Environmental Detectives – The Development of an Augmented Reality Platform for Environmental Simulations.

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RUNNING HEAD: AUGMENTED REALITY

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ABSTRACT

The mantra for bringing computers into schools has changed over the past 10 years going from "a computer on every desktop" to a "computer on every lap" and now to a "computer in every child's hand." Although some compelling examples of educational software for handhelds exist, we believe that the potential of this platform are just being discovered. This paper reviews innovative applications for mobile computing for both education and entertainment purposes, and then proposes a framework for approaching handheld applications we call "augmented reality educational gaming." We then describe our development process in creating a development platform for augmented reality games that draws from rapid prototyping, learner-centered software, and contemporary game design methodologies. We provide an overview of our development activities spread across 5 case studies with classrooms, and provide a design narrative explaining this development process and articulate an approach to designing educational software on emerging technology platforms.

Introduction: Moving to handhelds

The mantra for bringing computers into schools has changed over the past 10 years going from "a computer on every desktop" to a "computer on every lap" and now to a "computer in every child's hand" (Soloway et al., 1998). While this recent push from desktop computers and laptop computers to handheld computers has certain obvious advantages in terms of cost and maintenance, the educational affordances of this new platform have been sparsely explored. The limitations of the handheld computer, including its display size, stylus-interface, storage capacity and processing power limit make simply porting desktop applications to the handheld less than desirable (Ledbetter, 2001). Most handheld applications to date have been created to replicate the functionality of desktop applications (goknow, calculators, etc.). These early projects show that handheld computers have tremendous potential for getting digital technologies into students' hands and transforming learning, but educators may have to rethink traditional genres of educational software in fundamental ways to take advantage of the affordances of handheld technologies (Roschelle & Pea, 2002; Soloway et al., 2001).

Indeed handheld computers have several unique features associated with this form factor which suggest intriguing educational opportunities. Klopfer, Squire, Holland & Jenkins (2002) describe five properties of handheld computers that produce unique educational affordances:

a) *portability* –can take the computer to different sites and move around within a location
b) *social interactivity* – can exchange data and collaborate with other people face to face
c) *context sensitivity*– can gather data unique to the current location, environment, and time, including both real and simulated data

d) *connectivity* – can connect handhelds to data collection devices, other handhelds, and to a common network that creates a true shared environment

e) *individuality* – can provide unique scaffolding that is customized to the individual's path of investigation.

These affordances suggest an array of unique types of interactions, such as distributed, collaborative investigations, peer-to-peer networks, or synthesizing physical space with instruction.

As applications for handheld computers have matured, educators have begun taking advantage of these affordances. Roschelle and Pea (2002) review seven design experiments in handheld computing to better understand the affordances of handheld applications. Roschelle and Pea observe five characteristics of emerging handheld applications. Handheld applications: (a) augment physical space with the simulated data; (b) leverage topological (or physical) space; (c) aggregate individual's participation into group reflection opportunities; (d) situate the teacher as a conductor of activity; (e) use students' actions as artifacts for discussion. Roschelle and Pea conclude that these affordances which tend to create learning environments where individuals are engaged in different activities, distributed across space may create new design tensions around system couplings. Citing Morrison and Goldberg (1996), they argue that how information flows from device-to-device and how this information flow is controlled may become the critical issues in handheld computing applications. Roschelle and Pea write,

> Overly tight coupling, where every information exchange among personal devices is centrally controllable and tracked, may be too close to Orwellian scenarios. Overly loose coupling, where each Palm is an information island, will not lead to

> interesting shared knowledge spaces and activity artifacts. (n.p).

How to balance competing drives for individuality with distribution, and decentralized information flows with guided educational activities may be tensions central to the platform, and we believe that developing applications which explicitly explore these tensions is one way to advance our understandings of the affordances of handheld computing.

This paper outlines a design research program (Barab & Squire, in press; Brown, 1992) around handheld computers, attempting to map out the affordances of handheld computers to support learning. Specifically, we describe the development of Environmental Detectives, a multi-player, handheld augmented reality simulation game designed to support learning in advanced introductory (late high school and early college) environmental science. Our goal is to better understand the affordances of handheld computer simulation games so that we can build a general software platform for developing other handheld simulation games. A software platform would allow (a) developers to create new augmented reality simulation games more rapidly and cost-effectively, (b) teachers and instructional designers to create games for specific geographic locations, taking advantage of local conditions, such as an historical or environmental site, (c) teachers to custom-tailor games to meet students needs and refine games to meet students' needs, and (d) students to become game designers, creating simulation games.

This paper traces our process of creating Environmental Detectives from initial conceptualization through four field trials to our initial attempts at building a set of game development tools for creating augmented reality games. We argue that rather than prescribe a list of functions and build a robust platform from scratch, educational software developers might use a rapid prototyping process of creating multiple disposable programs that test the usability and pedagogical potential of specific functions. Central to this process is a commitment to assembling quick solutions to problems, adjusting design requirements and user specifications, and then scrapping code afterwards. We believe that this iterative process of designing, coding, testing, refining, and building specifications toward a general platform is applicable to other software domains where designers are interested in building genres or families of software, in particular desktop educational games and simulations. The paper concludes by reporting the findings of our four test case studies and articulating the functional specifications included in our current handheld gaming platform.

Software development on handheld computers

In recent years, an array of applications have emerged for handheld computers displaying the pedagogical potential of these devices. An array of applications is also emerging from the entertainment sector, suggesting powerful new models for interacting with handheld computers. Consistent with the broader research goals and pedagogical values of The Education Arcade (educationarcade.org) consortium, we are exploring how educational software might leverage the affordances of entertainment software to support learning. This section highlights recent developments in both educational and entertainment handheld computing applications and outlines a framework for thinking about educational handheld computing.

Applications on Handhelds and Mobiles

As Klopfer et al. (2002) describe, handheld computers have unique affordances, particularly, portability, social interactivity, context sensitivity, connectivity, and individuality.

Several of the emerging educational software programs on handheld computers employ different subsets of these factors and are described below.

Probeware. Probeware applications capitalize on the portability, connectivity and individuality of computers. Using probeware extensions, students collect data in real time using handheld computers, covering everything from dissolved oxygen in a stream to the velocity of a person running (Bannasch & Tinker, 2002). Enactments of probeware curricula usually involve student splitting into groups, gathering data from different vantage points, and then aggregating and analyzing results, so that each student is a component of a knowledge building process.

Knowledge Aggregation. Knowledge aggregation software, such as Picomap (Luchini et al. 2003), uses the connectivity and individuality of handheld computers to have students engage in research, activities such as concept mapping, and then aggregate information into knowledge networks. Students might develop concept maps of how a toxin flows through a watershed, and then upload their concept maps to a central computer where they compare maps and develop a more unified map reflecting the experience of their peers, building on the social constructivist notion of knowledge-building communities (Scardamalia & Bereiter, 1994).

Classtalk. Classtalk (Dufresne et al. 1996) and similar Personal Response System software networks individual machines or devices to a central server. Students answer questions and see their responses, allowing for instantaneous feedback and adjustment of instruction. While this format may seem like antiquated behaviorist-derived, fact-based instruction, creative teachers use Classtalk to propose challenging problems, elucidate misconceptions, or spur student discussion, using the individuality and connectivity of machines to create perturbations in both psychological and social systems so that students confront existing ideas and beliefs.

Participatory Simulations. Participatory simulations leverage the individuality and connectivity of handheld computers (Klopfer, et al. 2004, Soloway et al., 2001) or wearable (Klopfer and Woodruff, 2002; Colella, 2000) computers, to immerse learners in simulated dynamic systems. Participants become everything from viruses to agents in economic simulations, trading and sharing data which is digitally processed and fed back into the system. Participatory simulations often rely on wearable computers to display information about the participant's role or state in the simulation as both a mode of communicating information as well as engaging learners as they scan other participants and attempt to understand their role within a broader simulated system (Klopfer & Woodruff, 2002).

Location Aware Field Guides. Handheld computers allow students to take rich databases into the field—d atabases which if made location-aware can provide context-sensitive information, such as on-demand information about a local watershed, animal population, or historical site (Gay, Reiger, & Bennington, 2001). Cybertracker (Parr, Jones, & Songer, 2003), one of the most widely used software systems, uses global positioning satellite technology to allow students to record not just values for given measures, but exact positional or local information. Students might gather data from about local wildlife where it is fed back into a database for other people (often trained scientists) to examine. Location-aware field guides provide new opportunities for relationships with spatial data, relationships that are both connected to geographic location and can be spatially dispersed.

Entertainment Applications

Probeware, knowledge aggregation, Participatory Simulations, Classtalk, and location-aware field guides are five families (or genres) of handheld computing software packages that are emerging in educational technology. Other ideas of how to use educational technologies have been arising within the humanities, games, and research spheres, which provide intriguing new opportunities for rethinking interactions with handheld computers (Holland, Jenkins, & Squire, 2003). Several handheld games use emerging platforms in creative ways that have been, in our opinion, been underutilized in educational applications.

Pirates. Players use location-based information on their cell phones to navigate a multiplayer virtual world of pirates (Falk, Ljungstrand, Bjork, and Hannson, 2001). Players' physical location triggers events where they might gather clues and battle other pirates. Importantly, the game board corresponds to the real world, as islands, reefs, and other barriers are placed in the real-world and corresponding objects are placed in the game world.

MAD Countdown. Steffen Walz and colleagues developed MAD Countdown, a game where players work in teams using location-aware PDAs to diffuse a bomb that is hidden somewhere in the building (http://www.madcountdown.de/).

It's Alive. It's Alive has produced several proof of concept pervasive games on cell phones. *BotFighter* is a virtual paintball game and *SupaFly* is a virtual soap opera in which characters that you create interact with nearby characters and places. Both games take place in real place and in real time using positioning technologies.

Majestic. The most well-known example of pervasive gaming may be Electronic Arts' *Majestic*, which shipped in summer 2001. Majestic was a multi-channel conspiracy game played over instant messenger, FAX, cell phones, and the web. Players investigated an arson attack on a games company working on a government conspiracy game, quizzing virtual characters, gathering data across multiple media channels, and exchanging information with other players.

Although *Majestic* was released to much fanfare, it faired poorly in the marketplace due to technical difficulties and changes in the geo-political climate around September 11, 2001.

The Beast and Cloudmakers. *The Beast* was released in the summer of 2001 as advanced promotion for Steven Spielberg's *A.I. The Beast*, a game released in secret and played over the Internet, featured thousands of players collaborating across the globe completing puzzles ranging from distributed data-gathering and problem-solving tasks where players needed to be in several locations at once to code-breaking tasks that demand knowledge of foreign languages. What sets The Beast apart from other similar games was its complexity; no one person could possibly solve *The Beast* and the game led to several organizations of game players, most notably *Cloudmakers* (http://cloudmakers.org) who are still together and pursuing the goal of making and solving large-scale collaborative games. While *The Beast* was not a game specifically made for handheld computers, its spatially distributed nature and mix of online and offline game play make it an interesting model for handheld gaming.

These games suggest how handheld computers can supplement real world interactions, relying on context sensitivity and social interaction to create compelling new media. With most desktop educational software, student-computer interactions are the focus activity, whereas in these applications social connections and connections with physical space are the basis of experience. This hybrid virtual/actual world that is created allows the small, unobtrusive interface of a PDA to become an asset for applications instead of a liability. We refer to this model of using digital technologies to supplement physical activity as *augmented reality.*

Educational, Augmented Reality Gaming on the Handheld

Our goal for this project is to use the rich interactions of location-based handheld games in educational contexts. In deciding on a domain for this game, we looked to the Probeware activities around environmental quality data (Tinker & Krajcik, 2001) as one of the more successful handheld applications. In many ways these activities model authentic science well. Students collect data about their environment, devise questions and conduct studies. At the same time, these studies may be uninteresting to students when there is no apparent environmental problem, or they encounter problems that are beyond their skills and tools. Most importantly, there is a whole range of pedagogically valuable but impractical or implausible situations, such as "what if toxins are dumped into the environment," that are worth exploring.

We thought about how to leverage the simulation capabilities of the handheld computer to create a similar experience based on a simulated environmental problem. Consistent with the values of the Education Arcade, we brainstormed mechanisms that might create an emotionally compelling context for investigation, drawing heavily from the detective work of Erin Brokovich or A Civil Action, stories which effectively marry the dramatic potential of human heath problems and basic environmental science. Elements of the game that we considered are listed in Table 1.

Insert Table 1 About Here

We imagined how these functionalities could be combined in a game where players see a rash of health problems, do desktop research, and then gather data to ascertain their potential causes. We were particularly interested in using the information communication capabilities of the handheld computer to have events running without the users' knowledge. The computer might track players' actions and match them to known activities or locations, displaying information appropriately (imagine the computer making intimidating threats if you enter the correct section of the library) or the computer sharing information between groups without players' knowledge. In this first version of the game we pared down our list of desired functionalities, deciding that the essential interactions were the simulated tools, location awareness, non-player characters, library access, and spatial data collection.

Early in the design process we realized that in order to have an impact beyond our local area, we would have to create a method for quickly developing and deploying games. Because location-based games are inherently tied to geographical conditions which may afford different kinds of investigations, games need to be customized to local contexts in order to accurately depict local watersheds, airflows and conditions. Particular chemicals, such as TCE, may be commonly found across the country. However, we believe that most teachers will want to customize games to meet local conditions and capitalize on prominent features, such as waste treatment facilities, industrial plants, or power stations. We decided that in the long term, the ideal strategy would be to have an augmented reality game toolkit that allows teachers and students alike to build custom scenarios and tailor games to meet local needs. Building a toolkit for an experimental game genre in educational contexts, which have not yet been explored, seemed questionable, so we first set out to test the core game mechanics and elements of user experience in a stripped down game which could be run locally. Then, after building two or three instantiations of the game, we would create a standard format for building and deploying games. Last, we would create a toolset for building and deploying augmented reality games. This next section describes our rapid prototyping approach to developing games, including a description of our first field trials of Environmental Detectives.

Rapid Prototyping. Over the past decade, instructional designers have been abandoning traditional instructional design processes (i.e. the ADDIE model) and embracing alternative methods of instructional design (Wilson, Jonassen, & Cole, 1993). Rapid prototyping, a methodology growing out of industrial design and software design has been taken up by instructional designers as a development methodology which can save time and money in developing large scale systems (Maher & Ingram, 1989; Whitten, Bentley, & Barlow, 1989). Rapid prototyping methodologies involve building a working, small-scale prototype early in development in order to test key system features. Testing this prototype allows developers to better understand system requirements and how well the concept is meeting design goals. After building iterations of the initial prototype, designers scrap the first iteration and build the larger scale, having learned from initial development efforts and saving time and money by having a more tested, efficient design (Wilson, Jonassen, & Cole, 1993).

Tripp and Bichelmeyer (1990) propose rapid prototyping in instructional design as a means of iteratively defining goals and outlining instruction in the early stages of development. Tripp and Bichelmeyer distinguish between prototypes that are shallow in that they try to depict the entire look or form of a product minus particular functionalities, or they can be narrow in that they test particular functionalities or aspects of a system in order to understand how they meet instructional goals. Tripp and Bichelmeyer argue, and subsequent research has shown, that rapid prototyping methodologies can save time and money, as well as foster better collaboration among subject-matter experts and instructional designers, giving multiple stakeholders in the design process a tangible artifact to focus discussions (Schwen, Goodrum & Dorsey, 1993).

We believe that rapid prototyping is especially valuable when designers are experimenting with new technologies and delivery systems. In the case of augmented reality gaming, there are several unknowns, including how players make sense of augmented reality, the affordances of the technology to support learning, and the viability of using different methods for determining location within instructional settings. In particular, we are concerned with examining how porting design elements and technologies developed in gaming contexts and porting them into classrooms affects learning. Using gaming modes of interactions offer new possibilities for engaging learners, but also bring competition, collaboration, and new styles of play (not to mention unstable technologies) into classrooms (Holland, Jenkins & Squire, 2003).

Envisioning Scenarios. Consistent with rapid prototyping methodologies, a number of software engineers advocate writing user scenarios as a first step in software design (Microsoft Framework, 2001). User scenarios help the developer “get inside the head of the user” thinking of functions and needs that the user might want rather than software specifications the developer might want to provide. User scenarios can also help the developer imagine new interaction possibilities and uncover holes in the overall design process or design concept before coding begins. We believe that scenarios, which can include screen mock-ups and paper-based interfaces are especially important in helping concretize the abstract, helping different parties imagine new kinds of interactions.

Developing Environmental Detectives

Our first step in designing a particular scenario was to determine the desirable characteristics for a toxin. We deduced that the toxin should be a *ground-water contaminant*, have *moderate long-term health effects*, and be *common*, but not something that was common knowledge to local inhabitants. *Ground water contaminants* were chosen because airborne contaminants would spread too rapidly for the time-scale of this game and soil-borne contaminants move more slowly and have more dispersed effects. *Moderate long-term health effects* were ideal symptoms because stronger correlations between a toxin and health effects would make the responsible agent too easy to identify and demand less scientific investigations. Last, we decided that the toxin should be *common but not common knowledge*. Common toxins allow for multiple possible origins (as opposed to say, a leak from a nuclear reactor), but common knowledge toxins, such as PCBs in some areas would drive players too quickly toward a correct solution, forgoing any data collection, analysis, and argumentation.

At first we decided on mercuric chloride, a highly toxic compound used as a fungicide, and a common environmental contaminant with both acute and long term health effects. Exposure through inhalation as well as ingestion can cause health problems, providing multiple scenarios for ingestion and complicating the investigations. We identified several local sites which might use mercuric chloride, and began mapping out scenarios of how it might flow through a city. Consistent with our design approach, we next wrote 10-12 page user scenarios detailing the user experience, using these scenarios as exercises to uncover holes in our game play logic, necessary resources, and the size and scope of the gaming scenarios.

Domain expertise. Next we consulted with several professors of environmental engineering who investigate similar problems. The purpose of this consultation was two-fold – to confirm the use of mercuric chloride as a viable toxin, and to establish disciplinary practices that we could capture in the game. Quickly, environmental engineering faculty persuaded us that mercuric chloride would be a viable candidate for the game, but Tri-Chloro-Ethelene (TCE) would be ideal. One of the engineers had already designed a similar board game and found that TCE fulfilled similar criteria, there were many case studies of TCE contaminations, and the engineer offered to share information about TCE, its cleanup, and local geology.

We also discussed environmental engineering investigative practices. The engineering experts explained how environmental investigations are critically dependent on the interaction of primary (raw data collected by the researcher) and secondary (summative and background information from texts) data. The researcher needs to do "deskwork" on the nature of the chemical, its health effects, toxic levels, legal limits, similar cases, historical records and local geology, *while simultaneously* integrating "fieldwork", in which they collect data on local concentrations. A major challenge in teaching environmental engineering is how to help students understand the value of doing deskwork in environmental investigations because most students treated the investigation as solely a fieldwork problem whereby they were trying to "find the correct answer." In reality, investigations are run under tight time and money constraints, whereby there are no perfect answers. Often times the cause of a contamination can be found by visiting a library or talking to a worker in a local factory or machine shop, which can save the investigator months of work and thousands of dollars. Most students, however, just wanted to sample for toxins. This tension between deskwork and primary data collection and tendency for students to blindly collect data would become a core feature of our game design.

Location and Audience. We chose an initial target audience and location on convenience; a local university was starting a new environmental sciences program for freshmen and needed a kick-off event orienting students to environmental science. We focused the game around an on-campus scenario involving a large, highly publicized construction project under way which formed the foundation of the investigation. We hoped that choosing an early freshmen cohort would allow the game to port to college and high school audiences.

Generation 1: Proof of Concept

The first generation prototype had two primary goals – establishing the proper protocols for interfacing between the Pocket PC and the GPS modules, and creating a working scaleable architecture with the suite of tools that was emerging for the Pocket PC platform (an initial release of C# in the .NET Compact Framework). We decided that the two primary actions – digging sampling wells and interviewing contacts would have buttons on the screen at all times. Since the game was centered on a spatial context, we settled on using a map as the focus of the interface. This would allow users to see locations where they had drilled for samples and where there were contacts available for interviewing at all times (See Figure 1).

Insert Figure 1 About Here

The interface between the GPS and the Pocket PC turned out to be a great challenge complicated by two factors. First, at the time we began the project most GPS modules were tied to specific mapping software with which they were purchased. This meant that there was no sample code or programming community to look to for help in creating our software. The hardware manufacturers were not willing to help, because most of them made their income by selling map software for their hardware. While the GPS outputs data in a standard format, the initialization strings were not standardized, slowing startup. Second, the GPS modules themselves were erratic at best. In order to get a position reading (“a fix”) the GPS must “see” at least three satellites simultaneously. This required a direct line of sight to the sky on a clear day in a wide open space. Experience quickly showed us that in an urban area occasions under which one could get a reading from even one or two satellites were quite rare. While nothing that we were doing was theoretically beyond the capability of these machines, we found that off-the-shelf GPS hardware did not work as well as advertised.

By this first phase we had created a map-based interface that displayed information (interviews) when the player was in the vicinity of a designated point. Sampling could occur throughout the game arena based on simulated underlying data. Under just the right circumstances (usually standing on rooftops) we were able to confirm that navigation via GPS was also functional. Simple text-based descriptions set-up the problem for students and gave them additional information on key toxins (See Figure 2).

Insert Figure 2 About Here

Generation 2: Classroom Trials

The goal of this next phase was to get the hardware and software working reliably enough to pilot with a class. Two hardware changes occurred at this point: 1) The Pocket PC processors changed, which meant recompiling code and making other minor adjustments. We also switched to a different brand of GPS module, recommended to us by another research group working with commercial software. This change achieved a small gain GPS reliability of 10 to 20 percent (where reliability is measured as the percentage of time that we were able to get GPS 'fixes" outdoors in areas with a clear view of the sky). We developed a calibration algorithm which synchronized our map with the GPS location, further enhancing GPS accuracy. This second version also included a basic map with GPS navigation, the ability to drill sampling wells and receive text interviews, and a story that provided a context for the investigation.

The first trial took place with a freshmen environmental sciences class. The goal of this trial was to (1) try the GPS navigation software with a set of users other than ourselves, as we feared that we might have become overly familiar with the idiosyncrasies of our software; (2) test out the concept of augmented realities to gauge students' reactions (i.e., Was it confusing? Engaging?); (3) play-test the basic game functions for good balancing; (4) examine how students interacted with the machines to brainstorm new modes of game dynamics.

Five groups of two to three students used the game in a special Saturday afternoon session on a day with marginal weather conditions. The GPS only worked reliably for two of the groups; the other groups had intermittent signals that they supplemented by manual navigation that we had added to the interface for this event.

Feedback from the students participating in this trial showed that they enjoyed the combination of real and virtual worlds, as well as the interplay between primary and secondary information. Students were particularly intrigued by the virtual characters, and were excited to see more kinds of game play linked to character interactions (e.g. virtual races with characters, interrogations, or virtual "stalking"). While no one was able to satisfactorily diagnose the problem, there was consistent approval of the format and concept. All of the students requested to play the game again after the bugs were worked out. We were encouraged that these students valued the fundamental game premise and modes of interaction, and that the game play elicited the kinds of interactions (discussions over whether to drill for samples or interview more people) that we had hoped to see.

Generation 3: Classroom Implementations

One of the disadvantages of Augmented Reality games versus their virtual counterparts is that they are not amenable to playing outside in the winter. We therefore had a long hiatus between iterations of game play. This also meant that we had a long time to improve the game dynamics. During the implementation of the first game, one of the critiques was that information was poorly organized and difficult to access, and that much of the game was about finding the right information rather than solving the environmental problem. In response, we (1) revealed the department each interviewee is associated with, and (2) organized the contacts in a viewable list displaying the contact's name and departmental association (See Figure 3). This allows students to structure their exploration by relevance, and construct a logical plan for ordering interviews.

Insert Figure 3 About Here

This version also included additional non-textual media – pictures and video. Students playing the first iteration of the game found that the interviews felt somewhat impersonal and wanted videos that might make the experience more personal. Along with the video we rewrote the interviews to make them more identifiable to particular people.

We gave the simulation a more dynamic feel than the previous version by implementing timed events. In several locations one of the contacts will tell the student to meet another game character in another location within a particular time window (e.g. 30 minutes). This element of game play provided a sense of urgency and forced students to make quick decisions on the fly where they evaluated the potential value of information. It was also intended to make the game feel more organic – there were other people in the game that had schedules and priorities with which they needed to contend.

On the data / simulation side of the program, we limited the number of simultaneous wells that could be dug. In the first generation students could sample wherever they wanted whenever the wanted instantaneously. Students tended to dig wells quickly and without much thinking, as well digging was not a limited resource (as it would be in the real world). We changed this so that drills took three minutes to dig and an additional minute to process. Each player could only have three wells out a time (because they had only sufficient funds for three wells), and they needed to retrieve the sample from a well before they could reuse that rig.

At the same time, a new GPS chipset (SirfII) was released, providing a substantial improvement in GPS reliability. In reasonable weather we could get satellite fixes on most of campus and without any work on our part, we had an order of magnitude increase in reliability.

In the spring, we played this version of the game with three classes – two scientific writing classes that used this simulated research experience as a basis for a written report, and a teacher education class that used the opportunity to explore new technologies for teaching. Most of the students in these classes were able to complete or nearly complete their investigation in the course of a two hour class, making this our first real playable implementation of the game.

Students found the story compelling and enjoyed "augmented reality" modes of interaction (Klopfer and Squire, 2003). These students focused on primary data collection through the wells and were able to pinpoint the location of the contamination, but most were not as good at collecting the interview data and could not present solid plans for action.

In order to make the students evaluate their primary data more effectively we implemented sampling protocols that forced the students to make tradeoffs between processing time and accuracy of their samples (See Figure 4). This tradeoff was intended to encourage more thorough consideration of sampling designs and this mechanism was in place by the third spring trial. Initial transcript analysis suggests that this game mechanism did produce more critical discussions around what kinds of data were needed (Klopfer and Squire, 2003).

Insert Figure 4 about here

Several other factors emerged during this series of iterations, which are explained more fully elsewhere (Klopfer & Squire, 2003). We found that female dominated groups tended to seek interview sources rather than drill for readings, whereas male groups tended to drill for readings. Groups that were split between those favoring interviewing with those favoring sampling were the most productive from a pedagogical angle, engaging in many discussions defining and redefining the problem, weighing the importance of interview data vs. "hard" environmental readings, or arguing over the best plan of action. These results suggest that identifying different modes of game play and pitting different types of problem solvers against one another in different groups may be a productive way of fostering scientific argumentation within game play.

In an unanticipated event, one group stopped in the middle of the game and used Google to search for clues. This strategy, accessing other outside resources was not only acceptable within our rules but perhaps advisable, given the time constraints and use of authentic chemicals and historical data. Students were able to locate information quickly and easily on Google, suggesting the role that a tool such as Google can play in transforming an educational experience. When nearly any information publicly available can be accessed within a matter of seconds, game dynamics that rely on simple factual hunting or trivia-type problems become irrelevant. Although the presence of Google did not seriously disrupt this group, it did cause us to pause and rethink future developments of our game, particularly in how we bridge fantasy and reality. As game designers, we cannot assume that students "would not find out" about an historical case or the specific properties of a chemical; when the entire world is the gameboard and students have cell phones, PDAs and other devices, we must assume that if there is relevant information available on the Internet, that students might find it.

Generation Four: Expanding into New Contexts

By the end of our third spring trial, we felt that we had sufficiently defined the technological components to start designing our toolkit for designing scenarios (easily importing maps, calibrating GPS, placing interviews, embedding media, defining the source of the contamination, and defining the rates at which the contaminant spreads in the environment). The toolkit operates through a click and drag interface as shown in Figure 4. The libraries are all stored as a part of an XML database so that a customizable scenario can be created without any programming skills. All that is required to use the toolkit is to have the required media, interviews, media, and text, an appropriately scaled map, and GPS coordinates of two points on the map. The toolkit outputs a file that can be copied to the Pocket PC for playing, allowing an instructional designer to focus on game content rather than technological issues. We expect that even students will be able to build their own games in the near future.

Insert Figure 5 about here

To test the flexibility of the new toolkit, we created a game for an entirely new locale. A suburban nature center volunteered to host the game and match us with a local high school environmental science class. The site had ample open space with a clear view of the sky to support the GPS use. Additionally the site was a working farm, but formerly a NIKE missile base, which provided a rich history and context for the game, and new opportunities for combining different toxins and contaminants, in particular, new opportunities for creating "red herrings" around toxins that may have been left-over from the farm's days as a missile base.

Since the students at this game would be visiting this site for the first time, we thought that the story needed to be specifically tied to the land. We rewrote the back story (which now concerned the health of the animals on the site), as well as all of the interviews to tie into local conditions. We also shot the video on site to tie the media to the physical geography, something that earlier students had requested. Since we were working with a younger group of students (high school juniors and seniors in from a suburban school), we simplified language and included additional background information to make the problem more tangible, such as pictures of the drill rigs that they would be using.

The physical space of the nature center was significantly larger than the original campus game site (See Figure 5). To help students navigate, we gave most groups walkie-talkies with which they could communicate with each other and us as facilitators. We also had a slightly improved GPS, which increase reliability at least 50% again. There were few technical difficulties – only one of the 12 groups was unable to navigate via GPS.

Insert Figure 6 About here

There were many differences in the context between this version of the game and the previous ones. These students were younger, new to the site, more diverse in their academic capabilities, and playing on a larger, more difficult to navigate terrain. These factors combined to create a game experience entirely different from previous groups'. These students were less inclined to collect primary data. Instead, they were driven to collect the interviews, although they had difficulty interpreting information and using knowledge to plan an investigation. Instead the exercise became more of a scavenger hunt in which students could be overheard comparing the number of points that they had found. We attributed these differences to lack of personal connection to the physical space, the identities of players as younger, less scientifically-oriented, and perhaps a strongly female gender bias (females in earlier games were found to be more focused on interviews than males – Klopfer and Squire, 2003). By the end of the game, most of the groups had insufficient data to identify the source of the chemical spill.

Students in this game also had difficulty navigating the physical space. This was a large space and some sections contained few identifying marks. This difficulty in navigation parallels the difficulties that novices often face in virtual environments. Still, students were able to think across their virtual resources and physical space with ease. For example, students on the edge of a field nearly climbed over a barbed wire fence to get to the "next" interview on the other side until they looked at the map and found another way around. The virtual cues gave them strong motivation for taking physical actions.

In general the students had difficulty with the subtlety of the investigation, indicating that the game play may have been too difficult for this age without additional scaffolding. Students were unable to interpret the clues within the interviews to inform them as to where to go next. Many of the clues were tentative, forcing the students to evaluate the authority of the person speaking to them and weigh that against other evidence that they had collected. The problem itself, to identify the source of the contamination and come up with an appropriate plan of action, was not well enough defined for them to know how to proceed. The solutions that students presented suggested that they were looking for someone that would give them the answer, rather than them having to construct their own answers from the data that they collected. This calls into question their previous experience in collecting and interpreting data and has led us to better understand relationships between previous scientific investigation experience and game play strategies. Whereas the college student groups did not find it unusual at all to be doing an open-ended investigation, high school students framed the game as a scavenger hunt activity whereby the goal was to find the correct answer.

Students rated the experience of interacting with the technology and investigative experiences very highly. They unanimously requested more time for their investigation, suggesting that some of the seemingly haphazard decisions that they made were as a result of time pressure. Students also requested further direction in their investigation – which could be done either through up front directions, or additional scaffolding built into the software.

This run also contained some experiments in group collaboration. First, most of the pairs of students were given walkie-talkies with which they could communicate with each other. Students were rarely heard sharing clues, but they did share a lot of their technical expertise with each other. Even when students requested instructions from one of the facilitators, those instructions could be heard by the entire group. Second, while each pair of students was given a Pocket PC, two pairs of groups were told that they should play as a collaborative team and design appropriate strategies. While the students responded that this was a positive aspect of the game, students did little more than share data in the end.

Conclusions

This paper explores the design experiment of Environmental Detectives, arguing for a rapid prototyping approach to game design. We explain our development process across five case studies involving four instructional contexts with two different populations of users. We found this rapid prototyping approach useful in articulating the design features of location-aware, augmented reality games, and demonstrating that such applications could be successful in formal learning environments. This approach allowed us to get user data quickly; only six months after our initial brainstorm we were working classes of students using the program. This case suggests the value in quickly coding solutions to technical, user, and educational unknowns before overdesigning software and instruction.

Across all five cases, we saw two different ways of playing the game, which map directly to the two kinds of investigation strategies that our environmental engineers reported using in the field. First, many students saw the problem as a mathematical sampling problem whereby the goal was to map how the contaminant (TCE) spread through the environment, ignoring the social problem of what might have caused the spill or what remediation strategies should be used to solve it. Students adopting this approach were largely unsuccessful in identifying the contaminant, chasing down numerous "dead-end" leads. The second approach, collecting interviews, also resembled a scavenger hunt activity, whereby students thought that the game would be "won" by talking to the right expert who would then give them the exact location to drill. Students adopted the language of the scavenger hunt quite plainly, talking across groups about "who collected the most interviews." The most successful groups negotiated both forms of data, much as the designers and environmental engineers hoped they might. These groups tended to have multiple strong personalities who each argued for a different approach (quantitative sampling vs. qualitative observations). Often, these playing tendencies fell along gender lines, with men preferring sampling strategies and women preferring to interview others.

Across cases, few groups ultimately designed satisfactory solutions. Most groups could either locate the general area of the toxin or some basic remediation strategies, but none of the groups had a coherent plan that showed where toxins came from, drew data from previous investigations provided in their library, and then created a suitable remediation plan. In fairness, the challenge behind Environmental Detectives was an open-ended challenge; while the exact location of the initial spill could be pinned down, there was no one ideal remediation plan. Good solutions, however, would account for the different remediation options and understand the strengths and drawbacks of each approach. Most students opted for politically easy answers, such as "plant some trees to help remediate the problem [phytoremediation, a legitimate, but inadequate strategy] and monitor the situation."

Teachers responded to this shortcoming by having students present their remediation plans before their peers and then discuss as a group potential causes and remediation plans. Some classes voted on which group had the best solution; others compiled their data into one or two ideal solutions. Across all implementations how the teacher framed collaboration and competition had a great effect on the ensuing behavior; some teachers wanted groups to collaborate, others allowed them to go alone and encouraged competition among groups. These results remind us that it is not only the game itself that determines how a game is played, but the encompassing culture (whether it be a community of game players or a classroom context) that determines many of the game-play practices (Squire, et al., 2003). As we engage in future development, we are paying more attention to what kinds of scaffolds we can build into the program or framing of the problem to support collaboration and competition among groups.

Implications

There is a saying in the games industry that good games are easy to learn and difficult to master. We found that Environmental Detectives was relatively easy to learn, and at least for these students, not masterable in 90 minutes. Failure, a hallmark of the game play experience and in many psychologists' eyes, a key precursor to learning (e.g. Schank, 1994), occurred often in this game. One can imagine students playing the game multiple times, iteratively playing, debriefing, and trying new strategies on new maps or with different contaminants. In addition to helping students succeed, allowing them to build strategies and then using success as one form of feedback indicating their success, multiple iterations might help produce transfer across contexts, as students build understandings that are not tied to one particular situation but are developed across multiple cases (Bransford, Brown, and Cocking, 1999). Unfortunately, none of the teachers we worked with were able to deploy multiple iterations of the game. One can imagine students trying the investigation once, debriefing, and then trying again on a new map.

Roschelle and Pea (2002) argue that a challenge for handheld developers will be in managing tensions between power and information flows. Leveraging what Jenkins and Squire (2002) call contested spaces, we find that power and information flows make good focal points for handheld games. In Environmental Detectives, students had incentive to share information, in that no two students could cover the entire field at once. In future iterations, we hope to leverage these design tension further, pitting different groups against one another so that they will have to critically evaluate the quality of information that they are giving away. Students will need to decide if the location or value of an interview is sensitive information which can be given away, or if it should be kept. We believe that the most powerful applications of handheld computers may be in exploiting these design tensions between power and information flows and embedding them as core components of the educational experience. Restated, if a core affordance of handheld computers are components of a dynamic system, then educational software designers might think of applications where students have to critically consider when to share information within the broader system and when to opt out and act independently.

Educational technologists might benefit by noting how rapidly handheld hardware technologies are developing. In the 12 month course of this study, the accuracy of GPS devices increased three or four fold without any increases in price. The cost and power of Pocket PCs themselves changed, as costs nearly fell in half and units became more powerful and efficient. We believe that the next 12 months will see similar increases in both GPS devices and Pocket PC technologies, suggesting that projects such as this, which may appear to be "boutique" projects out of the range of most schools may in fact be widely available within 3-5 years.

Anticipating this more ubiquitous use of handheld computers, we have advocated the development of a handheld augmented gaming platform which may be used to allow students and teachers to create customized, location-specific games. Already we have created a rudimentary toolkit and a second game iteration. Working with this toolkit, we have students building murder-mystery games and virtual tours which are pushing the boundaries of this system. We have also begun work on indoor positioning via wi-fi, which allows for an entirely new breed of game to emerge.

Feature	**Function**	**Pedagogical Value**
Simulated Tools	Recreate tools similar to those used in Probeware environmental sampling, but with capabilities beyond the scale of what actual Probeware is capable.	Allow players to encounter pedagogically valuable but practically unfeasible hypothetical situations.
Location Awareness	Move about in a real space and while provided with location specific information.	Encourage mapping of simulation to the environment; encourage interaction with physical space.
Non-Player Characters	Receive information by "interviewing" non-player characters distributed throughout the game in the form of text, graphics, and video.	Contextualize story through characters to appeal to broad audiences, encourage engagement, and facilitate meaningful learning (e.g. Cordova & Lepper, 1996).
Spatial Data Collection	Collect and analyze data that is inherently spatial.	Leverage affordances of the environment for learning and situate simulated activities in the real world.
Library Access	Provide background information on the problem at hand that is accessible to all.	Allow students to access just-in-time resources to better support learning.
Collaborative Tools	Allow players to share data through infrared beaming.	Support collaboration and knowledge building.
Covert Interactions	Enable events to happen to a player without their knowledge, triggered through timed events, location information or player interaction.	Increase engagement through surprise and create meaningful learning moments by triggering teachable moments.

Table 1: Features, functions, and pedagogical purposes behind the augmented gaming platform.

Figure 1: Map-based interface to Environmental Detectives.

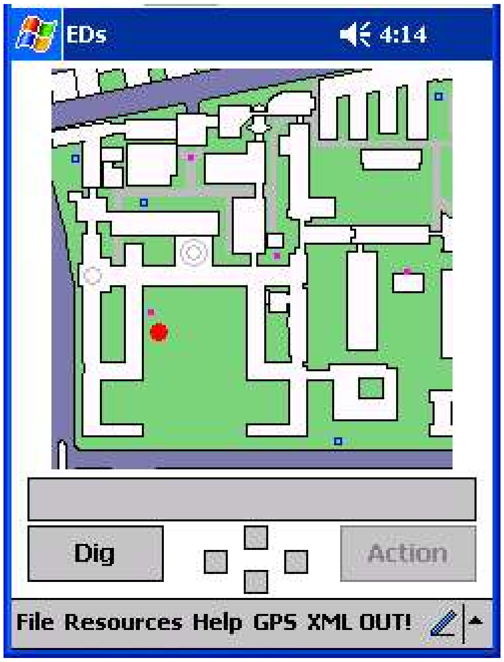
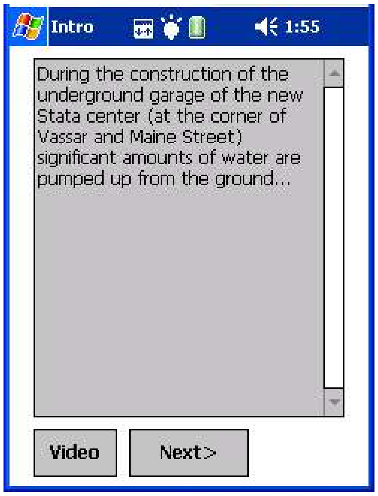


Figure 2: Initial, text-based problem Set-up



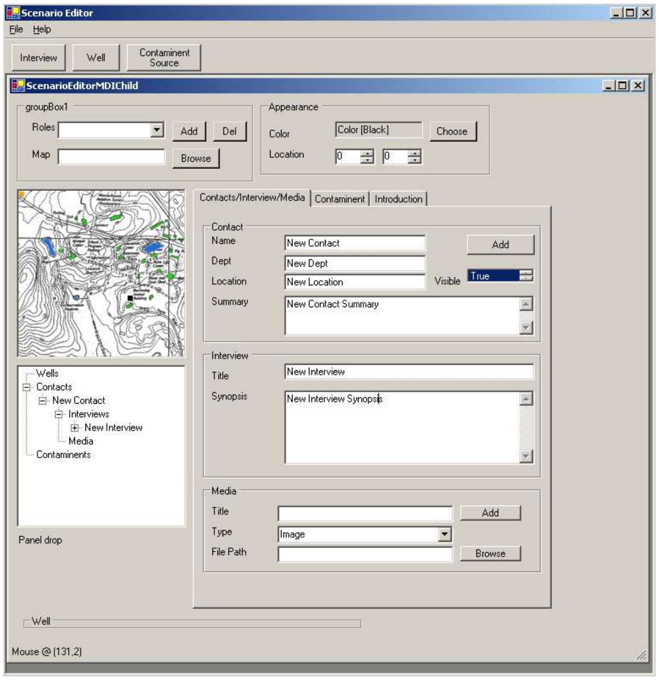
During the construction of the underground garage of the new Stata center (at the corner of Vassar and Maine Street) significant amounts of water are pumped up from the ground...

Figure 3: Remade Map-based interface and reorganized contacts list

Contact (Department, Location)

- AS Rep (Audubon Society, Society
- Charles Vest (Facilities, Livestock Sh
- Jason Casiano (Retail, Gift Shop)
- Karen Richmond (Veterinarian, Red
- Kris Scopinich (Education, Educatio
  - About Wells (Video)
  - * Pump (Image)
  - Wells and Drills (Blurb)
- Neil Finn (Nature, Nature Center)
- Pauline Maier (Facilities, Service She
- Peter Vacchina (Toxicology, Hill)
- Shirley Jackson (Librarian, Library)

Figure 4: Environmental Detectives Toolkit



Color: Color [Black]
Location: 0 0

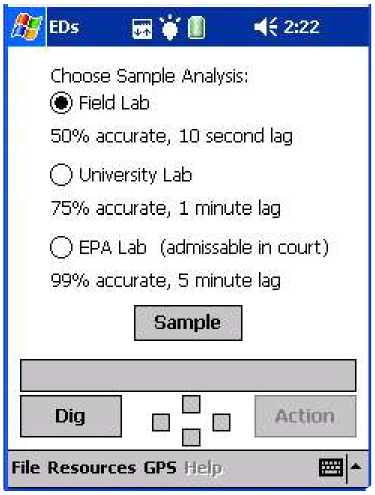
Name: New Contact
Dept: New Dept
Location: New Location
Visible: True
Summary: New Contact Summary

Title: New Interview
Synopsis: New Interview Synopsis

Type: Image

Mouse @ (131,2)

Figure 5: Trade-offs in time and accuracy



Choose Sample Analysis:

● Field Lab

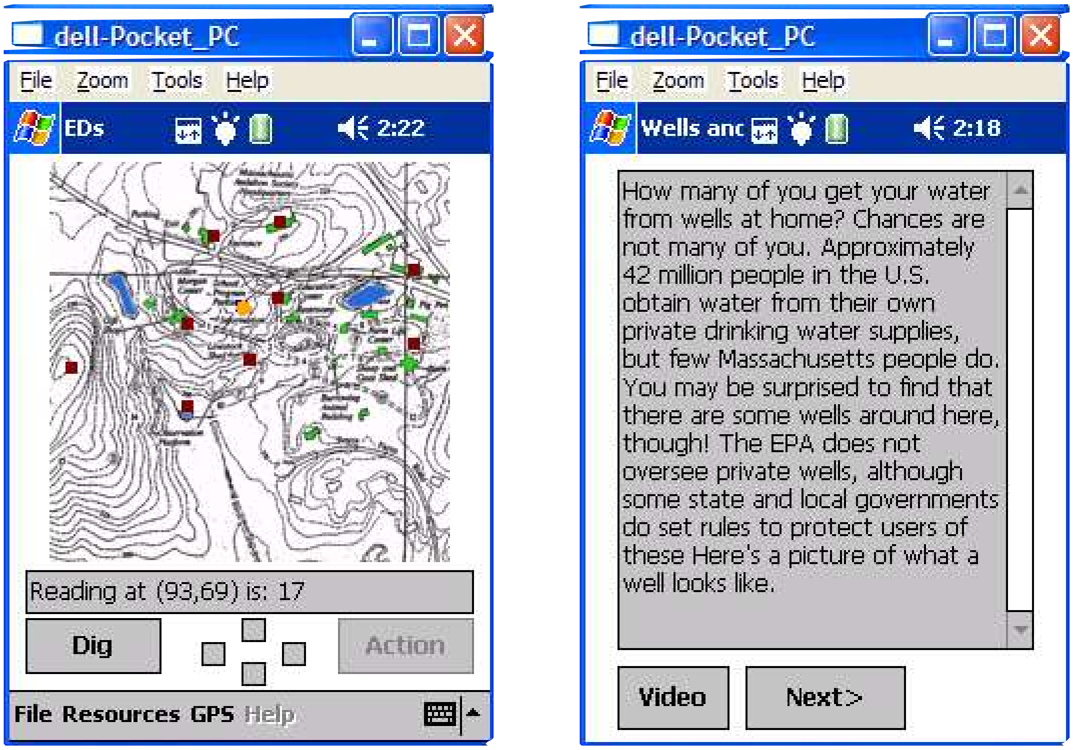
50% accurate, 10 second lag

○ University Lab

75% accurate, 1 minute lag

○ EPA Lab (admissable in court)

99% accurate, 5 minute lag



Reading at (93,69) is: 17

How many of you get your water from wells at home? Chances are not many of you. Approximately 42 million people in the U.S. obtain water from their own private drinking water supplies, but few Massachusetts people do. You may be surprised to find that there are some wells around here, though! The EPA does not oversee private wells, although some state and local governments do set rules to protect users of these Here's a picture of what a well looks like.

Figure 6: Screenshots from farm game implementation

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