* game engine and modern web technologies such *Ruby on Rails* to facilitate delivery *entirely* online beginning in 2012. The development team consists of a group of graduate students working collaboratively under the supervision and guidance of faculty. The team uses a four-phase, iterative process that is based upon development approaches used by practitioners in the field (Liu, Kishi, & Rhodes, 2007; Schoenfeld & Berge, 2004/2005) as well as the foundational model of educational design research as proposed by McKenney and Reeves (2012). These phases include *concept*, *design*, *development*, and *implementation*, each of which is coordinated through continuous and iterative processes of planning and evaluation (see Figure 1).

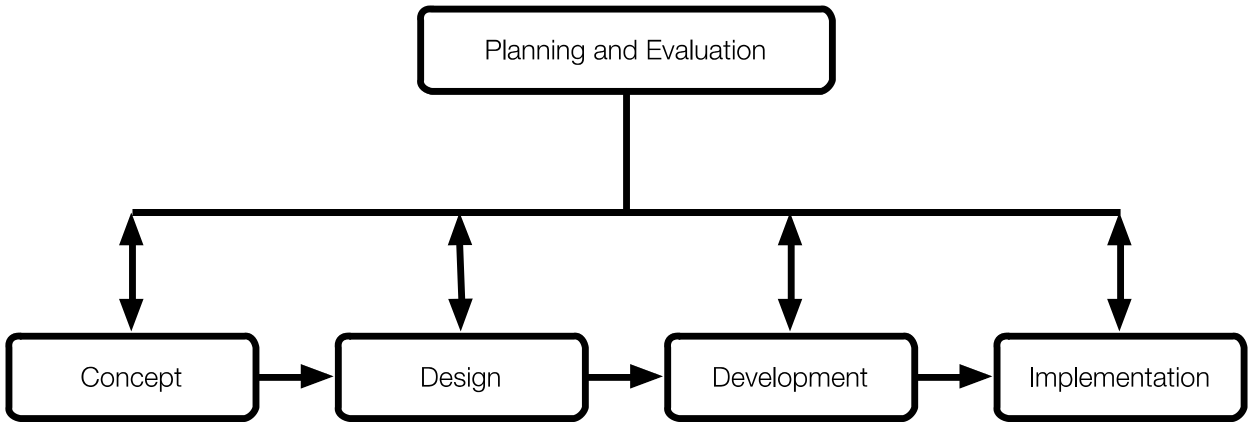


Figure 1. Project development process

During the *concept phase*, the goals, objectives, and desired outcomes of project related tasks are identified. For example, the team might identify a need, based on ongoing research, to enhance the scaffolds provided during the process of designing probes. An outcome might be that middle school students engaged in this process are able to achieve greater success in the use of the probes early in the problem solving process.

In the *design phase*, the team identifies components to be produced or refined, either to facilitate research or improve aspects of the user experience and classroom implementation. From this intial planning, the team develops specifications that consider overall functionality and user experience required by each component. The team then evaluates the viability and practicality of each proposed component, develops a scope of work outlining the specific deliverables that result from the design phase, and plans the development cycle. As an example, in implementing scaffolds for the probe design process, the team may design a range of guiding and reflective prompts that encourage students to articulate their thought processes regarding their selection of specific probe configurations and the manner in which their choices align with a hypothesis.

The *development phase* occurs simultaneously with the design phase. The ideas proposed during the design phase are developed into functional components that are made available for feedback and revision. The components are organized and integrated into one coherent product according to the design plan. Every member of the team is actively involved in evaluating and fine-tuning design ideas and creating elements of the product that reflect the intended design. During this phase, the team may take on a variety of multidisciplinary tasks. For example, some team members may engage in task of designing a suitable user interface for the new prompt functionality, while others may modify the backend web application to enable the new student responses generated by this functionality to be stored. As the team begins to create functional artifacts that reflect the intended design, appropriate changes to the design specification may emerge. In implementing the prompt functionality, for instance, the team may decide to alter the placement or timing of the prompts such that they are more appropriately integrated within the probe design process.

The team tests research-based design assumptions during the *implementation phase* to learn which design decisions are viable, how modifications to the design may influence the learning and problem solving processes and, most importantly, to evaluate theory in the context of iterative design changes. The developers are often present in the classrooms to observe the actual implementation and gain firsthand insight into teachers' and students' use and perceptions of the program. Feedback from middle school students and their teachers on learning, teaching, usability, and technology drives continuous improvement of the program. In validating the use of the new prompt functionality, the team might plan to observe students as they design probes, conduct A/B testing to compare the effectiveness of the prompts with a non-prompt condition, track student probe design processes through the use of click-stream logs, and discuss the overall usefulness of the new functionality with teachers and students. Results from this implementation phase inform a new iteration of the development process to further refine the new functionality. Alternatively, the team may determine that the functionality does not address the desired outcomes, leading to the consideration of a different approach altogether.

Project planning, evaluation, and revision are ongoing and occur throughout the development process. At each milestone during the process, members of the team reflect on the project progress to date, evaluate the process and outcomes, and make needed revisions based on the results. In the following, we discuss the key characteristics associated with this model.

1) Research-Based and Research-Driven Inquiry

Research is an integral part of the design and development process and is used to organize and plan the efforts of the team in all aspects of the project. Ongoing research on *Alien Rescue* is framed within a design-based research perspective that informs each of the four project phases. Design-based research (DBR) is an approach to research that emphasizes the generation and refinement of theory by evaluating reiterative enhancements to an instructional innovation within authentic settings (Design-Based Research Collective, 2003; McKenney & Reeves, 2012). DBR is based on the notion of iterative design experiments that focus simultaneously on the cyclical, evidence-based enhancement of instructional innovations and the refinement of related instructional theory (Barab & Squire, 2004; Brown, 1992; Cobb, Confrey, diSessa, Lehrer, & Schauble, 2003). This approach is particularly useful because it emphasizes the development of theory within the situated contexts of educational interventions, the importance of studying educational innovations within the context that they are used, the ability to conduct in-depth research, and the usefulness of research findings obtained through formative evaluation (Collins, Joseph, & Bielaczyc, 2004).

DBR balances high levels of innovation on the part of designers with the empirical approaches of researchers. The value of DBR is apparent in the design, development, adoption, and study of complex technology-enhanced learning environments. However, there are numerous challenges in conducting DBR, particularly with technology-enhanced learning environments. In particular, when we consider that research participants constitute collaborators in the ongoing design effort (Barab & Squire, 2004), the translation of research evidence into design modifications and theoretical understandings can be demanding. The requirement for multiple iterations is a significant challenge within the temporal scope of a DBR project (Anderson & Shattuck, 2012).

AR has been designed as a technology infrastructure to support data collection associated with DBR; research functionality is a central design requirement. This infrastructure consists of *Alien Rescue Core* and *Alien Rescue Extended.* AR *Core* contains the essential elements of the program and includes only components that have been validated through classroom-based research. AR *Extended* is a component of the infrastructure that allows for the implementation of program modifications or experimental features. This infrastructure intentionally supports the frequent iteration and design experimentation required to productively engage in formative evaluations, research studies, and doctoral dissertation research. It also supports the delivery of multiple versions of AR, enabling custom implementations and experimental comparisons between design variants. This platform facilitates DBR on learning environments within authentic classroom contexts, thereby strengthening the researchers' ability to test design ideas (e.g. designing various cognitive tools) and further aligning the program with the actualities of classroom use and adaptation. Project design, research, and implementation are, therefore, closely aligned. Research findings from classroom implementations are crucial in making project revisions and shaping the design process. The following is an example of how this infrastructure works.

Notebook as a cognitive tool. One of a set of cognitive tools built in *Alien Rescue* to support middle school students' problem solving is the notebook tool (Liu & Bera, 2005). It was designed to assist the middle school students in organizing, storing, and retrieving information. There is a large amount of information in *Alien Rescue,* some of which is intentionally ill structured and requires learners to constantly perform the task of eliminating irrelevant and redundant information. Thus, identifying key information, organizing related information, evaluating information, and making comparisons are essential to successfully solve the central problem presented by AR. However, such processes are often difficult for middle school students (Li & Liu, 2008). Early versions of the notebook tool were composed of a text box in which student could enter his or her notes. Classroom observations support the importance of recording and organizing information within AR given the support of a notebook tool, yet many teachers often modified the implementation by providing paper-based worksheets to provide more structure for students' note taking activities. Such observations led to a research study investigating a new design for the notebook tool (Li & Liu, 2007; 2008).

The new notebook tool design resulted in three key features. First, it included a series of data tables with rows and columns for students to enter information. Each table was pre-assigned to hold information for one of the alien species or one of the worlds in the solar system. Second, students could create various information categories/fields in the tables. Once a category was created, it became universal to all tables. For example, if a student created a category named "temperature" in the Mercury table, all other information tables would automatically have a temperature field created. Finally, the tool had a built-in query function that allowed students to make comparisons between information in any alien table and information in any planet table. A “compare” button was provided that presented students with a comparison between two or more notebook entries, allowing side-by-side comparison of multiple worlds or enabling students to view alien requirements alongside world data. This tool was designed in such a way that learners were responsible for all the planning, researching, thinking, and decision-making, while the tool supports learners’ cognitive processing and shares cognitive responsibilities such as storing information and supporting query constructions.

Research using this notebook tool showed that it supported knowledge construction by reducing extraneous cognitive load, increasing germane cognitive load, and, in general, sharing the cognitive load required for middle school students to productively record, organize, recall, and evaluate complex information (Li & Liu, 2007). The findings also showed that middle school students who had access to this tool received significantly higher transfer test scores on such cognitive skills as categorizing, differentiating, and analyzing/evaluation (Li & Liu, 2008). Given the research findings, the notebook tool within *Alien Rescue core* was redesigned to incorporate three levels of problem-solving support: Level one provides significant scaffolding while level three is open and without scaffolds. Students begin using AR with a level one notebook (see Figure 2). After students find homes for one of the alien species, the level two notebook is provided. Once they find homes for another two species, they will encounter the level three notebook. In this way, notebook scaffolding gradually fades as students gain more experience in problem solving.

Level 1	Level 2	Level 3

Figure 2. Multiple levels of the Notebook tool

This approach also allows the project team to engage teachers and students as co-designers of the learning experience that *AR* provides; findings from the field directly inform the program enhancement. As new designers and researchers join the project, they bring questions with them about instructional design and learning that are pertinent to the project. Instead of creating an entirely new product to answer their questions, the developers are able to build on the existing foundation that AR provides, to analyze the research-based decisions that have been made with regard to the design, and to branch off into experimental endeavors by adding to or changing (small or major) components (using AR *Extended*) of this collaborative product. Thus, the development model is both research-based and research-driven. Design changes to the core project are only incorporated after testing through research. Moreover, design modifications are only introduced with the intent of researching their effects on learning.

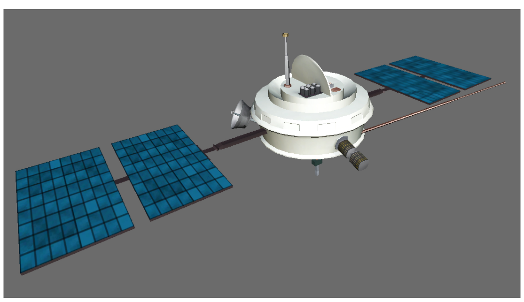
2) Iterative Program Design

Our development model is highly iterative. In many classroom implementations, middle school students often refer to *Alien Rescue* as a game; one student said: "*Alien Rescue* is educational, but at the same time interactive and fun, like a video game." The classroom observations highlighted the potential for research in which the design of *Alien Rescue* could be more aligned with students' perceptions of the environment as a game and the benefits of play in promoting motivation.

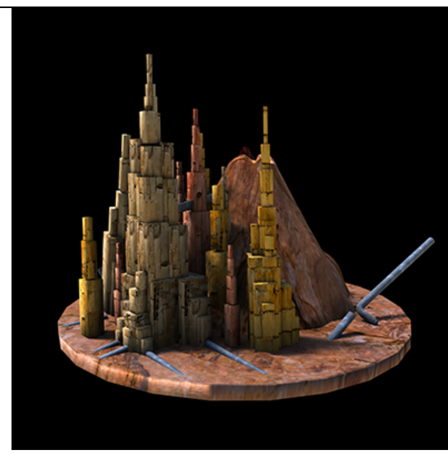
Given the feedback, we seek to balance an open-ended learning environment as guided by PBL as well as embedding game elements to make the learning fun. Through multiple iterations, we intentionally incorporate various game attributes such as challenge, control, fantasy, interaction, communication, mystery, role-play, representation, goals, sensory stimuli, adaptation, and 3D elements. We designed, tested, and improved various features using video, graphics, and interactive 3D elements and leveraged aspects of play and authenticity for the purpose of engaging and motivating students to learn science. For example, the Alien Database has been redesigned a number of times. Instead of 2D static graphics as seen in the earlier versions, the current version presents 3D models of six alien species, their physical characteristics, foods, and habitats to provide multiple representations of key content and to help establish a sense of fantasy (see Figure 3a, b, and d). The technologies we use in the program reflect the technological advancements familiar to middle school students in contemporary entertainment media such as digital games and film. The earlier 2D environment, therefore, has been transformed into an immersive 3D experience that provides a playful representation of content to align more closely with today's youth experience in playing with commercial games. Research studies have shown middle school students found the environment highly engaging and fun. For example, middle school students described AR as "freaking awesome!!!" "so unique," "soooooooo cool!!!!" and "sooooooooooooooooooooooooooo FUN!!!!!!!!!!!!!!!!" in a study by Liu et al. (2011). When asked to respond to the open-ended question: "How would you describe *Alien Rescue* to a friend?" the word "fun" has the highest frequency in a word cloud (Liu et al, 2013a). Another study also showed about 70% of the middle school students liked *Alien Rescue* as compared to other science activities (Liu, Rosenblum, Horton & Kang, 2013c).

a. Alien species

b. Alien food



c. Flyby probe



d. Alien habitat

Figure 3. 3D models created by student developers

Visiting middle school classrooms to observe how the program is used during the implementation phase has helped team members, future designers and researchers, understand how technologies can and should be used as cognitive tools to support middle school students' learning and teachers' implementation of a PBL environment. These classroom observations are often a highlight of these developers' project experience. As Jina Kang, a first-year doctoral student pointed out "It was fascinating to see the students enjoyed playing *AR* with classmates to solve the problems and they eventually built their own space science knowledge throughout *AR*." Working closely with teachers, we continuously incorporate their feedback to enhance the program. Currently, we are working on a teacher's dashboard, which will provide just-in-time data to support teachers' implementation, a tool teachers desired to have. We are also creating an ending scene for the program based upon teachers' and middle school students' comments.

3) Flexible Design Goals

McKenney and Reeves (2012) stated, "The products of educational design research are shaped by the participant experience, literature, and especially testing" (p. 15). In our model, participants not only include the target audience (i.e., middle school students and their teachers), but also the designers and developers that comprise the AR team. Harnessing graduate student developers' diverse talents and ideas is key to this development model. Graduate student developers' engagement in the project is largely driven by their interest in creating a quality technology program to enhance learning while developing technology production and research competencies. Within this iterative design process, graduate student developers play a significant role in developing and testing various design ideas and then integrating them if successful, while at the same time improving their design and development skills. *AR*'s continuous evaluation offers student developers a mechanism to receive feedback and develop strategies and approaches to help make *AR* successful in future classroom implementations. Because of this highly iterative design process, the design goals must remain flexible and allow for simultaneous design and development phases. Such an approach is noteworthy because it lessens the gap in design and technical understanding that often exists between instructional designers and developers. With this model, there is less concern that the design team is creating a vision of a tool that the development team cannot deliver. Likewise, during development, the team seeks to develop design iterations that are consistent with the learning-theory-based principles that underscore the design rationale of the program. By blurring this distinction between developer and designer, and by allowing for constant flexibility, the team can effectively use design constraints and strategies to inform development and, simultaneously, allow development constraints and strategies to inform the design.

This process has provided opportunities for graduate students to prepare for future careers as designers and developers, instructional technologists, and educational researchers. Membership on the team is highly dynamic; new members join following the departure of others or as new opportunities on the project emerge.

For example Jaejin Lee and Jason Rosenblum are both doctoral students in the current *AR* team. Jaejin is interested in investigating the effect of fantasy on learning and motivation within educational games while Jason is interested in researching the design of sound for educational games. The mechanism of *Alien Rescue Core* and *Extended* has enabled these researchers to conduct pilot and dissertation research to test their design ideas without affecting the *core* version being used widely in schools. According to Jaejin, “The participation of *AR* project gave me a chance to think about my dissertation topic and pathway to future career.” For Jason, AR has provided him with a way to explore his research interest in sound. As he points out, “Thanks to my involvement in AR, I now have a platform using AR *Extended* with which I can conduct research into participant experiences of sound in educational games.”

4) Collaboration Among Faculty and Graduate Students

The approach used in developing AR requires a higher degree of multidisciplinary expertise than might commonly be required of projects in which instructional design, technology development, and research are conceptualized as compartmentalized roles. Within the project, participants engage in collaborations that support the development of key competencies across each of the project's dimensions. All graduate students can participate in design, but are also required to apply and develop additional skills for the benefit of the project. Within the current *AR* development team, each member contributes specific skills (or talents), develops new skills as needed in order to meet the needs of the project, and provides important support to others in acquiring new skills. As a result, some team members spend much of their time developing game development and video skills while others are more interested in learning 3D modeling and web design. Some students assist the team by taking notes during team meetings and completing smaller, but essential, tasks. Others may plan agendas, support teachers in implementing the program, and lead team discussions. The faculty supervises the process and provides overall direction. More importantly, the faculty encourages and facilitates an open learning community and views it as a training ground for future technology developers and educational researchers. In so doing, this development environment becomes highly collaborative, relevant, and student-driven, because it allows students to engage in tasks that most interest them and/or that are deemed necessary for the project. Jaejin Lee reflected that his involvement with *AR* resulted in his developing "collaborative communication skills as an international student" in addition to his skills in 3D modeling. As a result, students who contribute to *AR* are able to learn essential skills in a more authentic environment than might otherwise be available to them as students. As the program evolves, team members' skills also progress and reflect current industry best practices and trends.

5) Graduate Student Peer Mentoring

In light of the highly collaborative and skill-demanding nature of this approach, peer-mentoring component is essential to success. Lucas Horton has been with the team the longest and has a significant background in a wide range of game and web development technologies. He has mentored numerous less experienced team members while continuing to develop new design, technical, and research skills and refining what he already knows by playing multiple roles such as project manager, designer, and programmer depending on the needs and direction of the project. Lucas said, "*Alien Rescue* requires an extremely varied and multidisciplinary skill set, leverages a number of sophisticated technologies, and has grown in complexity over many years of development. Opportunities for experts on the team to mentor newer team members are essential in supporting a sustainable design and development team. *AR* provides a context in which team members develop deep expertise in one or more areas over time, a community through which that expertise can be used to structure and guide the skill development of novice participants, and a framework through which knowledge is distributed among multiple team members to address large tasks."

For example, the team has adopted the *Ruby on Rails* (http://rubyonrails.org/) web development framework, an open-source technology frequently used in the creation of modern web applications. The tool was chosen for the project because it facilitates a consistent approach to developing web applications that can be shared across a development team and because it enables developers to quickly build relatively complex functionality. Web development using *Ruby on Rails* represents a substantial aspect of the project, as such, there are often more development tasks than one student can complete on his or her own. Additionally, few students from the team have sufficient experience in developing applications with this framework to be successful without help. To address this need, graduate students with more experience in web development such as Lucas are able to mentor students with less experience and coordinate work in a way that provides appropriate support for less-experienced students while allowing them to maintain productivity and make important contributions. This peer mentoring extends far beyond just programming and continues into project management, instructional design, and research as well.

It is important to recognize that this approach to mentoring is not defined by a "one expert, many students" model. Instead the embodied expert changes depending upon the context. A student, who has been involved with the project for a longer time might have sufficient experience with research and project management to peer mentor a newcomer to the project in those areas, but the newcomer might have skills in other areas in which he or she can mentor the project veteran. In this way, peer rather than subordinate relationships are established, and leadership roles become more fluid and shared. This type of environment results in opportunities for all involved to be both the mentor and the mentored.

As an example, Matthew O'Hair and Chu-Wei Lu are both masters students and joined the *AR* team shortly after they enrolled in the Learning Technologies Program. While they both had some graphic design experience using *Photoshop* and *Illustrator*, they were new to 3D modeling and the development of immersive technology environments. They were interested in using games for learning and acquiring advanced technology skills. During their time in the team, they began by supporting tasks such as creating 2D icons and graphics while learning 3D modeling, programming, and advanced video skills. They learned these skills with guidance and support from other team members, such as Lucas and Jaejin, who have more knowledge and skills in these areas. Over time, Matthew and Chu-Wei applied complex 3D modeling skills and (together with Jaejin and Lucas) produced some of the 3D models used in the current version of the program (see Figure 3). These graduate students eventually advanced in their project participation and took on a leading role in developing another scientific inquiry learning game, *Salamander Rescue*, which was designed to be a transfer task after middle school students' completion of *Alien Rescue*. They also began to mentor newcomers and share their acquired 3D and video knowledge and skills. They transitioned from initial peripheral participation to playing a more significant role in some phases of the project. Matthew stated, "I had the opportunity to work closely with talented and hard-working colleagues that I wouldn't have had the chance to work with otherwise. I see the *AR* project as a cornerstone of my graduate studies; it gave me the opportunity to work on a real-world project spanning multiple semesters whose applicability to my career and scope far exceeded any other assignments in the graduate studies."

6) Sensitivity Toward New Technologies

This highly iterative approach also requires that developers remain sensitive towards opportunities and demands made possible by new technologies during design and development. Team meetings are often used as a forum to discuss technology decisions, evaluate the performance of a chosen technology both within the development process and the classroom, consider the possible technologies that could be used to create new functionality, and track technology developments and the emergence of new innovations that are of interest to the team and may have potential application within the project.

Because *AR* leverages many technologies commonly used to develop 3D games, it has led all team members to learn and apply aspects of game design and development within the *Unity* game engine, 3D modeling applications such as *Maya, Modo*, and *Blender*, 2D graphics tools such as *Photoshop* and *Illustrator*, and web technologies such as *HTML5, CSS, JavaScript, Ruby on Rails*, and *PostgreSQL*. These technologies are chosen based on a number of considerations, including the usefulness of the technologies in delivering the desired functionality, the extent to which they represent modern, mainstream technologies that are relevant to the fields of game and interactive development and educational technology, the degree to which team members may develop competency in the technologies relatively quickly and with minimal guidance and support, the reliability and scalability of the technologies when used in a high-usage learning environment, costs associated the technologies, the interests of the development team, past performance of the technology within AR or similar learning environments, and the educational potential and career relevance of the technologies for the graduate student participants. Through this process, the team keeps pace with emerging web and game development technologies, development methodologies, and best practices. Maintaining sensitivity and agility towards new and emerging technologies has been critical in this context and mirrors the realities of the field.

An example of this process can be found in the team's selection of the 3D game engine used to develop the program. In 2008, AR was redesigned using the *Torque Game Engine,* a tool that was chosen due to its ability to deliver a game-like 3D experience while providing sufficient functionality for the creation of AR's cognitive tools. In addition, the tool compared well to similar tools available at the time, could be learned relatively quickly, and had relatively little cost. The completed version of AR was distributed via downloadable installers that installed a copy of the program on school computers. AR version 3 performed well and enabled the completion of several research studies. However, a number of issues emerged over the following two years that led the team to consider alternatives:

1. The game engine supported development of a version of the program for Windows computers, but presented obstacles in creating Mac and Linux versions. Thus, the newest version of AR was unavailable for a segment of our school user base.

2. The use of an installer made it difficult to distribute new versions of the program, implement studies with multiple conditions, or quickly address bugs or other issues with the program because the installation of a new version required intervention of school technical staff. In addition, the process of compiling and distributing installers consumed a great deal of the team's time that could otherwise have been spent on design and development tasks.
3. AR stored data locally on each computer, causing two problems. First, middle school students were required to use the same computer each day in order to access their work from previous days. Second, the retrieval of log files and other student data was a manual process that required researchers to copy files individually from each student computer.
4. The *Torque* game engine was somewhat difficult to use as a development tool and was quickly becoming obsolete in favor of more modern tools.

These findings led the team to consider alternatives before ultimately choosing the *Unity* game engine as its primary technology for the current web-based version. *Unity* was chosen because it was significantly more accessible to novice developers, facilitated the deployment of the program via the web using a browser plug-in (negating the need for installer-based distribution), provided functionality that enabled data to be transmitted to and from a central web server, and represented a new and modern technology that would enjoy greater longevity in the fields of game and interactive development. *Unity* has performed well as the development platform for AR and in recent years has become one of the most prevalent and widely used game engines.

Finally, it is important to note that the characteristics of the project also necessitate the selection of technologies on the basis of their educational potential and career relevance. Since all development team members have been graduate students who are preparing for careers as leaders in learning technologies, the innovative technologies used in *Alien Rescue* --and the approaches that guide their applications -- need to be appropriate not only as a means to an end in creating *Alien Rescue*, but also for the development of the graduate students as learners and professionals. The selection of *Ruby on Rails* is perhaps the best example of this concern. While a vast array of technologies is available for the development of web applications, *Ruby on Rails* presents an optimal mix of technological appropriateness and learnability, while being widely used and regarded as a mainstream web development technology within the industry. Technology decisions are challenging tasks for the team, as the process of selecting and implementing emerging technologies has also required the team to forecast technology trends that would likely be instrumental in designing learning environments in their future careers.

7) Student-Centered Learning

An overarching principle of this development model is that it is student-centered (Liu, Horton, Kimmons, Anderson, Lee, Rosenblum, Toprac, Li, & Sung, 2010). The characteristic of student-centeredness is reflected at multiple levels. The development of *AR* provides an excellent opportunity for graduate student designers to develop their skills as instructional designers, technology developers, and educational researchers. At the individual level, each student brings his/her talents, technical expertise, and research agenda. At the team level, all members collaborate and support each other and contribute to a coherent final product. Faculty and more advanced graduate students adopt a mentoring role and all take ownership of their learning. Although this process presents challenges at times, a requirement of each team member is to be flexible, adaptable, and to prioritize the goals of the project. Such an experience has not only enriched the students' learning but has also prepared them for their future careers.

Lucas stated, "*Alien Rescue* has been an essential component of my graduate work. It provides critical opportunities for researchers to consider the complex intersections between theory and practice while supporting designers and developers in building the knowledge necessary to deliver a sophisticated educational product." For these graduate students, participating in this project gives them an opportunity to develop both highly desired technical skills as well as apply research knowledge and skills in authentic settings. So far, this experience has helped a number of students find jobs as technology professionals. A total of six doctoral dissertations and three masters' reports have been produced as a result of working with *Alien Rescue*; another two dissertations are currently under way.

Summary and Next Steps

At present, the program is being used as part of the science curriculum by 16 middle schools in Central Texas with a diverse ethnic base. In addition, schools in at least 20 states and three countries have used and are using *Alien Rescue*. *Alien Rescue* won the *2012 Interactive Learning Award* sponsored by the multimedia division of AECT for its quality. In November 2013, this design and development model was recognized with the *Outstanding Practice Award* from the design and development division of AECT. As developers, enthusiastic feedback from teachers and students (see http://alienrescue.edb.utexas.edu/feature_videos.php) also serves as important motivation, and we feel a sense of responsibility to deliver a program that can make a positive impact on middle school students' learning.

The development of *Alien Rescue* has provided learning opportunities in an authentic setting for graduate students and serves as a training platform for future designers, educational technologists, and researchers. Our experience in developing *Alien Rescue* suggests that the successful application of DBR and research in PBL requires multiple interdisciplinary competencies and tightly integrated processes of instructional design and technology development. We view our strategy of developing and integrating these competencies within a self-sufficient team of graduate students and faculty as vital to enable effective DBR as well as the long-term sustainability and success of the project. Given our experiences, here are a few recommendations for those interested in pursuing similar endeavors:

- Decompartmentalize team approaches to building learning technologies such that individual participants can bring their expertise to bear on each phase of the project. Productive research following the DBR paradigm is challenging, but can be greatly facilitated by team members capable of contributing and integrating expertise across multiple disciplines. Multidisciplinary perspectives may also be viewed as an essential characteristic of success within our contemporary field and opportunities for students to develop broad expertise that prepares them for successful careers as educational innovators.
- Consider strategies for incorporating research functionality into the design of technology-based learning environments. Given the iterative approach to design and development as required by DBR, it is critical to design technology platforms that intentionally support processes of data collection, the delivery of experimental conditions, and the ability to make frequent, rapid design modifications. The adoption of web-based delivery and modern web technologies within the *AR* project has greatly facilitated these approaches and we continue to develop technology strategies that bolster our ability to conduct research.
- Use research priorities as a mechanism for organizing project work. Each year, the AR team selects a small set of program additions or modifications based on findings from

the previous research cycle. This approach ensures that design and development investments made by the team articulate with areas of theory that require further research, problem areas identified during classroom adoption, or design innovations that emerge from classroom observations and highlight opportunities for research.

- Apply a learning-by-doing approach to enable team members to develop key areas of expertise but also to ensure the long-term sustainability and scalability of technology projects. Developing and maintaining the AR project would be prohibitively expensive and time consuming given traditional approaches to design and development; limited access to skilled developers in particular would greatly compromise our capacity to innovate in ways that facilitate research. Our learning-by-doing approach ensures that the project has continual access to the expertise and personnel needed for it to succeed, all the while providing a venue in which students acquire important career competencies and experience.

The next steps for this research and development project will center on four primary areas: the intersection between digital games and problem-based learning, the creation and refinement of cognitive tools to support problem solving, the development of new tools and features to support teachers in implementing this PBL approach in their classrooms, and continuing to refine the existing program components to achieve an even higher quality instructional product. Through this project, we hope to further our understandings of PBL and related theories while advancing approaches and techniques for designing effective student-centered learning environments.

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