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EcoMOBILE – Designing for contextualized STEM learning using mobile technologies and augmented reality

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Abstract

The ubiquity of mobile technologies can unlock new opportunities for "anytime, anywhere" learning, and some argue that portable mobile platforms will inherently lead to more contextualized learning experiences. However, the meaning of contextualization and how to achieve it in mobile designs bears further examination, as the greater the level of contextualization, the more difficult it may be to scale mobile designs. Context is a product of the interaction among learners, the personal, social and physical resources at hand, and mobile technologies. We examine how, through the affordances of mobile technologies, designers might emphasize different aspects of social and physical context in order to support learning. In particular, augmented reality enables students to interact—via mobile wireless devices—with virtual information, visualizations, and simulations superimposed on real-world physical landscapes.

The EcoMOBILE activity considered here involved student participation in an outdoor field trip near their school using mobile broadband devices running augmented reality software. We present a case study highlighting two designs focused on a similar middle-grades science learning goal of exploring the local watershed – a place-dependent, collaborative design ("Take a Tour") and a place-independent, individual design ("Follow the Flow"). We implemented these designs with two different teachers each with four classes of students. We present detailed comparison of the design logic and features of each experience, and a summary of feedback from interviews and student focus groups with attention to feelings of contextualization, engagement and support for learning. Our results showed little difference in student comments related to the contextualization of the experience, which suggests that carefully constructed, yet minimalist designs may support a perception of contextualization that comes from the perspective of the user rather than from the device. A place-independent mobile learning experience may, with minimal modification, be used in a location other than the one in which it was designed, and may still have positive effects on feelings of contextualization, engagement and support for learning among participants.

Keywords
Augmented reality, mobile, ecology, ecosystem science, place-based, outdoor, field trips, middle school,

Biographical Sketches

Amy Kamarainen is a senior research manager at the Harvard Graduate School of Education. With a background in ecosystem science, Amy applies her understanding of science, technology, and learning to the design and evaluation of technologies that support science learning inside and outside of the classroom. The Ecological Society of America named Amy an Ecology Education Scholar in 2011.

Shari Metcalf is the Project Director of the EcoMOBILE and EcoXPT projects at the Harvard Graduate School of Education, and was Project Director of EcoMUVE. Her prior research focuses on educational technology projects in science, math, and sustainability education, including research on computer-based data collection and analysis tools for middle school science students. Her professional interest centers on the design of modeling, simulation, and immersive environments to support inquiry-based STEM learning.

Tina Grotzer is Associate Professor at the Harvard Graduate School of Education and a senior researcher at Project Zero. Her research investigates how complex forms of causality interact with learning. Tina received a Career Award from the National Science Foundation (NSF) in 2009 and a Presidential Early Career Award for Scientists and Engineers (PECASE) in 2011. She is the author of Learning Causality in a Complex World (Rowman Littlefield, 2012) and lead author of the Causal Patterns in Science curriculum series.

Chris Dede is the Timothy E. Wirth Professor in Learning Technologies at Harvard University. His fields of scholarship include emerging technologies, policy, and leadership. His funded research includes grants to design and study immersive simulations, transformed social interactions, and online professional development. In 2007, he was honored by Harvard University as an outstanding teacher, and in 2011 he was named a Fellow of the American Educational Research Association. He is currently serving as an Intermittent Expert at the US National Science Foundation.

Introduction

The potential affordances of mobile applications for learning include portability, social interactivity, context sensitivity, connectivity, and personalization (Churchill & Churchill 2008; Klopfer, Squire & Jenkins 2002; Liaw Hatala & Huang 2010; Traxler & Kukulska-Hulme 2005, Squire 2009). With these affordances in mind, context becomes key, as the power of mobile devices to support learning depends on a situated and contextualized decision to harness these affordances in service of learning. The ubiquity of mobile technologies can unlock new opportunities for "anytime, anywhere" learning (Sharples, Taylor & Vavoula 2005), and some authors assume that the portability of the mobile platform implies that learning with such devices will naturally be contextualized

(Naismith, Lonsdale, Vavoula & Sharples 2004, Looi , Seow, Zhang, So, Chen & Wong 2009).

However, the meaning of contextualization and how to achieve it in designs for mobile devices bears further examination (Sharples 2010 in Brown 2010). Context, as viewed from the perspective of situated learning theory (Greeno 1998; Brown, Collins & Duguid 1989), "is an emergent and integral property of interaction" (Liaw et al. 2010). Context is a cloud of influence, which is present, but not always discernable or actionable by the learner or the designer. Studies show that appropriate contextualization of learning can have positive effects on motivation and engagement (Cordova & Lepper 1996; Barab, Pettyjohn, Gresalfi, Volk & Solomou 2012). Mobile technologies can act as a mediator by shifting a learner's perspective on, access to, and awareness of elements of context. This leads us to consider the interaction among learners, their social and physical context, and mobile technologies. Mobile learning designers may consider the affordances of mobile technologies to invoke or promote dimensions of the social or physical context to serve engagement and learning.

Augmented reality (AR) applications, in particular, provide a mechanism by which designers of learning activities can configure natural environments as a rich physical and social context for learning (Klopfer 2008; Perry et al. 2008; Dunleavy, Mitchell & Dede, 2009; Squire 2009). AR applications use mobile broadband devices to provide learners access to digital information embedded in a physical location or outdoor environment (Dunleavy & Dede 2013, Klopfer 2008). Specifically, location-aware augmented reality uses the global positioning system (GPS) capabilities of the mobile device to trigger digital information at appropriate locations and times (Perry, Klopfer, Norton & Ave 2008; Price & Rogers 2004; Squire & Jan, 2007; Dunleavy & Dede 2013). Meanwhile, the design of the location-aware activity can guide students to work individually or in groups. Thus, the outdoor learning environment is instilled with physical and virtual learning resources available during the activity, and the social mode of interaction with these physical and virtual resources is shaped by the design of the activity.

Our work is focused on the domain of ecosystems science, and so natural environments are a focal physical context for application of ecosystems concepts and practices. Indeed, some argue that learning about science *requires* opportunities to observe and experience concepts in relation to real-world contexts, problems and issues (Davies 1996; Hodson 2003). Understanding the water cycle and watersheds is a fundamental learning goal for middle grades science courses, yet previous work shows that students have difficulty in understanding underground components or invisible processes involved in the water cycle, and find it difficult to connect textbook representations to water in their own backyards and neighborhoods (Gunckel, Covitt, Salinas & Anderson 2012; Shepardson, Wee Priddy, Schellenberger & Harbor 2007). Providing learners with rich and meaningful learning experiences that take place in the outdoors while also addressing learning goals dictated by standards is a big challenge. Mobile technologies afford rich opportunities to embed learning activities in a community or local outdoor area and thereby situate them in a physical context that is relevant to students and that can scaffold transfer (Grotzer, Powell, Kamarainen, Courter, Tutwiler, Metcalf & Dede 2014).

Theoretical Framework and Literature

Learners can gain deep knowledge and transfer skills when supported by activities placed in rich, real-world contexts, which allow construction of new knowledge based on 1.) personal context, 2.) sociocultural context, and 3.) physical context, including the resources available through instruction, scaffolding, and interaction (Falk and Dierking 2000). While this three-part model for contextualization proposed by Falk and Dierking captures a broad view of contextualization from the perspective of a learner, we found it useful to further consider context from the perspective of the designer using a hierarchical view proposed by Lonsdale and others (2004).

Lonsdale and others (2004) specify a nested hierarchy of contextual resolution, with "context" placed most broadly, then, with increasing granularity, the "context state", "context substrate", and "context features". This hierarchical view sets a frame within which a designer can consider what elements and scales of the context are "fixed" versus actionable within the design. Within the time and space of the proposed experience, what potential elements of context are relevant and useful? Further, what affordances of mobile technologies allow the designer to access, reveal or emphasize particular features of personal, sociocultural, or physical context?

Mobile technologies lend a number of affordances that support contextualization (Looi et al. 2010). Here we choose to focus on two aspects of contextualization – sociocultural contextualization and physical contextualization (Falk and Dierking 2000). Sociocultural contextualization may be thought of as setting individuals vs. groups as a locus of control and decision-making within the design. To what degree is group work and social interaction required and mediated by the mobile technology? At one end of the spectrum, the focus of design may be on the individual, calling forward one's personal experience and allowing the expression of identity, while encouraging individual action, agency, and responsibility (Figure 1). At the other end of the spectrum, a design may focus on teamwork, collaboration, and communication, requiring participants to work together, negotiate and peer-teach. Designs of mobile learning experiences that focus on the mobile device's affordances for personalization tend to promote the individual perspective, while designs that focus on the communicative and social interactive affordances of mobile devices push toward social and aggregative use of the technology.

Similarly, there is a spectrum along which we can think about the physical contextualization of mobile learning designs (Figure 1). Here we refer to geographical physicality of the user during the experience. At one end we can think about mobile learning designs that are place-independent. These could be mobile apps or games that make the most of mobile portability and work anytime and anywhere (Klopfer 2008). One example is the suite of mobile games (Ubiq Games) developed in the UbiqBio project, including a game called Island Hoppers — a mobile game in which the user can control the environmental conditions on a fictitious island with a population of bunnies (Perry and Klopfer 2014). The changing environmental conditions have effects on the traits displayed by the bunnies, and the game is intended to help students learn the mechanisms of evolution using game play. In games and experiences like this, the context is self-contained and self-referential such that there is no necessary tie to the physical environment or context; the aim is that they can be used in any context and across contexts (Klopfer 2008).

At the other end of the spectrum are place-dependent mobile designs, in which the mobile device and design take advantage of aspects of the physical environment to support learning (Squire 2009). In this case, the designer must know about specific elements of the physical location or environment and be able to predict aspects of the physical context in which the experience will take place. These designs may be particularly relevant in the case of informal learning environments such as science museums, cultural institutions, or outdoor environments (Price and Rogers 2004). An example is an experience called Mentira, developed to teach Spanish within the context of a particular neighborhood in Albuquerque, New Mexico. The game guides learners to visit specific locations in the neighborhood and the learning activities are set within the context of historical events that occurred in those places (Holden & Sykes 2012). Thus, the degree to which various affordances are harnessed within the design of the mobile learning activity can dictate where on the spectrum of contextualization the experience may fall (Figure 1).

AR platforms (e.g., FreshAiR, ARIS, TaleBlazer) provide mechanisms to integrate learning activities with game-based, problem-based, or narrative wrappers, which may serve as a mechanism for invoking personal, sociocultural and physical contexts for learning (Klopfer 2008; Squire 2011; Dunleavy and Dede 2013). AR activities may be designed as “place-dependent,” in which the experience leverages and relies on specific physical or historical elements of the space where the experience is situated; or “place-independent,” in which the experience is highly portable and place-agnostic (Klopfer 2008; Squire 2010; Dunleavy & Dede 2013). As AR and mobile technologies become increasing available and popular, it is important to understand whether and how place-dependent and place-independent activities can be designed to support student engagement and situated STEM learning, as the two approaches present a tradeoff between local relevance and scalability.

Here we present the design of an augmented reality learning experience called “Explore Your Watershed”, and describe two versions of this activity: one place-dependent and collaborative (“Take a Tour”) and one place-independent and personalized (“Follow the Flow”) (Figure 1). We describe how contextualization was envisioned generally for “Explore Your Watershed”, and then realized in the design of these two distinct experiences. Given that contextualization is an emergent property of the experience and is perceived by the user, we present results of interviews and focus groups to document how the student participants perceived various aspects of contextualization following participation in the experience.

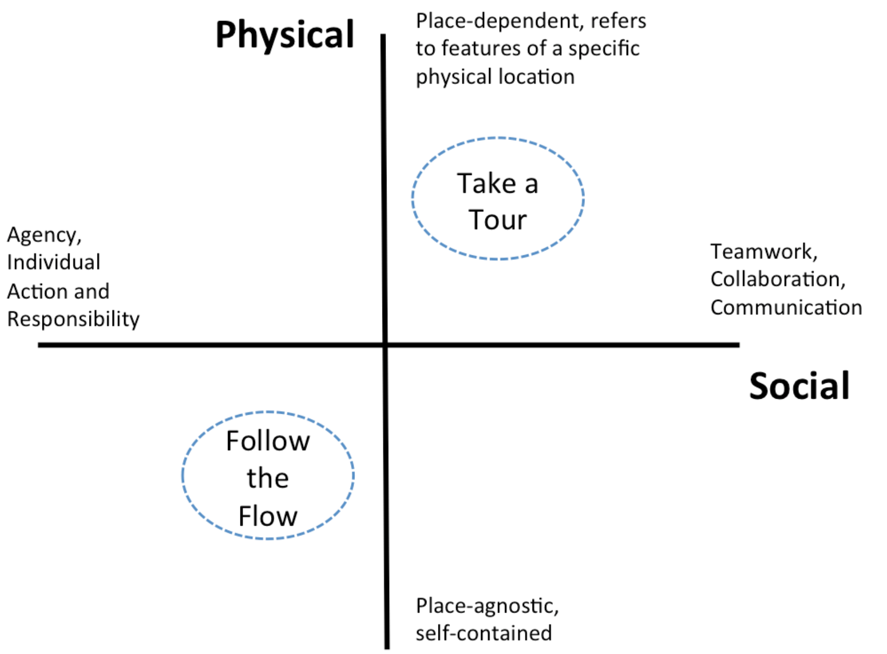

Figure 1. A visual representation of two dimensions of contextualization – social and physical. The dotted ovals show the augmented reality experiences developed for this project ("Follow the Flow" and "Take a Tour") in relation to these two dimensions.

Context and Design

As part of the EcoMOBILE (Ecosystems Mobile Outdoor Blended Immersive Learning Environment) National Science Foundation grant-funded research project, we conducted a pilot study in which an augmented reality application (FreshAiR, playfreshair.com) was used to create two versions of an outdoor learning experience called "Explore Your Watershed" – one place-dependent and one place-independent – to help middle school science learners (ages 11-14) understand how water flows in their watershed. Our goal was to use the affordances of the mobile technology to situate students' understanding of aspects of the water cycle within their own watershed. Also, we specifically used affordances of the mobile technology to reveal invisible processes (e.g., transpiration) and invoke geographic awareness associated with watershed concepts (Gunckel et al. 2012). The context-aware AR application uses the GPS functionality on a mobile broadband device (such as smartphone or tablet) to present students with visual overlays, questions, text, videos, images, and animations that are triggered upon arrival at designated locations. Student activities with FreshAiR are conducted using 3G enabled smart phones running on a commercial mobile data plan.

We relied on a number of technical affordances and design mechanisms to support physical and sociocultural contextualization during the experience, and we describe these below.

We took advantage of the following affordances of the FreshAiR AR platform in our designs:

- selection and tailoring of information based on "roles".
- location-based "hotspots" or triggers (based on heads-up display).
- display of text, images and videos.
- delivery of multiple choice and open-ended questions.
- two-way branching of pathways through the experience based on the answer to a question.
- a history view, which allows users to see previous information.

The **"Explore Your Watershed - Follow the Flow"** experience was designed as a *place-independent* experience with the idea that the content, hotspots, and media embedded in the experience could easily be transferred (by a teacher or other user of FreshAiR) to a new location. The design requires that the target location would have a form of running water accessible to the user at the second hotspot, but otherwise does not refer to specific physical features of the location in which the experience is embedded.

The **"Explore Your Watershed – Take a Tour"** experience was designed as a *place-dependent* experience, and was designed to give students a similar introduction to water flow through a watershed using the design plans and features of a recent renovation to the school's parking lots and water runoff system. The renovations included installation of permeable parking lot surfaces, grass swales along the edges of parking areas, and a grassy infiltration basin connected to an exposed pipe leading to a holding pond on the property (Figure 2). A connection between physical landscape features and media displayed to the student was built into the design. Specifically, when students arrived at a location in the real world with, for example, a constructed water infiltration system below ground (Figure 2B), the augmented reality software delivered a view of the blueprints for the underground filtration system (Figure 2A) and provided information about how water flow and filtration occur. Therefore, content and media displayed in the augmented reality application referenced specific physical features present at the hotspot locations.

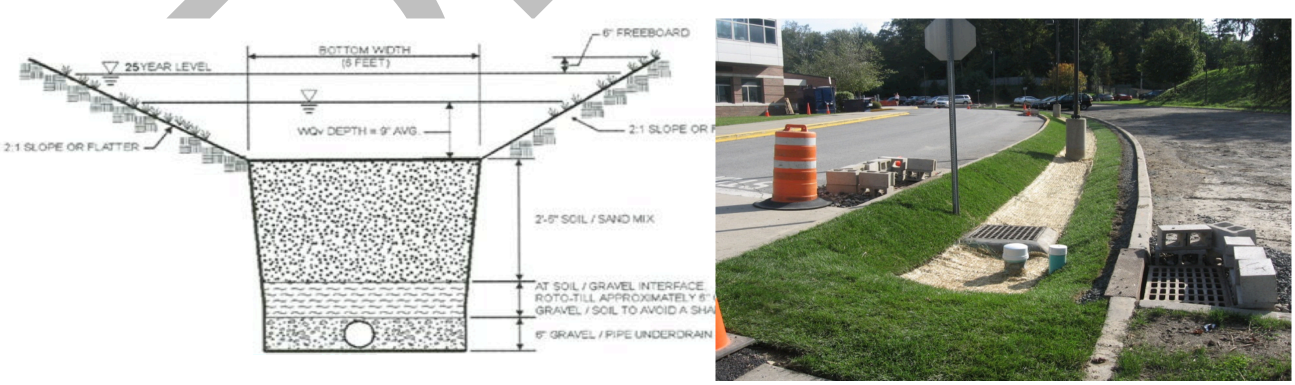

Figure 2. Panel a shows a below-ground schematic view of the design plans for a water infiltration system installed near the parking lot of the school. Panel b shows the same system as it appears in the real world.

Explore Your Watershed – Follow the Flow

Figure 3 provides an overview schematic design diagram showing the sequence and connections among hotspots and content for the Explore Your Watershed – Follow the Flow activity. After a brief introduction, participants began with a question to probe their understanding of the concept of a watershed (MC – watershed), and for students whose definition of watershed was not correct, the multiple-choice functionality of FreshAiR delivered just-in-time feedback in the form of a video about watersheds. Then students were prompted to look for the waterway nearby and physically scoop up a handful of water and drop it somewhere nearby (Figure 4a). The design pre-supposes that students would drop the water either on pavement or on a grassy or vegetated area nearby, so offered these two options, once again using the multiple choice functionality (Figure 4b). After this branch point in the design, participants would follow the flow of water either over land, or as it infiltrates into the soils and eventually into the ground water (Figure 4c and 4d). Regardless of which path the students initially chose, after their path reached its conclusion, they also had the option to follow the other path. Both paths of the experience eventually converged at a virtual "wetland" hotspot where the water is stored until it flows further downstream.

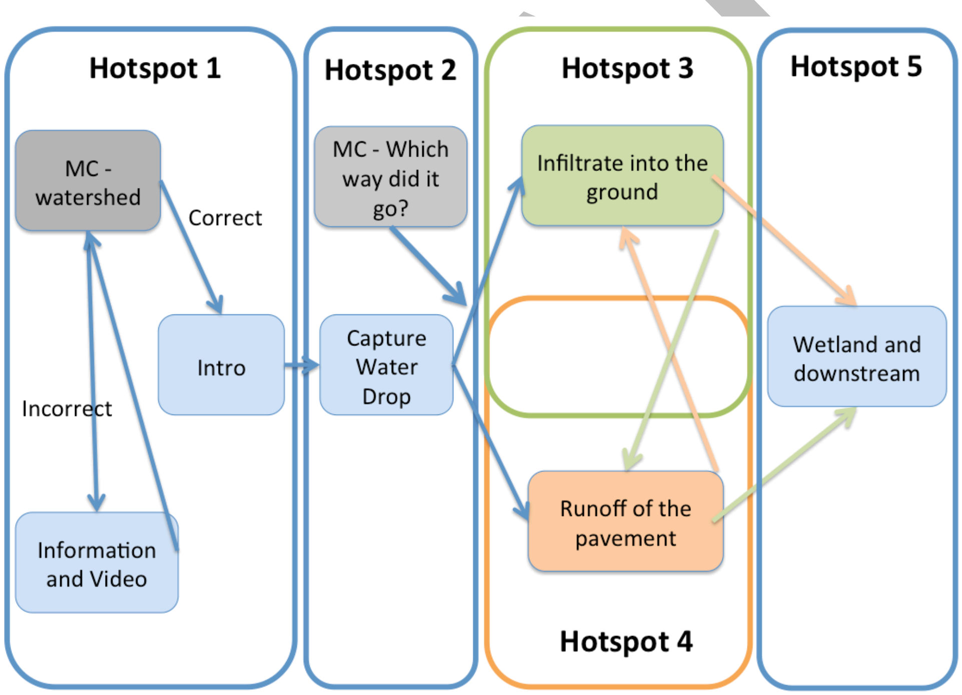

Figure 3. A schematic diagram showing the hotspots and sequencing in the Explore Your Watershed – Follow the Flow activity.

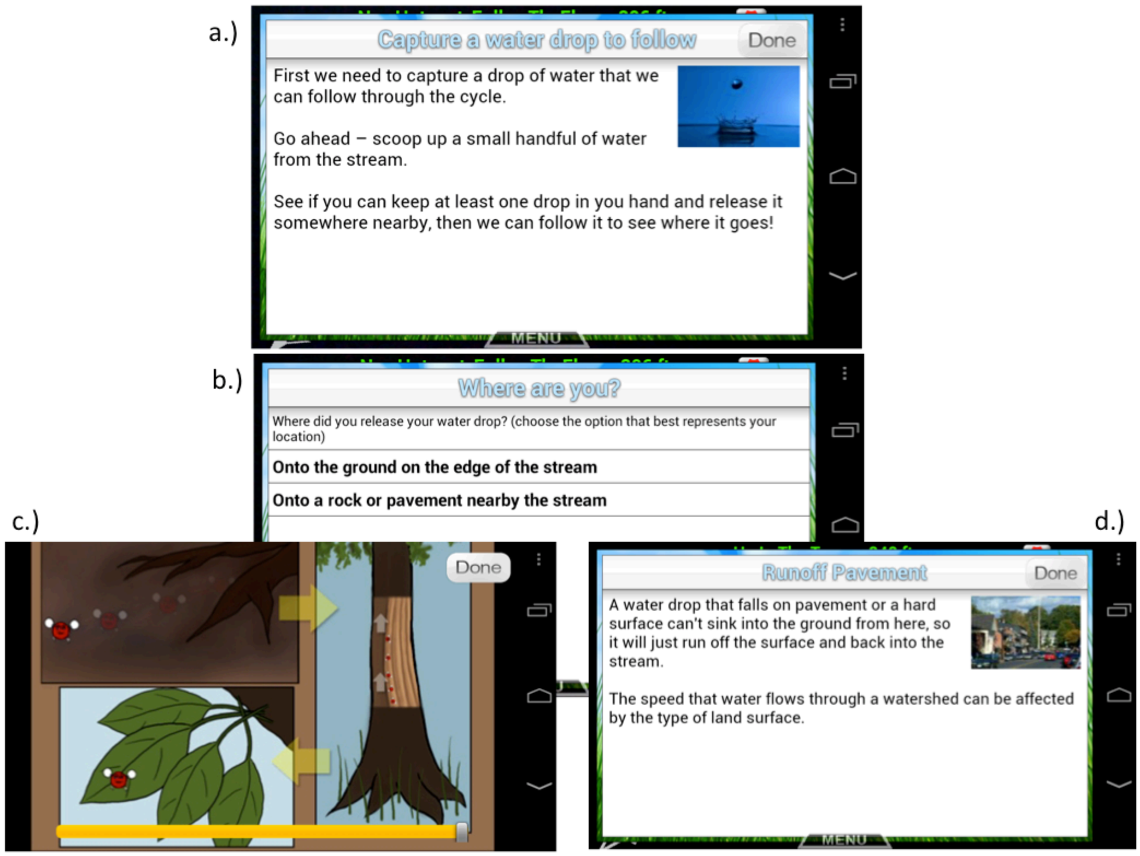

Figure 4. Screenshots of the media and instructions delivered to students using "Follow the Flow" activity when they arrive at Hotspot 2 (a and b), Hotspot 3 (c) and Hotspot 4 (d). Panels c and d demonstrate branching between two distinct pathways through the experience. Panel c was accompanied by text that read, "Water that drains into the soil may be taken up by tree roots and later released into the air through transpiration. At the same time, the tree roots help to keep soil from being washed away when it rains. This helps to prevent erosion."

While the design was place-independent from a designer's perspective, the activity does prompt users to interact with physical features in the landscape and therefore a form of physical contextualization is still achieved.

The social contextualization of this experience was designed toward the individualized end of the spectrum (Figure 1). The multiple choice question at the beginning allows the designer to deliver additional information to users who need it, but allows students who already have a grasp of the concept to move on more quickly. This provides a way for a designer to insert some degree of differentiated instruction within the augmented reality experience. Then, the user is given personal agency by being prompted to physically visit the stream bank and scoop up a handful of water. The action of moving water from the stream and dropping it somewhere nearby is meant to engage the user as an active participant in the storyline as they track where a virtual water drop goes next. As the user drops the water and uses the multiple choice selection to indicate the type of land cover on which the drop landed, the user may feel as though they are a participant in a "choose your own adventure" type of story. Finally, the movement of the student over the landscape as they go from hotspot to hotspot becomes a physical and experiential manifestation of the pathway the virtual water drop traveled. The design is intended to allow the user to access the content and hotspots at their own pace, and the sequential delivery of information based on location-based triggering when a user arrives at the virtual hotspot is intended to encourage a feeling of personalization.

Explore Your Watershed – Take a Tour

The Explore Your Watershed – Take a Tour experience used a mystery narrative to engage students in investigating the pathway a "suspicious" water drop had traveled. Informants were placed at augmented reality hotspots, and clues referenced physical features present in the environment (Figure 5). On the initial page of the experience, students were split into two groups, each of which followed separate, but complementary paths through the experience. The experience began with a watershed tour led by a virtual narrator called "Ranger Susan," but this tour was interrupted by a private investigator who asked the students to help (Figure 6). Both groups of students investigated how the water got into the stream; those on the "unseen" path explored overland flows, infiltration into the soil and groundwater - pathways that are not visible on the surface, while those on the "seen" path followed water through storm sewer grates, pipes, and landscape features that were visually apparent (Figure 5).

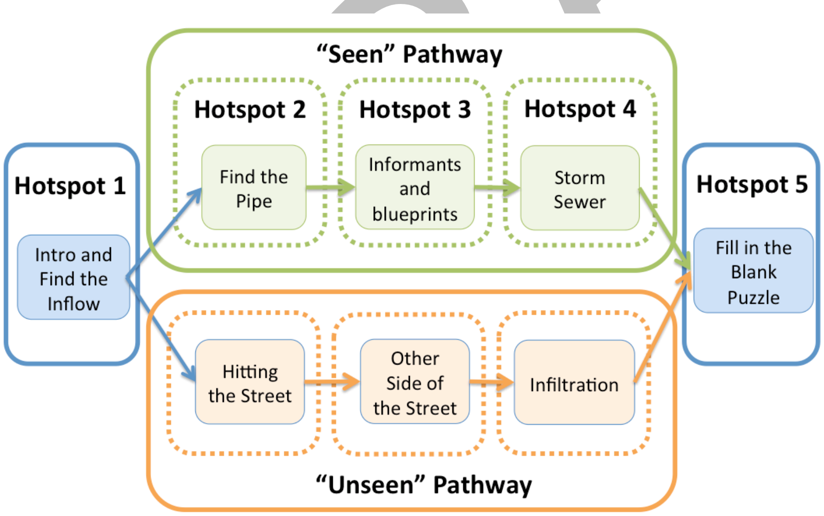

Figure 5. Schematic diagram showing the design of the Explore Your Watershed – Take a Tour experience.

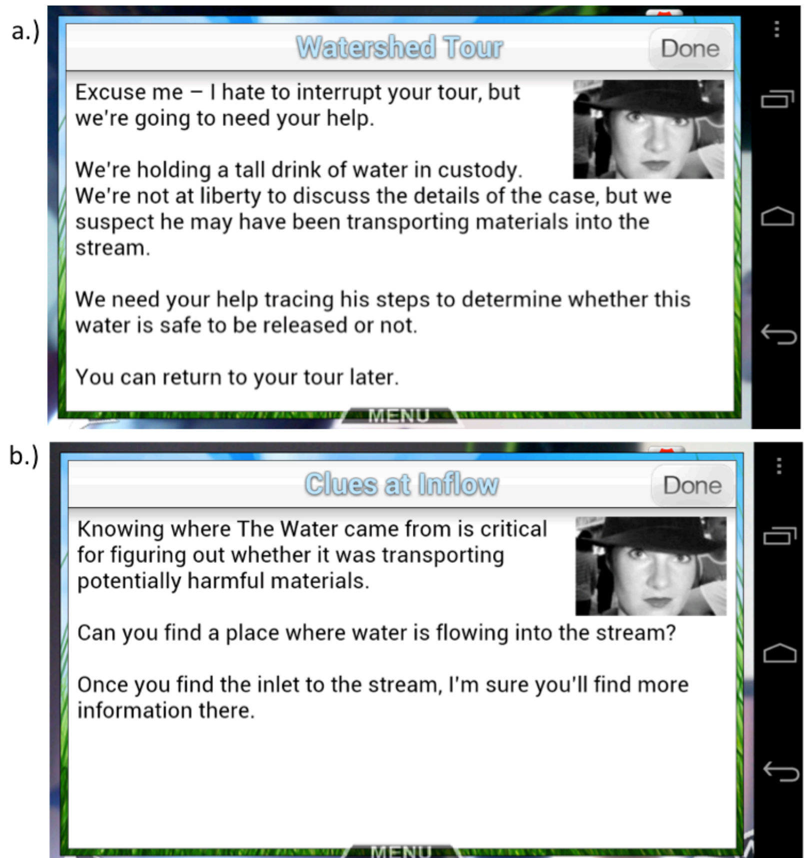

Figure 6. During the introduction a "private investigator" character interrupts the watershed tour to ask for the users help (a), and then directs them to explore and find the inflow to the stream (b). After tapping "done" the students saw a virtual hotspot near the location of the inflow.

Students following the "seen" path began by finding a hotspot at the edge of a pond where water was flowing from a small retention basin into the stream below (Figure 6). These students continued to a hotspot at the far edge of the same small pond where they saw a large pipe and spillway leading into the pond (Figure 7). The students next visited a hotspot located even further uphill where a small area of land was located behind a fence, and at this location the students were able to choose between receiving information from two different informants, using the multiple-choice and branching functionality of the FreshAiR platform (Figure 8a). These informants provided information and views of "blueprints" for the water filtration structure underlying the ground in that area (Figure 8b-8d). Students traced the water flow all the way back to a storm sewer grate near the road and parking area where water initially enters the storm sewer pipes and filtration system.

Figure 7. Students working together on the Take a Tour – Seen experience. They are standing near hotspot 2 where a large pipe leads down a rocky spillway into a retention pond (visible in the background).

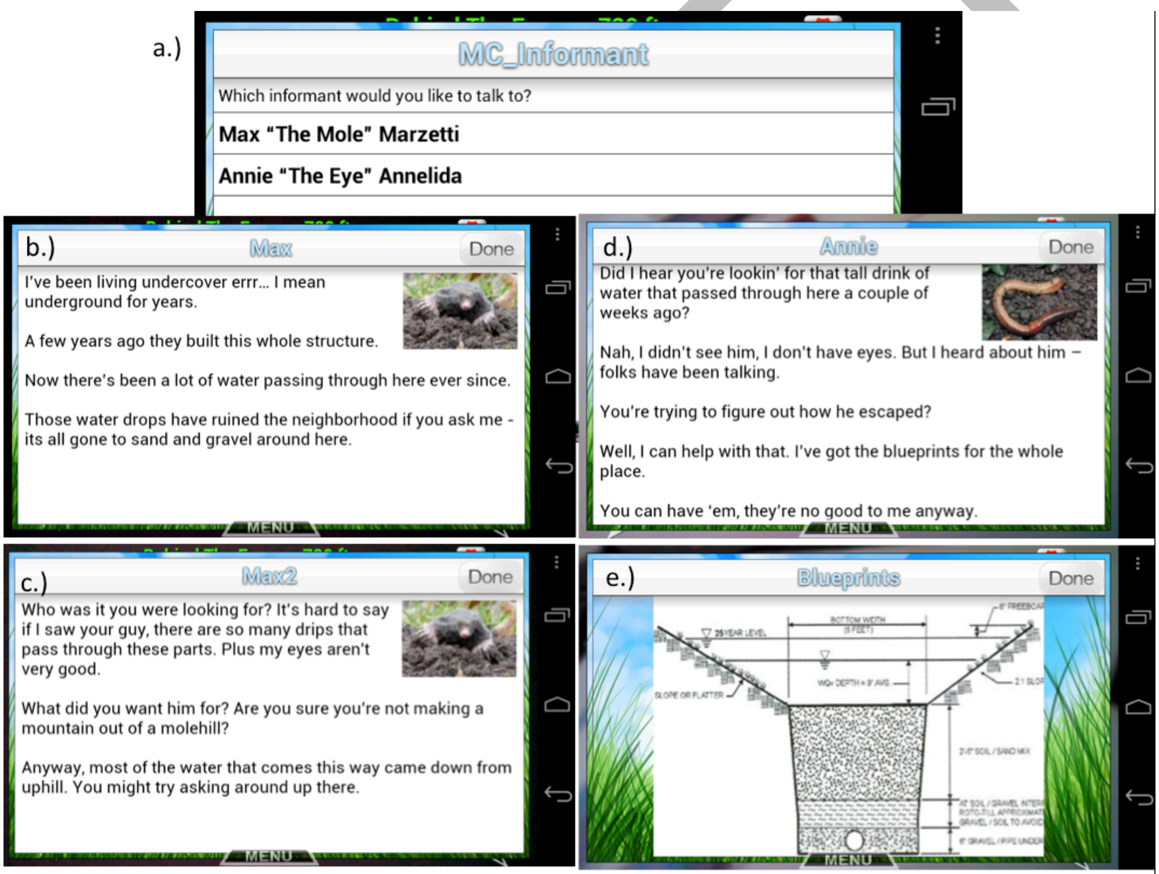

Figure 8. Screenshots showing Hotspot 3 for the "Seen" pathway. The multiple-choice functionality was used to provide students a choice of receiving information from two different "informants" (a). Panel (b) and (c) show text-based clue provided to the "seen" role by the informant named "Max 'The Mole' Marzetti". Panel (d) shows text-based clue provided to students playing the "seen" role by an informant named "Annie 'The Eye' Annelida", including virtual blueprints (e) for the water filtration system buried in the ground.

Students following the "unseen" path began similarly by finding the inflow between the pond and stream, but from there they navigated to a hotspot on the edge of a nearby road (Figure 9a). There, the students learned about how quickly water flows over roads and pavement and that it cannot soak into the ground through these surfaces, but may pick up suspended materials along the way. At another hotspot located on the other side of the road in a grassy area near trees, students learned about infiltration, transpiration, subsurface flow, and groundwater (e.g., Figure 9b). Thus, students following the "unseen" track were exposed to pathways for water flow that are less visually apparent, but are revealed through information, videos and images delivered through the AR platform.

a.)

b.)

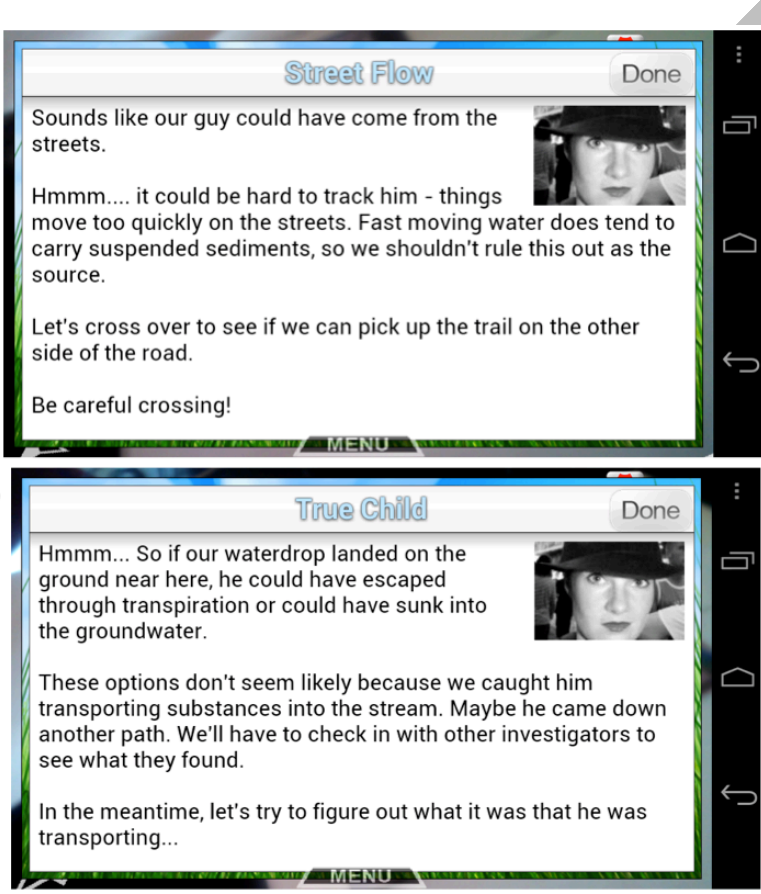

Figure 9. Information delivered to students playing the "unseen" role at the "Hitting the Streets" hotspot. Information delivered to students playing the "unseen" role at the conclusion of the "Infiltration" hotspot.

Eventually, the students on both paths needed to complete a fill-in-the-blank puzzle to solve the mystery of what the suspicious water had carried into the stream (Figure 10). In order to do so, the students could rely on clues embedded in the content of the experience (accessible later through the history function) or could collaborate with students who had followed the complementary path, as the clues provided to each were different (Figures 10a and 10b).

The Explore your Watershed – Take a Tour experience was place-dependent, as the content and hotspots throughout were located at and referred to specific physical features unique to this place – the holding pond, the drainage pipe, the road, constructed water filtration systems, and storm sewer drains. The augmented reality application and associated hotspots helped students navigate to and find these features in the area. This experience also helped students think about less obvious (underground and subsurface) pathways the water may flow by linking the above-ground view at a location with "blueprints" of the water filtration system buried beneath their feet.

The social contextualization of this experience was closer to a group-oriented experience than the 'Follow the Flow' experience (Figure 1). While students each had their own phone, received individual information and instructions, and could work at their own pace, the experience was structured by the two pathways through the experience and students could best meet the goal of the experience by collaborating with other students who had followed the opposite path (Figure 8). We used the "role" functionality provided by the augmented reality platform to construct different, but complementary paths for the experience. The use of inter-dependent roles is a common approach in the design of augmented reality experiences and games (Bressler & Bodzin 2013; Klopfer 2008; Dunleavy & Dede 2013), and follows from theories of group learning that support cooperative learning.

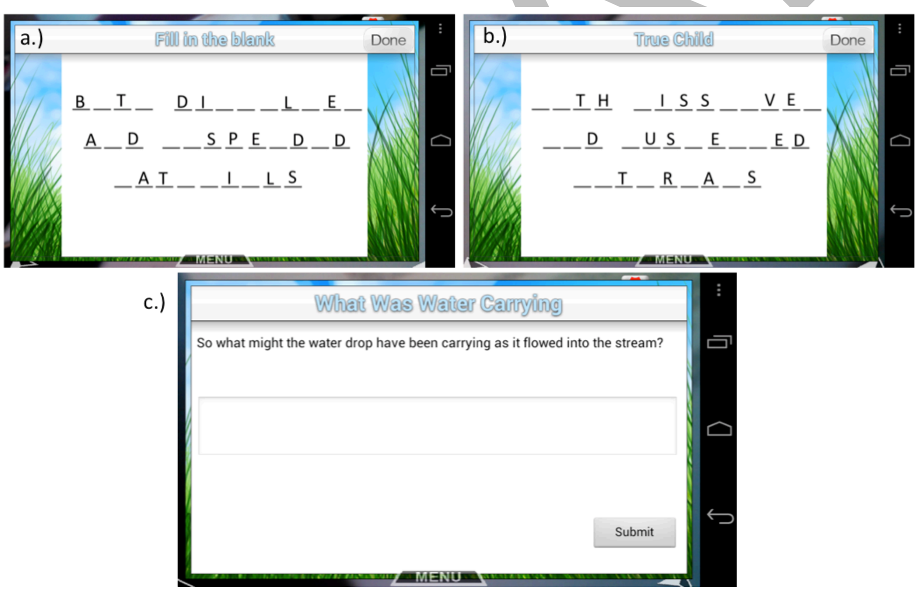

Figure 10. Fill-in-the-blank puzzle delivered to students following the "unseen" (a) and "seen" pathway (b). At the end of the experience, an open-ended question (c) provided a space for them to enter the answer to the fill-in-the-blank puzzle and receive feedback.

Implementation and Data Collection

The implementation of these two versions of the "Explore Your Watershed" EcoMOBILE experience was carried out with two teachers at two different schools each with 4 classes of 8th grade students (ages 13-14) in a relatively high socio-economic status school district outside of New York City. EcoMOBILE was integrated into their ecosystems science unit and was used in conjunction with the EcoMUVE curriculum (Metcalf et al., 2011). EcoMUVE is an inquiry-based ecosystem science curriculum that uses a multi-user virtual environment (MUVE) on laptop computers in the classroom. In EcoMUVE, students take on the role of a scientist in the form of an avatar, and they can navigate throughout the 3D virtual world to collaboratively collect data, information and observations to better understand the virtual ecosystem and changes happening there. The students working with Teacher A had completed the full EcoMUVE curriculum, while the students working with Teacher B had completed at least 3 days of the EcoMUVE curriculum before the field trip.

Each class received a short introduction to the technology and objectives of the field trip on the day before the field trip. The field trip was conducted during a 50-minute class period to a stream area immediately adjacent to the school. The place-dependent version of "Explore Your Watershed" (Take a Tour) (Figure 5) was implemented with Teacher B with four classes (n ~80) and the place-independent version (Follow the Flow) (Figure 3) was implemented with 1 teacher who also had four classes of students (n ~80). After the "Explore Your Watershed" experience, the students in all groups also completed additional field activities, one called 'Biotic-Abiotic Challenge' in which they looked for biotic and abiotic aspects of the environment and captured images in a note taking application called Footprints, and another in which they used another AR activity to learn more about various aspects of water quality (e.g. pH, dissolved oxygen and turbidity) which they then measured with environmental probes. For this chapter, our focus is on the ways in which the augmented reality application and design may support contextualization, so we limit our reporting to the aspects of the experience relating to use of AR by the students.

Throughout the field implementation of EcoMOBILE "Explore Your Watershed" experience, one researcher was documenting the experience with a portable video recording device and this person served as a troubleshooting assistant and silent observer. During the last 15 minutes of the experience the researcher collected open-ended feedback from participants, using prompts like "How did it go?" and "What did you think?" This resulted in impromptu and relatively unstructured summative interviews with participants immediately following the experience. In addition to these field-based exchanges, we conducted summative interviews with a subset of students who had participated in each experience in the days following the activities (including "Explore Your Watershed", "Biotic-Abiotic Challenge" and the water quality measuring activity). Students in Teacher A's class were interviewed in pairs, while students in Teacher B's class were interviewed in a focus group format.

All video data were transcribed, and the video clips were divided into exchanges, defined as a single topic- or question-based interaction between the interviewer and an individual or group of participants. In cases where interactions between the researcher and participant were more extensive, natural breaks in the interaction (marked by question prompts or changes in topic) were used to break the longer interaction into individual exchanges. In the case of exchanges that arose in response to reflective prompts from the researcher ("What did you think?"), we used a grounded coding approach to identify aspects of the experience that students reported as engaging or supportive of learning and also documented instances where students reported glitches or confusion in the content or the technology. The student responses were coded by two independent coders who were blind to which experience the participants had used, and the inter-rater reliability showed at least 80% agreement for each code category and an overall average of 93% agreement across all coding categories. We describe the overall characteristics and themes present across both experiences, and also assessed whether these themes differed in frequency between the two versions of the experience.

Results

Across the two teachers and total of 8 classes we documented 20 responses to the "What did you think?" prompt (11 from "Follow the Flow", and 9 from "Take a Tour"). A further 6 exchanges were collected based on the focus groups and post-interviews. Below we summarize findings based on these data sources. We found the emergence of common themes across both versions, and the frequency of these themes did not differ strongly between the versions. Below are representative quotes from the "What did you think" impromptu interviews from each group.

Take a Tour:

> *Interviewer: What did you think?*
> *Student: We got to use the phones and we were right there. The information just popped up in front of us. It was easy. It wasn't very difficult like I thought it would be.*
> *Interviewer: What was interesting or fun?*
> *Student: I found out that the dissolved materials were falling into the pond like from the rain and the water coming from the driveway and I didn't know that before. I found out why we have fencing in of the land or driveways.*
>
> *Interviewer: What did you think?*
> *Student: I thought that it was a good experience to have because we did EcoMUVE on the computer, but doing it in person made it more understandable.*
> *Interviewer: What did it help you understand?*
> *Student: It helped me understand how things get into the ponds and what happens- what goes on in the ponds and around us that we don't understand when we are just passing.*

Follow the Flow:

> *Interviewer: So what did you think of today?*

Student: I thought that it was fun because we actually got to go in the stream and it was hands-on.
Interviewer: So what was fun about it?
Student: It is just really interactive and I like it because we get to use phones. We actually get to see the stuff that we are studying.

Interviewer: What did you think?
Student: It was a fun experience. I think that we should it again. We should do more stuff about it because I like interacting with things. It was fun.
Interviewer: What did you like best?
Student: I liked the general part where you get to walk around and find the orbs.
Interviewer: Tell me something that you learned.
Student: I learned about the watershed. I had no idea what they were before that.

Due to the similarities in comments across the two experiences, our results focus primarily on the commonalities across the two experiences.

Impromptu feedback in the field – "What did you think?"

The "What did you think?" prompt was analyzed using a grounded approach in which we identified themes that occurred multiple times within the student responses, and then applied codes based on these themes to the entire data set. Emergent codes, example responses, and the frequency of exchanges across the entire data set that received each code are summarized in the table below (Table 1). The most prevalent themes mentioned were specific elements of the content (50%) and references to interactivity and hands-on aspects of the experience (40%). Other themes mentioned by 20-35% of participants were: connections to real-life or the community; being outdoors; specific aspects of the technology; hotspots; difficulties or confusion; things about the experience that were fun, interesting or cool; and glitches. Other themes that were identified, but not mentioned frequently (only 10-15% of respondents) were: social interactions and aspects of the experience that supported noticing or attention. Of the themes that emerged from the data set, a number can be categorized as related to positive engagement (e.g., hands-on/interactive, fun/interesting/cool), some are related to a feeling of frustration (e.g., confusing/difficult, glitch), a number related to support of cognition and learning (e.g., noticing/memory, references to specific content), and a number of these held relevance to our focus on contextualization (hands-on/interactive, social/working together, community, outdoors).

Table 1. The table below summarizes the codes identified to characterize emergent themes, offers examples of each, and shows the frequency with which these were represented in student responses to the "What did you think?" prompt.

Code	Examples of responses	Percent of exchanges that received this code
Hands-on/Interactive	"It is just really interactive and I like it because we get to use phones."	40%
Real-life/Community	"You remember being outside and going to the	25%

	exact places and seeing it in real life and its better because you remember it more.”	
Social/Working Together	“We are trying to partner up and to use this phone together.”	10%
Supporting noticing/memory	“You notice things that you wouldn't have noticed before like some of the pollution that we do have in the stream.”	15%
Outdoors	“You are outside actually doing something in science class but you also get to use really cool phones”	25%
Content	“I found out that the dissolved (or salt) materials were falling into the pond like from the rain and the water coming from the driveway and I didn't know that before.”	50%
Technology	“It is kind of cool actually. It is a 3D image of a duck, but it is not there. It is kind of cool actually. It looks realistic but in a digital way.”	30%
Hotspots	“Sometimes we had to go to hotspots we couldn't reach so we had to just click on them- that was the most difficult.”	25%
Confusing/Difficult	“I don't know. It said something about erosion. I don't know if you are supposed to take a picture or not?”	25%
Fun/Interesting/Cool	“You also get to use really cool phones and see different kinds of graphics. It is a cross between virtual reality and real life. It is fun.”	35%
Glitch	“It said how it went up a hill and it didn't make sense, but then all of a sudden it closed off.”	15%

There were some notable differences in the frequency of codes mentioned by students in the two groups. Students who used the “Follow the Flow” experience more frequently mentioned being outside ($X = 4.091$, df=1; p-value = 0.043), while students working with “Take a Tour” more frequently mentioned points that were difficult or confusing ($X = 6.11$, df=1; p-value = 0.013). Any other differences shown in the figure below were not statistically significant (Figure 11).

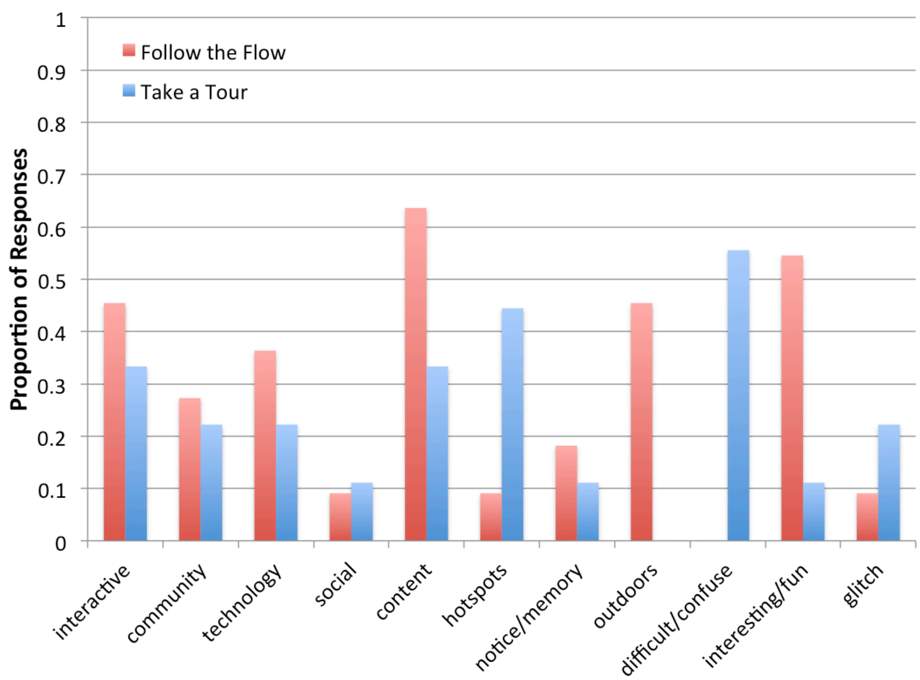

Figure 11. Comparison of the frequency of the occurrence of each code across the two experiences. The differences between the two groups were statistically significant in the cases of "outdoors" and "difficult/confuse" only.

Summative feedback – interviews and focus groups

Feedback from students during summative interviews emphasized the appeal of using phones because they are a part of everyday life, but not typically part of classroom instruction. These references to everyday life suggest that the use of the mobile devices offers connections to personal and sociocultural elements of the students' context.

> *Interviewer: Tell me what it is like to use the phone.*
>
> *[Participants in "Take a Tour"]*
> *Student A: Well I like it because it doesn't seem like it is school because smartphones are a part of our everyday life. We use phones, so it seems more fun instead of learning in the classroom, and it is right there and we get to capture it with the camera.*
>
> *Student B: The program changes [inaudible] and guides you through what is going on. It is really cool that we get to see our ecosystem through our phones because the phone can tell you specific facts that you wouldn't be able to know without that technology.*
>
> *Interviewer: Well you'd have to go back and look it up later.*

Student A: I would forget.

These students also highlight the value of the augmented information that was delivered during the experience. Students refer to the mobile devices and augmented reality software as providing access to just-in-time information during the learning experience.

When asked to compare the EcoMOBILE experience to previous science classes without these kinds of technologies, students mentioned differences in their level of engagement and also describe how contextualization enabled by the phones helped make the things they learned more memorable and understandable. In this case, the contextualization they describe is derived from the integration of learning material with a fun and meaningful experience.

Interviewer: What is the biggest difference between a regular science class- one that you took last year and one that uses technology.

[Participants in Follow the Flow]
Students C, D, and E [together]: It is more fun.

Student C: It is more fun and I actually think that I learn more because last year in science we did a lot of textbook work and did a lot of learning on smartboards, but using your phone and doing this experience can help my brain better because I can connect to it. Textbooks are really useful, but this is better.

Student D: Last year the teacher kind of piled stuff into our brain and it is hard to remember everything- like every little detail, but when you are actually using interactive things, it keeps it in your brain longer and you can really remember it because it was fun.

Student E: Where a textbook you have to remember the exact detail, but with the interactive you can remember back into the context kind of what you used it for and you can understand it better.

Comments above emphasize the relationship between experience, engagement and learning and suggest that the mobile augmented reality learning experience helped to support memorable, experiential learning.

Feedback captured in the interviews and focus groups suggests that the combination of the EcoMUVE curriculum and the EcoMOBILE field experiences may have been particularly powerful:

"Interviewer: So you were learning here on the computer and then on the mobile device. What is that experience like?

[Participants in "Take a Tour"]

Student B: The fact that we get to learn how it affects one community on the computer (referring to use of EcoMUVE in the classroom) and then to be out in the real world using the smart phones is really cool because you see how they connect and how they are similar and how each system and community is different.

Student A: I like how on the computer it seems like just a computer world but then you relate it to outside in the world. Then it is really alive and you see how it all works."

The EcoMUVE experience provides an additional degree of contextualization for the field- and mobile-based learning activities. Having had a group experience using the EcoMUVE software during class appears to provide a baseline of prior content knowledge and a meaningful content-relevant context within which students could think about, apply and extend their ideas. This may be considered an emergent aspect of contextualization, as the mobile learning activity was designed in a way that would be useable by a teacher independent of whether they also used EcoMUVE, yet it appears that students got even more from the mobile experience due to the combination of the mobile and EcoMUVE activities. Another group of students provided similar thoughts:

Interviewer: Did doing EcoMUVE help you here while you are learning?

[Participants in "Follow the Flow"]
Student F: It gave us the knowledge we needed to know what was going on.
Student G: Some of the vocab like nitrates, phosphates and turbidity.
Student F: pH- all that stuff we learned from EcoMUVE can be used here.

Student G: I thought EcoMUVE was also fun, but it was less of an interactive- actually being out here by the stream. I kind of like this better. It is cool because we have the tools as opposed to clicking buttons.

Students further distinguish between the EcoMOBILE and EcoMUVE experiences by describing a sense of freedom or of possibilities associated with using the mobile devices in the field, which conjures up dimensions of personal context including choice and control (Falk and Dierking 2000).

Interviewer: What was it like to learn something on the computer and then go out into your backyard?

[Participants in "Follow the Flow"]
Student D: I found it to be two different experiences almost like we were learning two different things. We learned turbidity, nitrates and phosphates all that stuff from EcoMUVE and then when we move into our own environment, we knew how to apply it and it was a different experience.

Student D: It definitely felt a lot more unlimited. Because with EcoMUVE it felt like there was a lot you could do with it, there was only so much you could do. There was a small area that you were confined to there was only so many tools that you had and it was hard to actually do something unique. The only way you are going to do is to go out into the real world and you learn more by actually collecting samples and doing test instead of just clicking something and getting an answer

Throughout the focus group interviews, students emphasized how the mobile devices, AR, and field trip activities supported experiential aspects of the activity that they found engaging and useful for learning. Dimensions of contextualization we outlined in our conceptual framework and design arose within interviews and focus groups, yet additional dimensions not emphasized in our design also arose. While the relationship between EcoMUVE and EcoMOBILE was not strongly emphasized in this particular design, this kind of feedback suggests it could be useful to do so in the future.

Discussion

As outlined early in this chapter, a number of affordances of mobile technologies and augmented reality can be harnessed to instill a sense of contextualization. Prior work has shown that even simple fantasy contexts can lead to increased learning and motivation, compared to the same learning experience delivered in an abstract format (Parker & Lepper 1992). As digital technologies provide ever increasing opportunities to imbue the world and our experiences with digital and virtual elements, it is important to better understand how to design experiences that create an appropriate balance of real and virtual that is useful for engagement and learning (Rogers, Price, Fitzpatrick, Fleck, Harris, Smith, & Weal 2004). Here we offered two designs with varying degrees of contextualization, and found little difference in student comments, suggesting that designs with low levels of inherent contextualization (place-independent mobile learning designs) can actually lead to perceived contextualization that is similar to that of strongly place-dependent designs.

While the designs were intended to represent and instill distinct levels of physical and social contextualization among the users, the feedback received from the two groups showed few discernable differences in the way the students describe their experiences. Many students (40% of respondents) referred to the experience as hands-on or interactive, 25% referred to ways in which the experience connected them with their community or related to their "real life," and 25% mentioned that being in the outdoors was significant to them. Notably, students who completed the experience that was designed to be place-independent more frequently mentioned being outside or in the outdoors compared to students who used the place-dependent version. This may suggest that, through the use of mobile technologies, learning activities that are designed as place-independent can still engender in the user feelings of a physically contextualized experience.

In looking at students who described the experience as interactive while in the field, we saw that students, in equal measure, also referred to either technology or the outdoors in the same statement about interactivity, but did not refer to all three in the same statement. So, although designers and theorists may talk of contextualization as an interaction between the user, the device, and the environment, students seem to highlight specific aspects in their descriptions of their experience while not mentioning non-focal elements. As such, in the process of the activity, some students may view the device as the focal point of the activity with the outdoor environment viewed as the context, while others seem to view the outdoor environment as the focal point and relegate the device to being part of the context of the experience. It is interesting that both viewpoints seem to be supported by the same design. This may suggest more needs to be done to understand whether mobile technologies play a mediating or more direct role in the experiential aspects of the activity.

We took advantage of the “context-aware” capabilities of the mobile phone to trigger information at particular AR hotspots, and these hotspots were rendered using a heads-up display on the mobile device. In 3 of the 4 instances that hotspots were mentioned (during the “what did you think?” prompt) following the “Take a Tour” experience, students mentioned glitches or confusion associated with the hotspots. Reviewing the full transcript and context in which these instances occurred revealed that 3G wireless data signals in the area where “Take a Tour” was implemented were not always strong and likely led to glitches in which the hotspot may not be activated as intended. Such incidents reveal weaknesses in both the technology and the design. Even in this high-SES community near New York City, there were locations where mobile data service was not sufficient to support a consistent, error-free mobile learning experience. Also, because our design was specifically tied to the physical features (e.g., drainage pipes) at the particular location associated with the hotspot, the students may not have accessed all of the information and learning resources available. Place-independent designs may be more flexible and therefore less vulnerable to glitches associated with inconsistent data or GPS signals.

While the two designs we tested occupy different spaces along a spectrum between place-dependence and place-independence, one might imagine designs that push even further toward extreme ends of these designations. If we had pushed further toward either end in our design, we may have seen a greater contrast in the outcomes among the groups. Yet, we believe the place-independent design achieved a functional level of independence that would allow a teacher in another location, with a certain set of minimum requirements, to adopt and implement the place-independent version. Such findings have implications for whether mobile learning experiences will ultimately generalize to be easily usable by teachers and students operating on a variety of mobile devices, in different locations, using different mobile data service providers. We plan to design and release versions of similar AR experiences for independent use and modification by teachers, and will work closely with a subset of teachers to understand their experiences during the initial stages of independent use.

Conclusions

Many STEM educators are striving to make activities and experiences more relevant and engaging; community-oriented, experiential, and project- and problem-based approaches are often proposed to increase engagement in STEM fields, promote relevance of otherwise abstract concepts, and provide interdisciplinary anchors for teaching STEM concepts along with Common Core learning goals (Bouillion & Gomez 2001). While these approaches have shown a great deal of promise in particular cases, community-oriented and experiential learning activities may be difficult to implement at scale, and the contexts in which project- and problem based activities are cast can become overly contrived. Designs of mobile learning activities like those described here may play a valuable role in addressing challenges of integrating project-based learning in classrooms and community-oriented learning by providing a middle ground between the two.

Mobile devices have been heralded as being "context-aware"; in these cases the sensors and GPS capabilities of the mobile devices are used to detect aspects of the user's location and surroundings and deliver relevant information or support based on this inferred context. Ubiquitous learning systems (Shih et al. 2011, Liu, Tan & Chu 2009) have arisen as a new brand of mobile learning envisioned as an integrative system that provides adaptive support in real time to learners. The use of "context-aware" devices and ubiquitous learning models raises questions about the need to collect and use streams of real-time data as the user progresses through the experience. It is argued that in order to support a learner who is operating in a ubiquitous learning environment, mobile devices must accomplish a constant monitoring of the learner, their progress in the learning activity, and the changing context (Shih et al. 2011). While the ubiquitous approach is impressive in its totality, there is a concern that, at least in the next few years, these context-aware devices and the data they create and consume may prove to be so resource-intensive as to be difficult to create or maintain in any but the most progressive and well-funded learning environments.

Our work with EcoMOBILE comes at the issue of mobile learning and context from a different perspective. We seek to use context-aware affordances of mobile devices (here specifically GPS) to help students themselves become more "context-aware" by paying closer attention to their surroundings, their place in the community, and the physical and social resources that are available for learning (Price & Rogers 2004). The results of our experiment suggest an alternative to the data- and technology-intensive requirements envisioned as necessary in ubiquitous context-aware mobile learning systems, and instead suggest that carefully constructed, yet minimalist designs may support a perception of contextualization that comes from the perspective of the user rather than from the device. The lack of significant differences in the student experience between our two designs is a welcome result as it suggests that a place-independent mobile learning experience may, with minimal modification, be used in an environment other than the one in which it was designed, and may still have positive effects on feelings of contextualization, engagement and support for learning among participants in a new location.

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