Lessons Learned about Designing Augmented Realities

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ABSTRACT

While utilizing GPS-enabled handheld computing units, we have developed and studied augmented reality (AR) curricula to help middle school students learn literacy and math. In AR, students move around an outdoor physical environment, interacting with virtual characters and artifacts on their handheld computer. These invisible objects and characters provide clues to help solve a mystery, guiding the students through a process of inquiry and evidence building. The first AR curriculum we developed, Alien Contact! is based on a scenario where aliens have crash landed near the students’ middle school. Students, working in teams, learn math and literacy skills in the course of determining why the aliens have come to earth. This study describes the design heuristics used during the initial development and deployment of Alien Contact!, the results of two formative evaluations of this curriculum, and the impact these findings have had on revising our design heuristics for a subsequent AR curriculum about beached whales, called Gray Anatomy.

Keywords: augmented reality; curriculum design; educational technology; GPS; global positioning system; handheld computers; instructional technology

INTRODUCTION

Researchers are starting to study how AR modalities for learning aid students’ engagement and understanding (Dunleavy, Dede, & Mitchell, in press; Klopfer & Squire, 2008; Klopfer, Yoon, & Perry, 2005; Klopfer, Yoon, & Rivas, 2004). This article explores the background of AR, describes the Handheld Augmented Reality Project (HARP) at Harvard University, explains the results from formative evaluations of the first AR curriculum created through HARP, and delineates how the lessons learned from this evaluation impacted the development of a subsequent AR curriculum.

THEORETICAL FRAMEWORK

The theory that learning occurs most effectively in authentic setting is not new. Hendricks (2001)
stated that complex social interactions are at the heart of learning. Brown, Collins, and Duguid (1989) more precisely defined this thinking through their belief that individuals’ interactions with their social teams lead to their adoption of learned behaviors. This phenomenon, which Hendricks called situated cognition, is different from practices in traditional educational settings. There is ample research to substantiate that social interactions are important for accomplishing challenging learning tasks. Bandura (1977), Vygotsky (1978), and Scaife and Bruner (1975) found that observation of and assistance from others at times precedes and always interacts with human cognitive development. Bandura (p. 12) highlights the importance of “symbolic, vicarious, and self-regulatory” processes in social learning. As compared to a psychological view where learning is a matter of an individual “performing responses and experiencing their effects.” Bandura elaborates on his theory that learning is a social process, explaining that we learn everything vicariously before we learn it directly because it is the only way we can “acquire large, integrated patterns of behavior without having to form them tediously by trial and error. The harder the task to be learned, the more we must learn it through observation first.

Hendricks (2001) found evidence to support the idea that practices based on situated cognitive theory can have significant impacts on immediate learning. Klopfer et al. (2004) focused on the use of technology to facilitate situated learning environments—particularly through the use of handheld and wearable computing devices. Through the use of participatory simulations they found that students were more motivated, engaged, and excited by the process of participatory learning than they are by more traditional means of learning.

There are different types of motivation, and they have different impacts on learning and sustaining learning (Ryan & Deci). Extrinsic motivation ranges from, at one end, a sense that our behavior is controlled by others who do things to regulate our behavior, to the other end, where we have a sense that we are in control of our own actions and get support from outside actors but little direct regulation of our behavior (Ryan & Deci). Most of the incentives to succeed academically in postsecondary education are designed to stimulate various forms of extrinsic motivation. For example, in a competitive classroom, some students’ suboptimal performance, made explicit through student rankings and bell curves, serve as extrinsic motivators for other students to achieve.

There is strong evidence that cooperative learning is better for stimulating intrinsic motivation than competitive learning (Gehlbach, 2007). Classrooms that focus on cooperative learning make students responsible for one another’s outcomes (Gehlbach). Social learning approaches may be more likely to foster intrinsic motivation, the form of motivation most likely to positively influence persistence, because it is the most self-directed form of behavior regulation and taps into our innate desire and capacity to seek out challenge and explore (Ryan & Deci, 2000). Later research by Klopfer et al. (2005) substantiated these earlier findings as to the impacts of simulations. More recently, Rosenbaum, Klopfer, and Perry (2007) placed their participatory simulations within the context of augmented reality.

**AUGMENTED REALITY**

Squire and Jan (2007) define augmented reality as “games played in the real world with the support of digital devices (PDAs, cellphones) that create a fictional layer on top of the real world context” (p. 6). Squire and Jan focus on place-dependent AR games, which require participants to come to specific locations to work through the game. Alternatively, place-independent AR
games are designed to overlay game elements on a map of any physical location.

In AR environments, students interact with virtual and physical objects, people, and environments. Unique capabilities of AR include the amplification of real world environments, the ability of team members to talk face-to-face while interacting simultaneously in the virtual environment, and the capacity to promote kinesthetic learning through physical movement through sensory spatial contexts. In the form of AR that we studied, students utilize GPS-enabled wireless devices that allow them to engage with virtual information superimposed on the physical world. For example, a student may be guided by a map of Washington DC on their handheld to walk to the Lincoln Memorial. When they arrive, an image may appear of the memorial itself containing architectural specifications, or a movie may become accessible that talks about famous events in history that have occurred at this location, or they will be asked to perform a particular task. By infusing digital resources throughout the real world, augmenting students’ experiences, improving their recognition of patterns, critical features, background information, and reinforcing what they are learning through multiple sensory experiences (i.e., hearing about the memorial from an expert, seeing it with their own eyes, and even possibly touching a feature of the memorial itself while seeing that feature explained up close on their handheld device). Unique capabilities of AR include the amplification of real world environments, the ability of team members to talk face-to-face while interacting simultaneously in the virtual environment, and the capacity to promote kinesthetic learning through physical movement through sensory spatial contexts.

In addition, the current software developed to facilitate the delivery of AR curricula allows authentic team interactions and collaboration. This is due to the fact that the technology provides individuals within a team of students the ability to take on different roles within the augmented reality environment, thus allowing each individual to interact with the virtual elements in different ways than their teammates. While students may arrive at the same physical location as their group, a different artifact, interview, or task will appear on their handheld device than on their teammates who holds a different role. This is more authentic as a collaborative tool due to the fact that individual students within a team must collaborate and share information in order to progress through the game. The frequently seen suboptimal practice that team work is turned over to an individual student within the team to complete is not possible with this pedagogical approach; each individual must participate for the team to be successful.

**THE HANDHELD AUGMENTED REALITY PROJECT**

HARP is part of a three-year federal grant through the U.S. Department of Education Star Schools Initiative. HARP is a collaborative effort between Harvard University, the University of Wisconsin, and the Massachusetts Institute of Technology to study the efficacy of AR technology and curricula for the instruction of math and language arts at the middle-school level.

This project has as its primary objective to design and study engaging and effective augmented reality learning environments using wireless handheld computers equipped with GPS receivers. In order to do this, HARP personnel have developed an AR curriculum called **Alien Contact!** and a subsequent curriculum called **Gray Anatomy** that incorporates many of the lessons learned from formative evaluations of the earlier curriculum.

**ALIEN CONTACT! CURRICULUM**

We designed **Alien Contact!** to teach math and literacy skills to middle and high school students (Dunleavy et al., in press). This narrative-driven, inquiry-based AR simulation is played on a Dell Axim X51 handheld computer and uses
GPS technology to correlate the students’ real world location to their virtual location in the simulation’s digital world (Figure 1).

As the students move around a physical location, such as their school playground or sports fields (Figure 2), a map on their handheld displays digital objects and virtual people who exist in an AR world superimposed on real space (Figure 3). When students come within approximately 30 feet of these digital artifacts, the AR and GPS software triggers video, audio, and text files, which provide narrative, navigation, and collaboration cues as well as academic challenges.

In *Alien Contact!* the students are presented with the following scenario: Aliens have landed on Earth and seem to be preparing for a number of actions, including peaceful contact, invasion, plundering, or simply returning to their home planet, among other possibilities. Working in teams (four pupils per team), the students must explore the augmented reality world, interviewing virtual characters, collecting digital items, and solving mathematics and literacy puzzles to determine why the aliens have landed. Each team has four roles: chemist, cryptologist, computer hacker, and FBI agent. Depending upon his or her role, each student will see different pieces of evidence. In order to successfully navigate the augmented reality environment and solve various puzzles, the students must share information and collaborate with the other

![Figure 1. Dell Axim & GPS receiver](image1)

![Figure 2. Students exploring school grounds](image2)

![Figure 3. Handheld display of digital objects on school grounds](image3)
members of their team. As students collect this data, they will discover different possibilities for why the aliens may have landed. It is up to the students to form hypotheses based upon the data collected. At the end of the unit, the students orally present their findings as a team to the class and support their hypothesis with data collected in the field (Figure 4).

In order to keep the game space uncluttered, only the current and next interactions are shown on the map at any one time. This reduces confusion pertaining to the order of the game, and clarifies where the students should progress to next. This is done through a triggering mechanism built into the game development editor. Each character or object with which the students interact activates the next character or object to appear in the progression and deactivates the previous character or object.

In its full form, Alien Contact! is a six-day, multidisciplinary curriculum that includes two days dedicated to playing the game, and four days interspersed to introduce concepts, allow for analysis and synthesis of data gathered during the game days, and enable students to develop and present their hypothesis for why the aliens have come to Earth. This curriculum is based on Massachusetts state standards and fosters multiple higher-order thinking skills. In designing this unit, HARP personnel targeted concepts in math and literacy typically difficult for middle school students to master. Using the spring 2005 8th grade MCAS test as a reference to determine high-need areas, project personnel focused primarily on aspects of ratio, proportion, and indirect measurement (Math Standard 6.M.3, 8.M.4, 8.N.3) in combination with how English vocabulary has been influenced by Latin and Greek languages (ELA Standard 4.18, 4.21, 4.24). However, other Math and ELA standards are embedded within the unit, such as reading graphs (Math 6.P.6, 8.D.2) and conducting team discussions and presentations (ELA 2.4, 3.8, 3.9, 3.11, 3.13).

This game also aligns with other standards. The Partnership for 21st Century Skills, a state-level, public-private partnership geared at making U.S. public education relevant in the 21st century, has recognized education’s role in building social capital through education and how challenging this will be. The Partnership for 21st Century Skills believes key skills students need include: global awareness and civic literacy; communication and contextual learning;

Figure 4. Students presenting their hypothesis
and leadership, ethics, and social responsibility (Hardy, 2007). The Organization for Economic Cooperation and Development (OECD) has included new measures in its Programme for International Student Assessment (PISA), a 42 country comparative study conducted every three years on the skills that 15-year-olds are developing in school. In 2003, PISA added a problem-solving section to its international assessment designed to assess cross-disciplinary, problem-solving skills. In future iterations of the problem-solving skills section, PISA plans to include an assessment of collaborative problem solving skills (OECD, 2008).

In addition, the game content and structure are designed to allow for multiple entry points on which teachers may build in future iterations (Dunleavy et al., in press). The design allows teachers the flexibility to emphasize: (1) different academic standards; (2) different content areas (math, ELA, science, social studies/history); and (3) different current events (energy crisis, oil shortage, global nuclear threat, cultural differences).

This design rationale is three-fold: (1) build in multiple entry points for teachers; (2) build in mathematical and linguistic patterns that, when recognized, reveal the ubiquity and mystery of mathematics and language; and (3) build in multiple layers of complexity that will engage and challenge students regardless of ability and will provide teachers opportunities for differentiation. As students engage in the mathematics and literacy of the content, the curriculum attempts to capitalize on some of the inherent properties of these fields that are fascinating (e.g., mapping latitude and longitude, ancient languages, and cultures) regardless of the standards that are targeted.

AR in general and Alien Contact! specifically incorporates several elements from popular video games that increase learning and engagement: (1) narrative and setting; (2) differentiated role playing; (3) master goal divided into subtasks; (4) interactivity; (5) choice; and (6) collaboration. In Alien Contact! the narrative and setting is the unfolding saga of the aliens’ interactions with Earth. To infuse this situation with challenge and invite curiosity, each student’s differentiated role is presented with an alternate, incomplete view of the game space. For example, when presented with a piece of alien spacecraft debris, each team member is given a different dimension of the wreckage to measure or a unique clue as to how to measure it. If the students do not collaborate, they will not be able to solve the problem and advance to the next stage of the game (Figure 5).

The master goal of the curriculum unit is to discover why the aliens have landed. However, in order to collect sufficient evidence to form a hypothesis, the students must successfully complete multiple subtasks requiring math and literacy skills. Throughout the scenario, the

Figure 5. Students collaborating to measure a physical object used in the AR gamespace
students interact with virtual characters, digital items, and each other to navigate the game space. Choice and collaboration are embedded within the entire unit. Finally, the entire scenario is open ended, with multiple possible explanations for why the aliens have landed.

FORMATIVE EVALUATION

During the fall of 2006 and the spring of 2007 early iterations of the Alien Contact! curriculum were implemented for the purposes of conducting formative evaluation of the format. As there was no existing design for developing in-practice AR curriculum, much of this formative evaluation was intended to develop the heuristics for developing appropriate and effective AR curricula. The methodology and results of this pilot formative evaluation are described in depth by Dunleavy et al. (in press); however, for clarity purposes, the methodology and findings of this study are described here.

Utilizing a multiple case studies design, a series of data collection techniques were implemented at three sites (selected through convenience sampling) in order to gather in-depth information on how students and teachers perceived the AR curriculum. These data sources (including observations, formal interviews, informal interviews, and Web site postings) provide rich, contextual data that allowed for triangulation of results.

These data were qualitatively analyzed within each site using a structured-coding scheme that followed an initial open-coding process. The initial open coding resulted in 30 descriptive codes, which were then analyzed iteratively using pattern matching analysis. The analysis from each case study was then used for cross-case analysis to determine if there were similarities across implementations in usage and perceptions.

RESULTS

Through the analysis of case study data from the initial formative evaluation, Dunleavy et al. (in press) documented high student engagement during the implementations of the Alien Contact! AR curriculum. According to Dunleavy et al. “high motivation and engagement seems logical and almost a given during an activity that has students go outside with handheld computers and search for clues about aliens, it was nonetheless a critical threshold that needed to be reached during this first year of the AR design development.”

Students and teachers reported several factors that played a role in motivating them throughout the curriculum implementation. Among the most common factors mentioned by both teachers and students were the use of the GPS-enabled handhelds themselves, the ability to collect data outside, and the interdependence of the roles within the team dynamic. In addition, teachers focused on how the AR curriculum engaged previously disengaged students (Figure 6).

However, in addition to the increased motivation, Dunleavy et al. (in press) also found significant logistical limitations in implementing AR curricula. In particular, hardware and software issues, particularly due to GPS errors, interfered with the seamless integration of this technology. Another issue dealt with the substantial management and technical support required to maintain the instructional process and the technology—a problem deemed to be prohibitive in any effort at scalability. Also of concern were findings of substantial cognitive overload on the part of students involved with the AR curriculum. Students and teachers indicated that learning the technology while also trying to work relatively complex content problems caused confusion and led to some students giving up before completing tasks.

Another result from the research was the discovery of unanticipated competition between teams. Due to the linear nature of the learning path (that is, all students moved from one character to another in an identical and predict-
able progression), student teams were able to visually see where other teams were within the progression. Therefore, each team had the sense that they were either ahead or behind other teams in the game space. This led to student teams hurrying through the activities in order either keep pace or pass other students, whom they viewed as their competition. As would be expected, this resulted in students missing valuable information within the game space.

An additional unanticipated finding was a desire on the part of the students to know the right answer. As would be expected with students at the middle-school level, especially with those accustomed to commercially available games designed to provide closure, participants expressed a strong desire to know why the aliens were actually here at the end of the game (this was usually articulated through the focus group interactions). In most cases, the ambiguity of the game’s multi-hypothesis nature was difficult for these students to accept.

It is important to note that current implementations of the Alien Contact! curriculum are validating the findings from the formative evaluation—particularly where the issues of technical and logistical support are concerned. Students appear to be motivated by the AR curriculum; however, competition between student groups is present in nearly every implementation, and the issue of having the right answer continues to persist.

FURTHER EVALUATION

Building upon the formative evaluation conducted by Dunleavy et al. (in press), further research is being conducted to study the impact that Alien Contact! has on academic achievement and affect. Through a pre-test/post-test, control-group design, it will be possible to draw preliminary conclusions about how effective this version of an AR curriculum can be in an educational setting.

Data for this analysis is being collected during the spring of 2008. The control curriculum is identical to the Alien Contact! AR curriculum in terms of content, however, it is played inside using a board game rather than outside using the handheld computers (Figure 7).

MODIFICATIONS BASED ON FORMATIVE EVALUATION

HARP personnel responded to the results from the formative evaluations to better design a subsequent AR curriculum called Gray Anatomy.
This section will describe the initial version of this new curriculum and the changes that were made to our AR design template based on the findings of the formative evaluations discussed previously.

**Gray Anatomy**

Gray Anatomy, just as is the case with Alien Contact!, is a scenario-based AR curriculum. As the game begins, students are presented with a scenario in which a gray whale has beached itself. Working in teams, the students must interview virtual characters, inspect virtual objects, and work through mathematics and language arts problems to determine what occurred and why the whale beached.

Similarly to Alien Contact!, this curriculum also focuses on middle-school, Massachusetts state math and language arts standards. In this case, the math standards revolve around data analysis, statistics, and probability (MCAS standards 6.D.1 and 8.D.3) and the ELA standards include thematic identification and support (MCAS standards 11.3 and 11.4), understanding a text (MCAS standard 8.19), and support hypotheses with evidence from text (MCAS standard 8.24). Additional standards that are touched upon are numbers and number sense (MCAS math standards 8.N.10 and 8.N.11), vocabulary and concept development (MCAS ELA standard 4.17), formal and informal English (MCAS ELA standard 6.6), questioning, listening, and contributing (MCAS ELA standard 2.4), and oral presentation (MCAS ELA standards 3.9, 3.11, and 3.12).

As with Alien Contact!, this curriculum incorporates the previously mentioned video game characteristics that increase learning and engagement. However, several substantial changes have been made to the game play in response to the results from evaluating Alien Contact!’s design.

**Cognitive Overload**

The most difficult of the concerns identified by evaluations of Alien Contact! was the issue of cognitive overload. Due to the fact that the overload was caused by difficulties synthesizing several tasks, each of which was relatively complex in and of itself and was dependent on the individual student, it was difficult to develop solutions to address the problem. For this reason, several steps were taken to mitigate complexity of the tasks required in the Gray Anatomy curriculum.

The first step taken was to limit the number of characters or objects that any student would interact with during a given time period. Initially, the Alien Contact! curriculum incorporated far too many characters and objects. Through the
formative evaluation conducted by Dunleavy et al. (in press) as well as lessons learned through subsequent implementations of the AR curriculum, we determined that between five and six items or characters per AR session is optimal for progressing through the game in a timely, efficient, and effective manner. For this reason, each of the two game days involved with *Gray Anatomy* include a maximum of six interactions.

In addition in attempting to limit the scope of the interactions that any individual student might have, we also made efforts to limit the opportunities to misunderstand directions for given tasks. The *Alien Contact!* curriculum depends to a great extent on providing written textual directions to students. In many of these cases, the content required at least one scroll to complete the reading of the directions. Following several of the principles of game design for effective learning laid out by Gee (2003), it was decided to focus on using multimedia for the delivery of directions and content through the game. According to the work of Gee, by leveraging the technological capabilities of the handheld computers themselves, the AR games pace can effectively provide multimodal meaning (i.e., use materials other than text to provide meaning). In addition, by providing materials in other formats than simply through text, the curriculum can address semiotic principles (i.e., identifying and appreciating the interrelations between multimedia elements in a complex system) (De Oliveira & Baranauskas, 2000).

More tangentially, in response to a perceived need for greater clarity throughout the game, a new design paradigm was implemented for *Gray Anatomy*. As HARP staff did not have any previous experience designing AR curricula, this first effort was done without a roadmap. In essence, project staff designed the process for developing an AR curriculum through the process of developing the AR curriculum itself. Based on lessons learned from this *bootstrapping* design strategy, a more structured development process utilizing a storyboarding approach was implemented for the development of *Gray Anatomy*. This process involved multiple meetings among HARP staff during which the broad strokes of the story involved with the curriculum were outlined. In these meetings, we decided that there would be various possible theories to why the whale would have beached, one of which would be a correct response. Documents were developed to guide the formulation of these different theories, and each member of the HARP team designed one set of evidence that can confirm or deny individual theories using these guides to assure consistency across the different answers.

**Competition**

The other major unanticipated issue seen throughout our evaluations of *Alien Contact!* was the competitive interactions among the student teams when playing the game. As was discussed earlier, this was generally due to the fact that all students followed the same path of characters and objects, and thus each team could see which other teams were ahead or behind them in that progression. On its face, competition is not necessarily a negative thing to build into a game; however, in this instance, it did have negative repercussions. Because of the competition, students who wished to *win* would rush through the individual interactions that make up the game and would miss important information that they needed to progress through subsequent characters or to identify possible support data for individual hypotheses.

In order to undercut this competition across teams, the HARP staff developed a nonlinear path through the game. Instead of each character/object triggering the next character to appear along a proscribed path, an entry-point character will trigger all of the other characters in the game. This entry-point character will direct the students on the scope and sequence of the game playing experience and will inform them that each team must visit all of the other characters within the game space during the course of the AR event. The path through which the students progress can be determined by them, thus making it less likely that student teams will see other teams as ahead or behind them.
Modifications Based on Other Considerations

In addition to the modifications that were made based on our evaluation findings, there were also several modifications that came about due to informal analysis of the Alien Contact! curriculum and implementations that took place after the formative evaluation was conducted.

Flexible Roles

The first change occurred due to difficulties that were caused by the hard coding of four roles within the Alien Contact! curriculum. As was mentioned previously, students were placed into teams of four, with each of the students within a team taking on one of four roles (chemist, cryptologist, computer hacker, and FBI agent). However, the relative inflexibility of this system caused difficulty when there were a number of students that was not divisible by four. What would be done with any excess students? In implementations of Alien Contact! these additional students would be allocated to teams and would duplicate one of the four roles (thus a team might have two chemists). Obviously, this is not optimal due to the fact that the content was developed to assure that each of the students within a team would receive unique information that would need to be shared with other members of the team in order for the team to be successful. Having two students playing one role, although expedient, created a situation where the additional student was not necessary to the team’s success.

In order to combat this situation, Gray Anatomy was designed with a flexible role structure. The AR editing software and the needs of the curriculum design still dictated the hard coding of roles within the game space. However, HARP personnel decided that two different versions of the game would be created. The first version would have three students in each team. Each of these three students would take on one of the following roles: marine biologist, oceanographer, and reporter. The second version of the game would entail two students pairing together to play the game. These two students would play the game as the marine biologist and oceanographer.

In keeping with the design paradigm used within Alien Contact!, the reporter would receive unique information within the three-person version of the game. The fact that this information would be necessary to progress through the game effectively created the problem of how to allocate the reporter’s information to the participants within the two-person version of the game. The solution for this was to have the reporter incorporated as a character the paired students would interact with within the game space itself. Thus, each of the two students would still be receiving all of the information that any student working within the three-person version would see, while allowing the flexibility to accommodate any number of students without the need of duplication of roles.

Correct Answer

Another issue that was present within most of the implementations of the Alien Contact! AR game was a desire on the part of the students to know the correct answer to the question of why the aliens had come to earth. Manifesting itself within the focus team interviews that followed the full implementation of the curriculum, students asking for the right answer lead to discussions of the need to use data to support hypotheses in ambiguous situations. Although this is a valuable lesson for students to learn, and one that Alien Contact! attempts to convey, one of the strengths of many commercially available games is that they build to a climax and then offer closure (whether this is on a small scale based on individual tasks within a game or on a larger scale as the structure of the entire game). For this purpose, HARP personnel decided that Gray Anatomy would include such a correct answer.

This, however, presented its own unique challenge, as there is no explanation widely accepted in the scientific community as to why whales beach themselves. In a game based on
having students answer this question, it is not appropriate to offer a solution as correct if the wider scientific community cannot support such an assertion. Such an act would provide students a false sense of the real world and would be impossible to support ethically.

The solution that the HARP staff decided on was to have a series of “crackpot theories” that were viable sounding, but which each had a “fatal flaw” that made them impossible to have actually caused the beaching. Thus, whichever theory was not fatally flawed could be seen as the correct answer to the simulation. HARP staff developed three theories, two of which are fatally flawed. These theories, along with the corresponding characters used to support or debunk them, make up the suite of interactions that each team of students has over the course of two days of outdoor AR interactions.

**Redesigned Control**

In order to do rigorous research into the efficacy of both AR curricula as an instructional strategy, we use a pre-test/post-test control group research design. As such, a board game version of the AR game is developed to act as the control curriculum to determine what value, if any, the technology adds. All content was the same as would be found in the AR curriculum, and the team dynamics remained the same. This board game consists of an 8x8 checkerboard, around which student teams move game pieces. Each of the 64 squares on the checkerboard corresponds to an envelope on a tri-fold poster demonstration board. According to where they were in the game, the team is directed to open a particular envelope, which holds cards that deliver the role-based content for that interaction. In addition, the teams are directed to move their game pieces to the corresponding next square on the checkerboard.

Using the version of the board game initially developed for Alien Contact!, HARP staff determined that the design of the board game made it unnecessary to interact with the actual checkerboard for all but the most ancillary activities. In order to make the interface more interactive and engaging, the board game portion of this control curriculum was redesigned. The new version of the board game includes a foam board image of a neighborhood with puzzle-piece shaped, yellow spaces interspersed throughout the image. As students move through the game, they receive puzzle pieces that show them with whom or what they were interacting with next and in which envelope that character’s or object’s information would be found. This redesign dramatically improved the feel of the board game and has created a situation where the students need to interact with the board, making the control curriculum more similar in its format to the AR curriculum.

**Shorter Curriculum**

Another modification made to the curriculum template for Gray Anatomy was to switch from a six-day to a five-day schedule. The Alien Contact! curriculum follows a staggered indoor/outdoor pacing. As was discussed earlier, four of the six days within the Alien Contact! curriculum are dedicated to work in a traditional classroom setting. Each day immediately following the two game days are dedicated to analyzing and synthesizing the data that were gathered during the gameplay. This had the consequence of creating an awkward schedule that required more than one academic week for completion.

This awkwardness of the schedule led to a switch to a five-day curriculum plan for Gray Anatomy. Rather than having an analysis and synthesis day following each of the two game days, there is only one analysis day following two straight game days. It is postulated that this change will have dual benefits. The first benefit is to create a schedule that works within a single academic week. The second benefit is to create a more focused analysis opportunity.

**Curriculum Focus**

Another issue that has been addressed for Gray Anatomy was the focus on integrating the different content areas more meaningfully.
Alien Contact! can be implemented as a math curriculum, an ELA curriculum, or a combination of math and ELA. The decision to split the combined curriculum and only implement that math or ELA content areas was made in order to facilitate the ability to recruit individual teachers for the project. If a math teacher wished to implement Alien Contact!, however, there was no corresponding ELA teacher to conduct those sections of the curriculum, so it would be more difficult to recruit teachers. The focus for Gray will be on an integrated math and ELA curriculum rather than on separate math and ELA. This is in line with skills that students need in their future work, which is interdisciplinary. It also significantly reduces logistical problems or need for so much technical support of setting up two different games.

Teacher Involvement

Finally, there is discussion about how to get the teachers themselves more involved in the delivery of the curriculum rather than having it be something that the research team comes in and does. It was never intended that the research team would teach the content itself, as the future of AR lies in its ability to be a seamless part of the learning environment run by the in-service teachers. With implementations of Alien Contact! it has been necessary for the research team to play a relatively large role in managing the content. In order to mitigate this for Gray Anatomy implementations, the game will be played fully with teachers before the students play so they themselves are engaged in situated learning and learn the process involved. This has the indirect benefit of getting buy-in from the teachers both for the technology and for the process of situated learning. Second, the HARP team is considering ways (both technological and non-technological) to have teachers gather feedback from students after the first outdoor day so they can more closely track individual student’s progress and give them formative feedback to improve their experience for the second outdoor day.

CONCLUSION

The development and deployment of AR technologies is still in its early stages. Since these types of curricula incorporate nascent technology, taking the long view about their potential for student learning is appropriate. As Dede (2005) asks when discussing the learning styles associated with “Millennial” students, “What new forms of neomillennial learning styles might emerging media enable?” (p. 8). We know that students will increasingly bring learning strengths and preferences to the classroom derived from the ever more sophisticated and pervasive use of cell phones. This trend implies that instructional designs merging physical and virtual environments hold great promise for building on learners’ emerging skills and inclinations. Our early research is promising in demonstrating AR can enhance student motivation, involvement, and excitement; and our current studies are examining the extent to which learning outcomes are enhanced over comparable control curricula.

As a field, instructional designers are at the beginning of identifying best practices for developing effective AR curricula. Systematically building on findings from early studies such as our work will not only improve later AR curricula, but also may lead to improvements in the technology itself, particularly as AR moves to its eventual target device, the cell phone. By migrating this emerging interactive medium from custom, school-supported PDA/GPS technologies to standardized, commercial-provider-supported, cell phone technologies, educators can realize the advantages of using ubiquitous, powerful devices students could bring from their homes to classroom settings.

AR can reach its full potential only when this leveraging of student-owned technologies is realized. Any instructional design that depends on school-based personnel maintaining and managing complex, custom sets of equipment has inherent weaknesses. Maintenance and management is time consuming, and the equipment is prone to obsolescence; the total cost of ownership by the school system is substantial.
when this includes initial purchase, maintenance, technical personnel, and replacement costs. Beyond those issues, if educators are responsible for equipment evolution, this will dramatically slow the advance of AR technologies. Compared to large telecommunications companies rapidly enhancing their equipment to gain market share in the lucrative cell phone market, educators have neither the technical capacity nor the competitive incentives to rapidly improve AR devices.

We estimate that, within a year or two, the next generation of cell phones can deliver the types of AR developed in our studies. Such a migration in AR infrastructure will require a substantial shift in how teachers and administrators treat cell phone usage in school settings. At present, many educators see cell phones as a barrier to effective instruction because of their potential to distract students’ attention and to facilitate cheating. Once schools go beyond banning cell phones, or reluctantly accepting smart phone technology as a necessary evil, to instead developing ways to incorporate these powerful devices for the improvement of student learning, then educators will have a commercially supported learning infrastructure with which students are already familiar and fluent, paid for and maintained external to education, and available for learning inside of classrooms and out. AR is a fulcrum for leveraging this evolution.

REFERENCES


Patrick O’Shea is the director of the Handheld Augmented Reality Project at Harvard University’s Graduate School of Education. This project is focused on studying the potential of GPS-enabled handheld computing in educational settings to improve academic and non-academic outcomes. In addition, Dr. O’Shea has more than 15 years of experience working at every level of education. Among his accomplishments, Dr. O’Shea has consulted internationally for the Bill and Melinda Gates Foundation, built online testing protocols, designed, implemented, and evaluated large-scale university-level projects, and has extensive experience with practical applications of technology in the educational setting.

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