

**Examining the Design of Media Rich Cognitive Tools as Scaffolds  
in a Multimedia Problem-Based Learning Environment**

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Learner acquisition of problem-solving skills is an important education goal, especially as those skills relate to complex problems. Solving complex problems, however, proves to be especially challenging for young learners. Problem-based learning (PBL) is an effective instructional approach that promotes the development of problem-solving skills. When complex, student-centered learning environments such as PBL are implemented, the inclusion of embedded scaffolds can boost motivation and facilitate learning. Technology-based scaffolds within these environments are often called cognitive tools: instruments that can enhance the cognitive powers of learners during their thinking, problem solving, and learning.

This paper examines the various cognitive tools embedded in a multimedia enriched PBL environment for middle school science known as Alien Rescue and shares the research findings of the use of these cognitive tools in assisting young learners' problem solving. The goal of this paper is to illustrate strategies for designing media rich cognitive tools to support learning.

### **Research Framework**

Our research is based on a theoretical framework that draws upon literature on the use of technology as cognitive tools (e.g. Jonassen & Reeves, 1996; Iiyoshi, Hannifin, & Wang, 2005; Kim, & Reeves, 2007; Lajoie, 1993, 2000; Pea, 1985; Salomon, Perkins, & Globerson, 1991). The overall emphasis is to design effective cognitive tools to assist students' problem solving in student-centered learning environments. The context of the research reported here is Alien Rescue.

Alien Rescue is a technology-enriched problem-based-learning (PBL) program (Liu, Williams, & Pedersen, 2002). Alien Rescue's goal is to engage sixth-grade students in solving a complex problem that requires them to gain specific knowledge about our solar system and the tools and procedures scientists use to study it.

Problem-based learning is an instructional approach that exemplifies authentic learning and emphasizes solving problems in richly contextualized settings. PBL emphasizes the importance of active, self-directed learning from the learners and of everyday relevance of the problems under investigation (Schmidt, 1995). The aspect of anchoring learning in real world contexts in PBL has been found to provide opportunities for transferring knowledge and skills from the classroom to authentic settings more easily (Stepien, Gallagher, & Workman, 1993). PBL has been shown to result in better long-term content retention than lecture-based instruction, and supports the development of problem-solving skills (Hmelo & Ferrari, 1997; Norman & Schmidt, 1992).

The benefits of PBL, however, are accompanied by specific implementation challenges (Hoffman & Richie, 1997). Namely, complex student-centered learning environments, such as PBL, need scaffolds embedded within them to facilitate learning (Pellegrino, 2004). Technological tools often are designed to serve as these scaffolds, and when they are used in such learning environments, they are often referred to as cognitive tools. According to Jonassen (1996), cognitive tools are, “Computer-based tools and learning environments that have been adapted or developed to function as intellectual partners with the learner in order to engage and facilitate critical thinking and higher order learning” (p. 9). Cognitive tools are instruments that can enhance the cognitive powers of learners during their thinking, problem solving, and learning processes (Jonassen & Reeves, 1996; Pea, 1985; Salomon, Perkins, & Globerson, 1991). As such, cognitive tools should be of particular use in supporting students' accomplishment of complex cognitive tasks (Kozma, 1987).

Multimedia technology can enhance the PBL delivery through its video, audio, graphics, and animation capabilities as well as its interactive affordances to allow students to access

information according to their own learning needs and present multiple related problems in one cohesive environment (Hoffman & Richie, 1997). Multimedia-enhanced PBL environments provide a new and different means that can assist students to develop problem-solving skills, to reflect on their own learning, and to develop a deep understanding of the content domain (Cognition and Technology Group at Vanderbilt, 1997). In Alien Rescue, various media was used to enrich the designs of cognitive tools in creating an immersive multimedia environment and to scaffold conceptual understanding and complex problem solving of young learners.

### **Designing Media Rich Cognitive Tools**

#### **Alien Rescue Environment**

Alien Rescue begins with a video presentation that explains a group of six alien species, each with different characteristics, have traveled to Earth because their solar system has been destroyed. Students take on the role of scientists who are tasked with the mission of finding new homes that can support these aliens, thereby ensuring their survival. To accomplish this goal, students engage in a variety of problem-solving activities; these activities include researching the aliens' requirements for life and analyzing species specific factors, such as habitable temperature ranges, and the basic atmospheric composition needed for survival. To identify a suitable home for the aliens, students must discover critical scientific characteristics of the planets and moons in our solar system by querying provided databases and collecting direct observations using simulated probes.

Students must also engage in planning and decision-making as they determine how to use the provided resources efficiently and then recommend an appropriate choice for relocating each alien species, supporting each choice with a justification. Critical aspects of the program design include an intentional lack of definitive outcomes and a range of locations with suitable

characteristics for placing each of the six alien species. The program is designed according to the National Science Standards and the Texas Essential Knowledge and Skills (TEKS) for science and as a science curriculum unit for approximately fifteen 45-minute class sessions. More information about Alien Rescue can be found at <http://alienrescue.edb.utexas.edu>.

### **Media Rich Cognitive Tools**

To support middle school students in solving the complex problem, Alien Rescue includes a set of fourteen cognitive tools (See Table 1). These cognitive tools are multimedia based, interactive, and found to be highly engaging for students (Liu, Toprac, & Yuen, 2009). By using Lajoie's (1993) four conceptual categories, we describe the tools in terms of their primary function: Tools (a) share cognitive load, (b) support cognitive processes, (c) support cognitive activities that would otherwise be out of reach, and (d) support hypothesis generation and testing.

First, in order to *share cognitive load*, the four databases (*i.e.*, Alien Database, Solar System Database, Mission Database, and Concept Database) provide access to highly-organized information stores that contain textual, visual, and animated media. These databases are essential to students, providing important information for use during the problem-solving process. Additionally, these tools can help learners manage their cognitive load by reducing memory burdens and by providing structured ways of storing, accessing, and understanding information. As an example, a student wishing to obtain information on the Akona alien species could access the Alien Database and receive data on the alien's appearance, habitat, diet, and behavior. Audio narration accompanies the text in both Alien and Solar Databases. Students can select to listen the audio narration if they want. PBL environments typically involve a lot of reading. Audio narration is provided with the intention of helping slow readers or ESL students in particular.

Second, the Notebook and Notebook Comparison tools are examples of tools that *support cognitive processes*. The key characteristic of these tools is that they serve to augment the learners' existing problem-solving capabilities. To illustrate, the Notebook tool assists the learner in organizing, storing, and retrieving information that can be used throughout the problem-solving processes. The Notebook Comparison tool allows students to compare information contained in multiple notebook entries and assists students in identifying forms of critical information needed to solve the problem.

Third, despite the data-richness of the database tools, the information they contain is not sufficient for the learners to completely justify a solution through their use alone. Probe Design and Probe Launch centers are provided to *support cognitive activities that would be out of reach otherwise*. These tools support a very specific purpose within Alien Rescue by allowing the collection of additional data that are unavailable anywhere else within the program. Using the Probe Design and Probe Launch centers, learners are able to equip exploratory space probes with numerous measurement instruments, such as thermometers, seismographs, and cameras, and then direct those probes to collect data on specific worlds of interest.

The Mission Status Center, Solution Form, and Message tools represent a fourth type of tool that *allows hypothesis testing*. The Mission Status Center provides an interface for the learners to observe data that the probes have captured, and the Solution Form provides a space for the learners to generate and submit their completed solutions. The Message tool serves as a repository of text messages sent to the student during problem solving.

Table 1. *Descriptions of Fourteen Cognitive Tools Provided in Alien Rescue*

Tool Categories	Tool Functions
Tools sharing cognitive overload	

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Alien Database	Provides information on the aliens' home worlds, their story, and their characteristics and habitat requirements.
Solar System Database	Provides limited information on the characteristics of selected worlds within the solar system.
Missions Database	Provides information on selected NASA missions.
Concepts Database	Provides instructional modules on various scientific concepts.
Spectrograph	Allows students to interpret spectrogram images found in the Alien Database.
Periodic Table	Allows students to look up information on the elements.
Spanish/English Glossary	Provides Spanish translations of selected English words found within the program.
Tools supporting cognitive process	
Notebook	Allows students to generate and store notes on their research findings.
Notebook Comparison Tool	Supports students in comparing information contained in multiple notebook entries.
Tools supporting otherwise out-of-reach activities	
Probe Design Center	Provides information on real scientific equipment used in both past and future probe missions. Students construct probes by deciding probe type, communication, power source, and instruments.
Launch Center	Provides an interface for launching probes. Students review the probes built in Probe Design, and decide which probe(s) to actually launch considering the budget.
Tools supporting hypothesis testing	
Mission Status Center	Allows students to view data retrieved by probes. Students must interpret this data in order to turn it into information that they can use in developing the solution. Malfunctions are possible, and poor planning can result in mission failure and wasted budgetary

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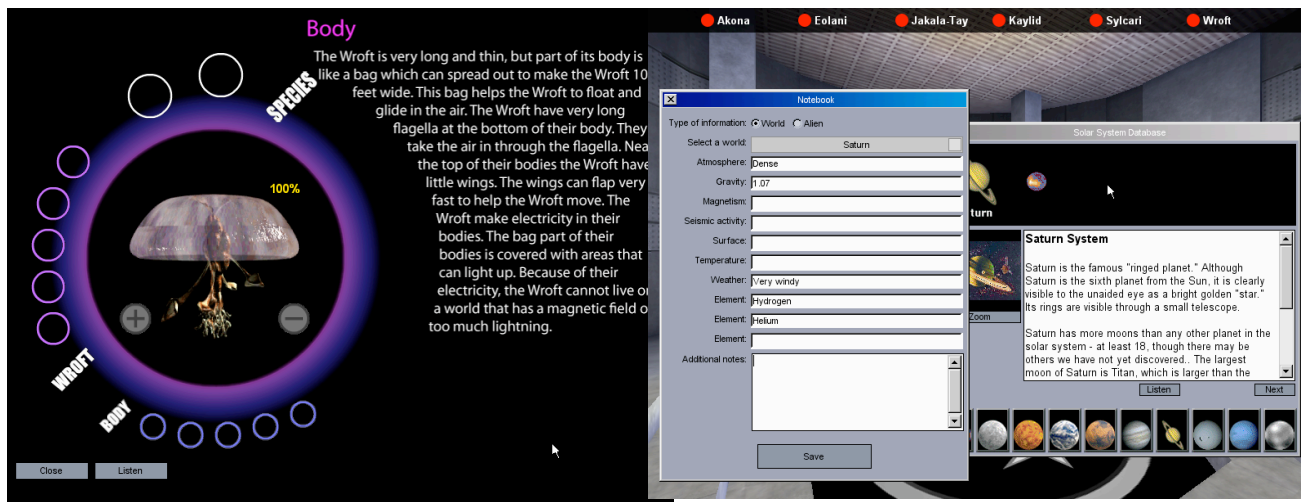
	expenditures.
Message Tool	Serves as a repository of text messages sent to the student during problem solving.
Solution Form	Allows students to submit solutions and rationales for the problem that can be reviewed and critiqued by the teacher

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Cognitive tools can guide conceptualization and interpretation of a problem through the use of internal and external representations to express relationships among concepts and attributes (Zhang & Norman, 1994). Cognitive tools, such as the Alien Database and the Solar System Database use multimedia to provide forms of external representations. Other tools such as the Notebook and Solution Forms provide ways in which the students can develop and articulate internal representations of the problem itself, and their interpretations and understandings of the information presented within the program. The design of these tools integrates certain principles from Mayer's Cognitive Theory of Multimedia Learning (2009). Many of the tools are multi-modal and provide representations of content through the use of text, images, animation, video, and sound. Information within the program is segmented in ways that promote student comprehension and facilitate knowledge building, while, at the same time, further problematizing the learning task. For example, the Solar System Database provides structured multimedia content on the planets and moons of the solar system, but is intentionally incomplete. While the tool encourages students to hypothesize on potential solutions, a good solution can only be found by supplementing the information found within the Solar System Database through the use of other cognitive tools. That is, each of the fourteen tools has its unique function. Together they provide necessary scaffolding to support students' problem solving. In all, the design of these cognitive tools can allow the elements of a problem to



productively interact with one another and, hence, facilitate learners' processing of the problem (Sweller & Chandler, 1994). Although these tools are provided and available at any time, the decision on which tool to use at what point of the problem-solving process is entirely up to the students. Figure 1 provides screenshots of a few tools.



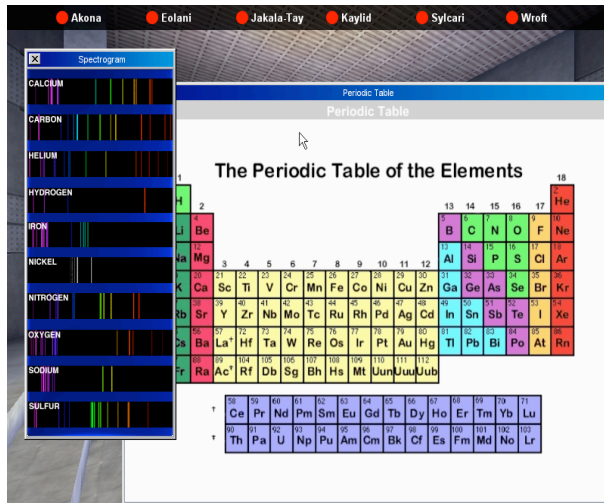
(a) Viewing a specific alien in the Alien Database

(b) Taking notes while researching in Solar System Database



(c) Designing a probe in the Probe Design Room

(d) Viewing results of a probe mission in the Mission Status Center



(e) Using the Periodic Table & Spectrograph to interpret database information



(f) Navigating the 3D environment, in Communication Center

Figure 1. Screen Shots Showing Some Cognitive Tools Provided In Alien Rescue.

## Research on Use of Cognitive Tools

### Use of Cognitive Tools In Facilitating Students' Problem Solving

We are interested in finding out how these cognitive tools can provide scaffolding and provide some empirical evidence to support the theoretical notion that technology-based cognitive tools play an important role in assisting students' problem-solving (Jonassen & Reeves, 1996). We conducted a series of studies -- each building on the previous -- and the research context consisted of the same problem-solving environment, Alien Rescue, in each study.

#### Study 1

In this study ( $N=110$ ), we used sixth-graders' log data to examine their tool use patterns while navigating the PBL environment to see *which tools were used and at what stages of their problem-solving process* (Liu & Bera, 2005). All student actions performed while using the program were logged to a data file. The log file consisted of time and date stamped entries for each student. The data set consisted of the number of times a student accessed each of the

cognitive tools and the amount of time the student stayed in each tool. Descriptive statistics and cluster analyses were performed on the log data.

The results showed that tools supporting cognitive processing and tools sharing cognitive load played a more central role early in the problem-solving process whereas tools supporting cognitive activities that would be out of students' reach otherwise and tools supporting hypothesis generation and testing were used more in the later stages of problem-solving. The findings also indicated that the students increasingly used multiple tools in the later stages of the problem-solving process. The various tools, in performing different functions, appeared to enable students to coordinate multiple cognitive skills in a seamless way and, therefore, facilitated their information processing. Results also suggested that students with higher performance scores seemed to exercise more productive use of the tools than students with lower performance scores.

## ***Study 2***

In Study 2 ( $N=164$ ), we examined *patterns of cognitive tool use among collaborative groups of sixth graders to determine the ways in which group tool use patterns may affect students' individual performance and their experience of the problem-solving process* (Bera & Liu, 2006).

Cluster analysis of log data was used to identify the types of tool-use groups. The results revealed that cognitive tools interacted with group members to create different types of tool-using groups, and that students with similar characteristics (i.e. students with a low level of need for cognition) functioned differently depending on the type of work group with which they were associated. The findings of this study offered some empirical evidence to show that cognitive tools, individual differences, and group processing can interact for sixth graders during their

problem solving. Group tool use patterns seemed to support a more contextual approach to individual cognition and learning.

### ***Study 3***

Although the log data provided an objective and unobtrusive way to examine students' actual use of tools, we can only infer about the thinking processes students engaged in while selecting the tools. In this study ( $N=161$ ), we further investigated *the connection between sixth-graders' tool use and their cognitive processes* by using self-reported data from a questionnaire asking sixth-graders to report the cognitive tool(s) used for each of their problem-solving steps (Liu, Bera, Corliss, Svinicki, & Beth, 2004).

Using Chi-Square analyses and MANOVA, we found that different cognitive tools were used for different cognitive processes and that students' degree of engagement in cognitive processing was positively related to the frequency of tool use. These results indicated that there was a connection between cognitive tool use and cognitive processing. In addition, tool use patterns reflected different learner characteristics. Students, who were more metacognitively or information processing oriented, exhibited different characteristics in the consistency and activeness of their tool use. However, there was no difference in the diversity of tool use or the performance scores between the two groups of students. The findings from this study also confirmed the tool use patterns revealed by the log data in the first and second studies.

### ***Study 4***

As a follow-up step in our investigation (Liu, Horton, Corliss, Svinicki, Bogard, Kim, & Chang, 2009), we matched log data with self-reported surveys for a more explicit investigation of students' thinking processes as reflected by their tool use. We also added stimulated recall as a way to elicit information on students' cognitive processes at specific points in the problem-

solving process. Our goal was to further examine *the cognitive tool use patterns using multiple data sources and to investigate whether students with high and low performance scores used cognitive tools similarly.*

This study (N=61) was conducted in a more “laboratory” setting with undergraduate students using the same problem-solving environment as in previous studies with sixth-graders. We believed college students, as compared to sixth-graders, would be able to articulate their thinking more easily and clearly. Three data sources were used: (1) log files to find out the overall tool use patterns, as in Studies 1 and 2; (2) a self-reported survey to understand which cognitive tools were used for which cognitive processes (as in Study 3), and (3) stimulated recall interviews for insight into why students used a particular tool at a particular time.

With multiple data sources, both objective and subjective, the results of this study with college students confirmed the findings from previous two studies with sixth graders (Liu & Bera, 2005; Liu, Bera, Corliss, Svinicki, & Beth, 2004). The descriptive analysis, based on the log data, provided a visual representation of tool use patterns, indicating certain categories of tools were more dominant in use during different stages of problem solving (e. g. tools sharing cognitive load and supporting cognitive processes were more heavily used earlier), and there were indications that students simultaneously used multiple tools while engaged in integrating and evaluating information. Results from the Chi Square analyses based upon the self-reported data showed strong connections between cognitive processes and cognitive tool use. Moreover, the stimulated recall data confirmed the findings from these two analyses and showed deliberate and careful use of tools by the students.

The MANOVA revealed no overall significant differences in the diversity, consistency, and activeness of tool use by the three performance groups (low, intermediate, and high). This

finding suggested that different types of tools were needed and used by the college students in this study, as they were by sixth-graders in the previous research (Liu & Bera, 2005; Liu et al., 2004), but did not provide evidence that students with higher performance reported using the tools more consistently or actively than the other groups as in a previous study.

### ***Study 5***

Currently, we are examining tool use patterns of 15 advanced learners (graduate students majoring in science, learning and cognition, and instructional technology) and investigate how they use the tools to assist their problem-solving using stimulated recall interviews and log files as data sources. The goal is to gain further insights on how experienced learners use the tools and how cognitive tools can be designed to assist novice learners (i.e. sixth-graders) to problem solve.

### **Students' And Teachers' Motivation In Using The Cognitive Tools**

Because motivation is often considered to be a necessary antecedent for learning (Gottfried, 1985; Lepper, Corpus, & Iyengar, 2005), we have also conducted two studies examining students' and teachers' motivation in using the student-centered learning environment. Fifty-seven sixth-graders were interviewed to find out in what ways students consider Alien Rescue motivating to learn science (Liu, Toprac, & Yuen, 2009). Analysis of the interviews using the constant comparative method showed that students were intrinsically motivated and that there were eleven key elements of Alien Rescue that helped evoke students' motivation: authenticity, challenge, cognitive engagement, competence, choice, fantasy, identity, interactivity, novelty, sensory engagement, and social relations. These elements reflect the five sources of intrinsic motivation: problem solving, playing, socializing, information processing, and voluntary acting, with problem solving and playing contributing the highest level of intrinsic

motivation. Analyses showed that the use of media rich cognitive tools with the immersive multimedia environment contributed to ten of the eleven elements that correspond to the five sources of intrinsic motivation.

The analyses showed the following features that make the learning environment more compelling and engaging for these sixth-graders. They are 1) situating the central problem within a science fiction premise, 2) using video by newscasts to announce the arrival of the aliens, 3) placing students in the role of a scientist, 4) providing a 3D environment for students to explore, and 5) providing numerous databases of information enriched with videos, graphics, 3D images, and animation.

Students in the study repeatedly described their experience of using Alien Rescue as fun, interesting, and enjoyable. The two strongest sources of intrinsic motivation are their participation in problem solving and playing. The students expressed pleasure in engaging cognitive challenges while problem solving and the environment afforded these middle school students the feeling of playing while problem solving. The cognitive tools played an important part of enhancing intrinsic motivation as students relied on them in solving the complex problem. This includes providing tools that students consider are authentic and used in the “adult world” such as the Notebook, Probe Design and Probe Launch Centers, and informational databases about NASA missions, and our solar system. These tools are interactive, supporting fantasy and sensory engagement. The cognitive tools provide students both cognitive scaffolding in assisting them to solve a complex problem, and also motivational scaffolding in making them feel less overwhelmed or helpless.

Liu, Wivagg, Geurtz, Lee, and Chang (2010) conducted in-depth interviews and classroom observations with a group of eleven teachers, who have used Alien Rescue for a

number of years, to examine teachers' motivation and implementation techniques in using Alien Rescue as a PBL environment. Findings showed that teachers used both "soft" and "hard" scaffolding to support their students' problem solving. According to Saye and Brush(2002), "soft" scaffolds are dynamic and just-in-time guidance teachers provide as they "continuously diagnose the understandings of learners" (p. 82) and "hard" scaffolds refer to "static supports that can be anticipated and planned in advance based on typical student difficulties with a task" (p. 81). The "hard" scaffolding embedded within Alien Rescue in the form of cognitive tools is an important contributor to teachers' motivation in adopting Alien Rescue as a part of their curriculum. The teachers pointed out the media rich environment (with characteristics such as use of multimedia, students as scientists, authentic learning, and game-like) helped them address students with different learning needs and provided teaching tools their students find enjoyable and challenging. More importantly, because these cognitive tools provide scaffolds to students, teachers can make best use of their time during their teaching to help individual students who are most in need.

### **What We have Learned And Future Research**

The findings of the series of studies on tool use patterns suggested that the built-in cognitive tools in Alien Rescue assisted the students' understanding of the problem and facilitated their strategic problem solving. The tools appeared to activate problem-solving processes the students may not have otherwise performed without having quick access to the cognitive tools. Apparently, embedding a diverse range of cognitive tools in the problem space helped the young learners conceptualize the problem and conceive a solution process. Using the tools in various categories over the entire problem-solving process, students are provided an opportunity to apply higher-level thinking skills. Together, the results from this line of research



provide some empirical evidence that multimedia-based cognitive tools play an important role in assisting sixth graders' problem solving, and facilitated the internal and external representations of a complex problem.

Preliminary findings suggested that there was some connection between more effective and strategic use of tools and better performance (in Study 1). The findings in Studies 2 and 3 suggested that students with different characteristics appeared to have used tools differently, indicating that other factors may influence tool use. Yet, the inconclusive finding from Study 4 calls for further studies examining the relationship between tool use and performance, and on strategies to support learners' productive use of tools in their problem-solving process.

Literature has indicated both "soft and "hard" scaffolds are necessary in supporting students' learning (Ertmer & Simons, 2006; Saye & Brush, 2002). The cognitive tools as "hard" scaffolds in this case contributed significantly to students' and teachers' motivation in using Alien Rescue. Intrinsic motivation is shown to be highly correlated with the academic success of students, and is thought to be the antecedent to learning. Thus, designers of multimedia learning environments need to consider incorporating elements that promote the sources of intrinsic motivation such as problem solving, playing, information processing, voluntary acting, and socializing.

Given what we have learned so far in this process, we are continuing our research and development in several ways with the ultimate goal of designing effective media rich cognitive tools to support learning. Current design and development work surrounding Alien Rescue emphasizes the development of a research platform for future inquiry on the design and implementation of cognitive tools, issues of student motivation, and strategies for classroom implementation. A new version of Alien Rescue is in the works. Guided by the emerging

paradigm of design-based research, this new iteration of Alien Rescue will provide a modular architecture that enables frequent revisions, the ability to integrate experimental features, and an adaptable design that enables research from a variety of perspectives. A key feature is the use of real-time 3D to create an even more immersive environment that augment the authenticity and contextualization of the problem solving tasks with new technology tools. The 3D environment has the potential to impact student motivation and is an important element in potential lines of research that investigate the intersection of digital game-based learning and problem-based learning.

Ongoing research into the design of cognitive tools will utilize the new design of the program to implement new cognitive tool designs, modify existing designs, and manipulate the ways in which cognitive tools are presented within the environment. For example, since the articulation of well-reasoned solution rationales is of key importance to the students' problem solving process, one area of research might investigate ways to enhance the solution form tool with various forms of scaffolding. Audio is an important element in multimedia and yet, is often overlooked. Audio can provide signal to cue students to certain important aspects of the environment that students miss. Understanding how audio can serve as a scaffolding tool by incorporating layers of audio effects, music, and background sound into Alien Rescue represents a new research dimension for the project.

Our overall goal is to improve learner acquisition of problem-solving skills to solve complex problems. We will continue to develop and research Alien Rescue, using an iterative design-based research approach, to learn more about how to design better tools to promote motivation and learning. Our future research trajectories include enhancing cognitive tools, implementing communication and collaboration features, and integrating digital game-based

learning techniques. In these ways, we hope to not only improve student learning and motivation to learn science, but also to inform multimedia design and PBL theories.

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