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ECOMOBILE

Designing For Contextualized Stem Learning Using Mobile Technologies And Augmented Reality

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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; Squire, 2009; Traxler & Kukulska-Hulme, 2005). 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 (Looi et al., 2009; Naismith, Lonsdale, Vavoula, & Sharples 2004).

However, the meaning of contextualization and how to achieve it in designs for mobile devices bear further examination (Sharples, 2010, in Brown et al., 2010). Context, as viewed from the perspective of situated learning theory (Brown, Collins, & Duguid 1989; Greeno, 1998), "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 (Barab, Pettyjohn, Gresalfi, Volk, & Solomou 2012; Cordova & Lepper, 1996). 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 (Dunleavy, Dede, & Mitchelll 2009; Klopfer, 2008; Perry et al., 2008; Squire, 2009). AR applications use mobile broadband devices to provide learners with access to digital information embedded in a physical location or outdoor environment (Dunleavy & Dede, 2013, Klopfer, 2008). Specifically, location-aware AR uses the global positioning system (GPS) capabilities of the mobile device to trigger digital information at appropriate locations and times (Dunleavy & Dede, 2013; Perry et al., 2008; Price & Rogers, 2004; Squire & Jan, 2007). 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-grade 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 et al., 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 & 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, Baber, and Sharples (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 & 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 8.1). 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 8.1). 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 any time and anywhere (Klopfer, 2008). One example is the suite of mobile games (Ubiq Games) developed in the UbiqBio project (Klopfer, Sheldon, Perry, & Chen 2012), 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 & 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 (Klopfer & Squire 2007; Rogers & Price 2008; Squire, 2009; Squire & Jan 2007). In this case, the designer must know about specific

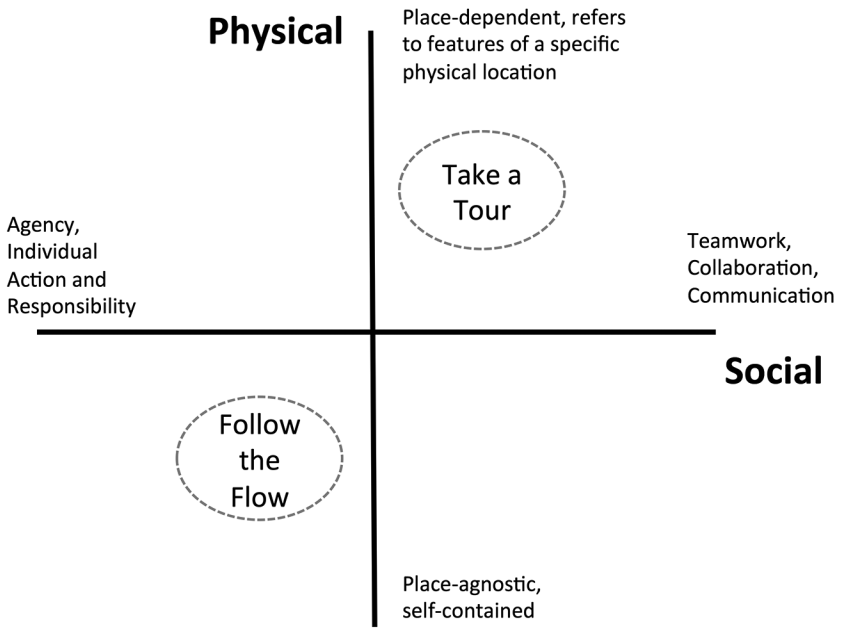


FIGURE 8.1 A visual representation of two dimensions of contextualization – social and physical. The dashed ovals show the augmented reality experiences developed for this project (Follow the Flow and Take a Tour) in relation to these two dimensions.

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 & 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 8.1).

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 (Dunleavy & Dede, 2013; Klopfer, 2008; Squire, 2011; Squire & Klopfer 2007). 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 (Dunleavy & Dede, 2013; Klopfer, 2008; Squire, 2010). As AR and mobile technologies become increasingly 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 science, technology, engineering, and mathematics (STEM) learning, as the two approaches present a tradeoff between local relevance and scalability.

Here we present the design of an AR 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 8.1). 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.

Context and Design

As part of the Ecosystems Mobile Outdoor Blended Immersive Learning Environment (EcoMOBILE) National Science Foundation grant-funded research project, we conducted a pilot study in which an AR 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 (age 11–14 years) 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 smartphones 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.

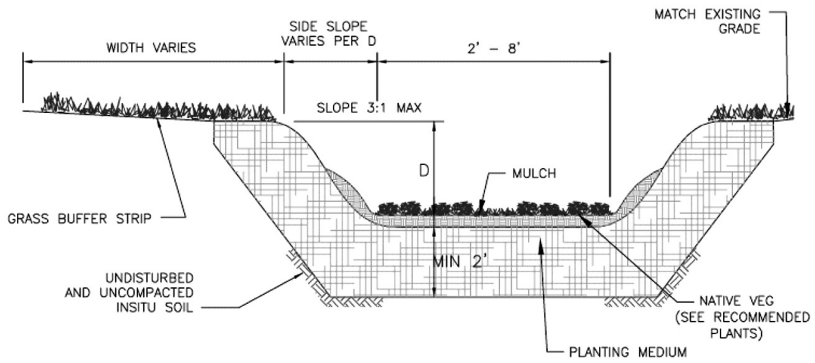
The Explore Your Watershed – Follow the Flow experience was designed as a place-independent experience with the idea that the content, hotspots, and media embedded in the experience could easily be transferred (by a teacher or other user of FreshAiR) to a new location. The design requires that the target 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 8.2). 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 8.2b), the AR software delivered a view of the blueprints for the underground filtration system (Figure 8.2a) and provided information about how water flow and filtration occur. Therefore, content and media displayed in the AR application referenced specific physical features present at the hotspot locations.

Explore Your Watershed – Follow the Flow

Figure 8.3 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 8.4a). The design presupposes 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 8.4b). After this branch point in the design, participants would follow the flow of water either over land, or as it infiltrates into the soils

(a)



(b)

FIGURE 8.2 (a) Below-ground schematic view of the design plans for a water infiltration system installed near the school parking lot. (b) The same system as it appears in the real world.

and eventually into the ground water (Figure 8.4c and d). 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.

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 8.1). The multiple-choice question at the beginning allows the designer to deliver additional information to users who need it,

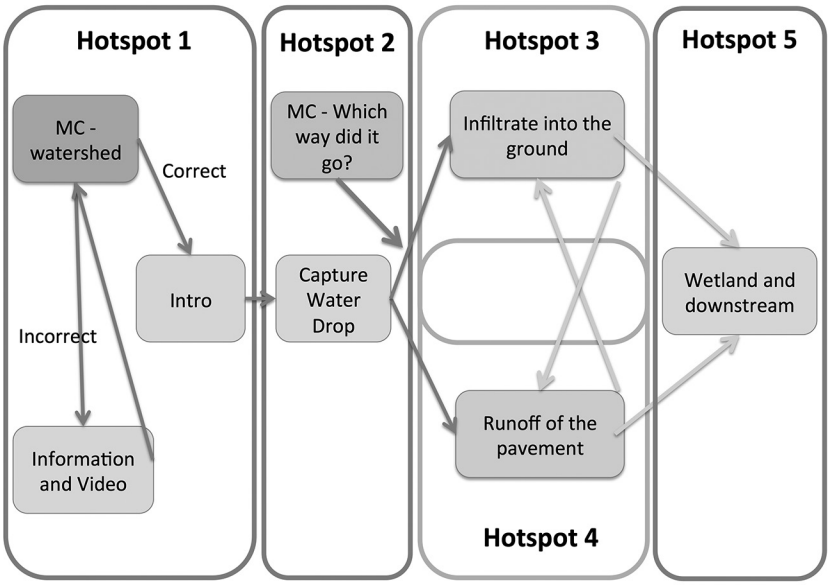


FIGURE 8.3 Schematic diagram showing the hotspots and sequencing in the Explore Your Watershed – Follow the Flow activity. "MC" indicates an embedded multiple-choice question within the experience, which serves as a branching point between two pathways through the experience.

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 AR 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 users as active participants in the storyline as they track where a virtual water drop goes next. As users drop the water and use the multiple-choice selection to indicate the type of land cover on which the drop landed, they may feel as though they are a participant in a "choose your own adventure" type of story. Finally, the movement of students 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 users 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

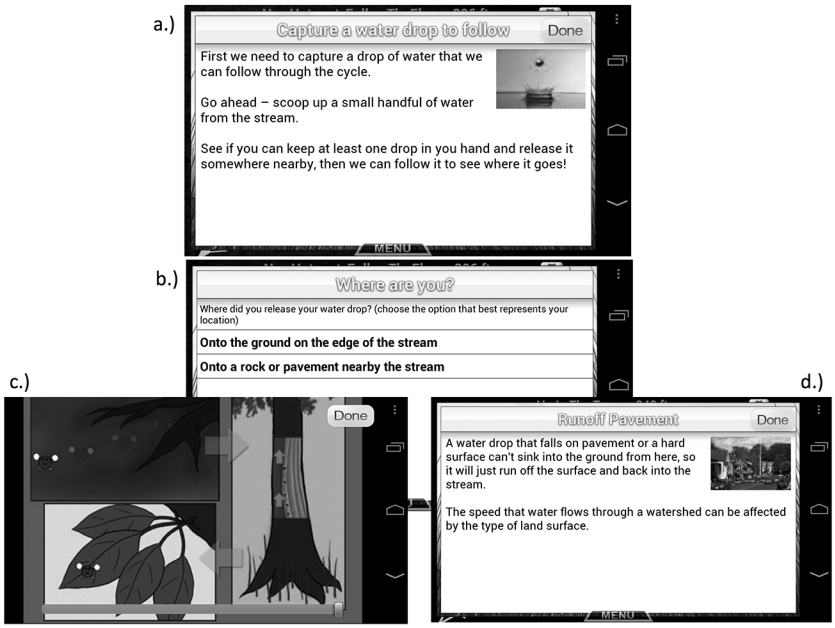


FIGURE 8.4 Screenshots of the media and instructions delivered to students using Follow the Flow activity when they arrive at hotspot 2 (a and b), hotspot 3 (c), and hotspot 4 (d). Panels c and d demonstrate branching between two distinct pathways through the experience. Panel c was accompanied by text 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."

traveled. Informants were placed at AR hotspots, and clues referenced physical features present in the environment (Figure 8.5). 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 8.6). 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 8.5).

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 8.6). 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

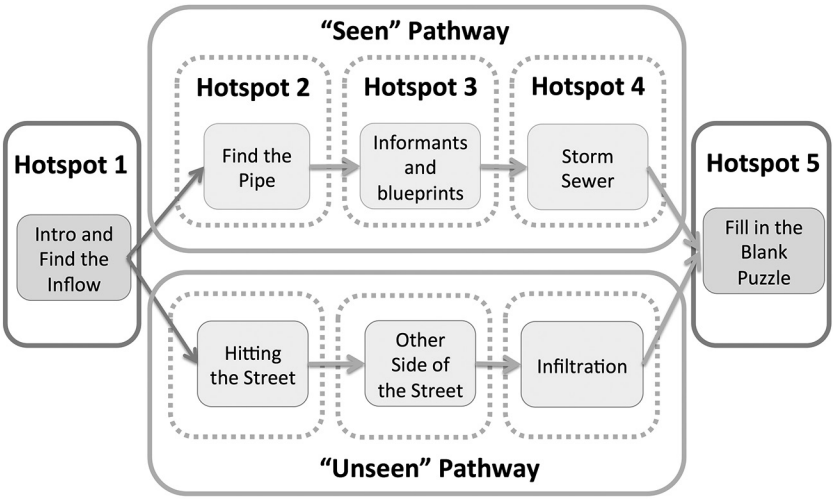


FIGURE 8.5 Schematic diagram showing the design of the Explore Your Watershed – Take a Tour experience.

the pond (Figure 8.7). 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 8.8a). These informants provided information and views of "blueprints" for the water filtration structure underlying the ground in that area (Figure 8.8b–d). 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.

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 8.9a). 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 8.9b). 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.

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 8.10). 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

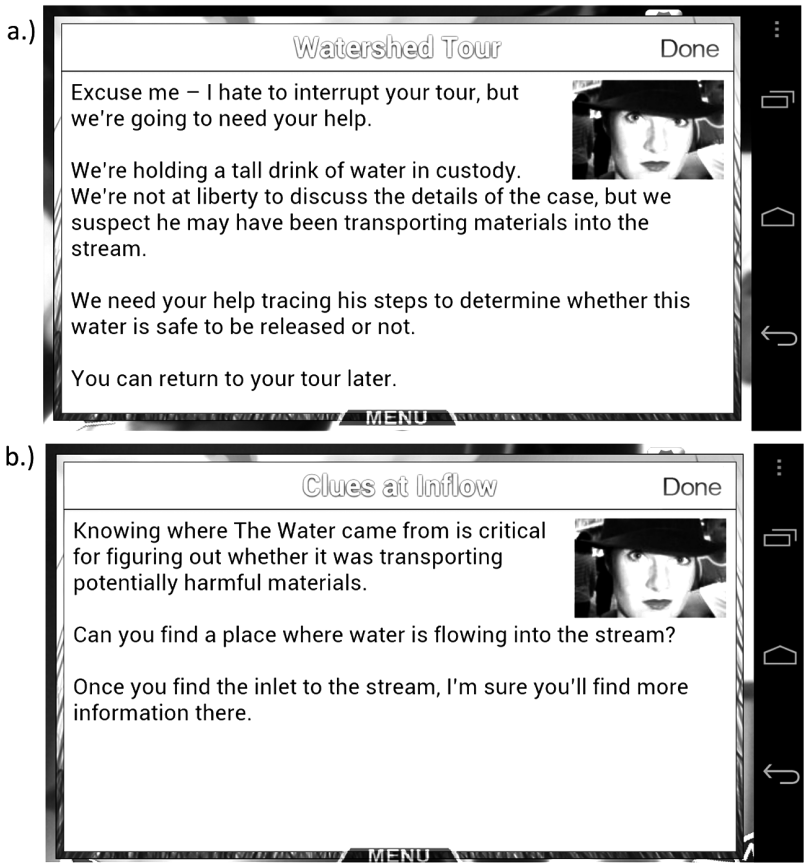


FIGURE 8.6 During the introduction a "private investigator" character interrupts the watershed tour to ask for the users' help (a), and then directs them to explore and find the inflow to the stream (b). After tapping "done," the students saw a virtual hotspot near the location of the inflow.

could collaborate with students who had followed the complementary path, as the clues provided to each were different (Figures 8.10a and b).

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 AR 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.

FIGURE 8.7 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).

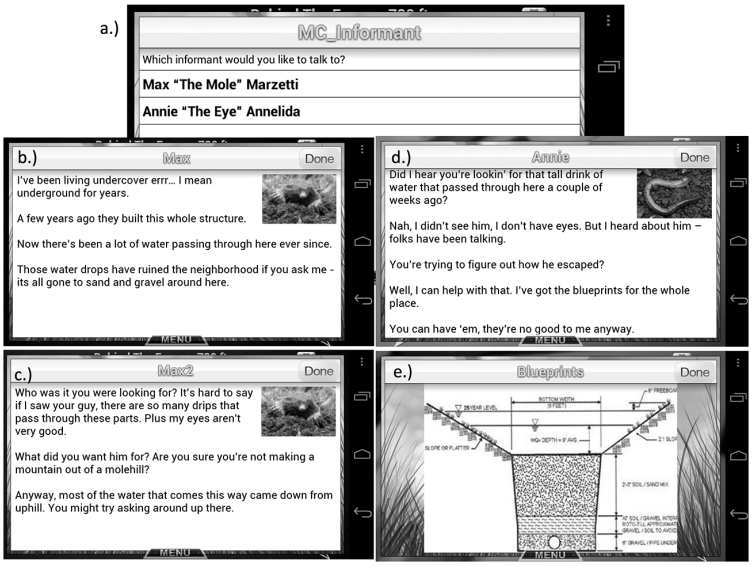


FIGURE 8.8 Screenshots showing hotspot 3 for the "Seen" pathway. The multiple-choice functionality was used to provide students a choice of receiving information from two different "informants" (a). Panels (b) and (c) show text-based clue provided to the "seen" role by the informant named "Max 'The Mole' 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.

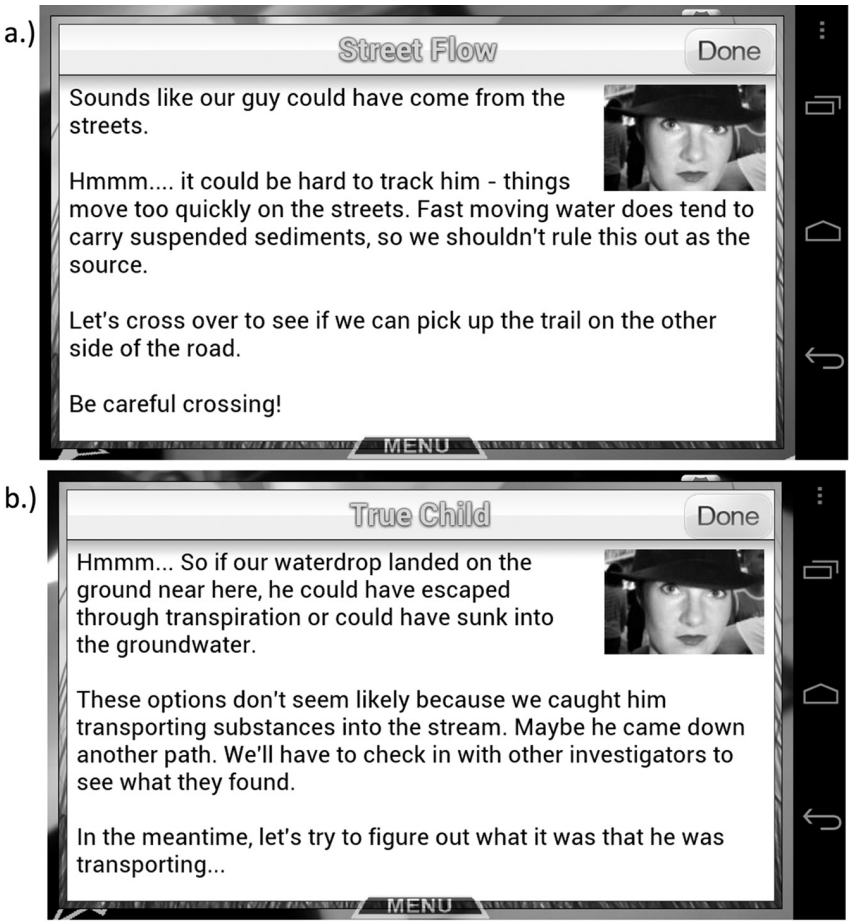


FIGURE 8.9 Information delivered to students playing the "unseen" role at the Hitting the Streets hotspot. Information delivered to students playing the "unseen" role at the conclusion of the "Infiltration" hotspot.

The social contextualization of this experience was closer to a group-oriented experience than the Follow the Flow experience (Figure 8.1). 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 8.8). We used the "role" functionality provided by the AR platform to construct different, but complementary, paths for the experience. The use of interdependent roles is a common approach in the design of AR experiences and games (Bressler & Bodzin, 2013; Dunleavy & Dede, 2013;

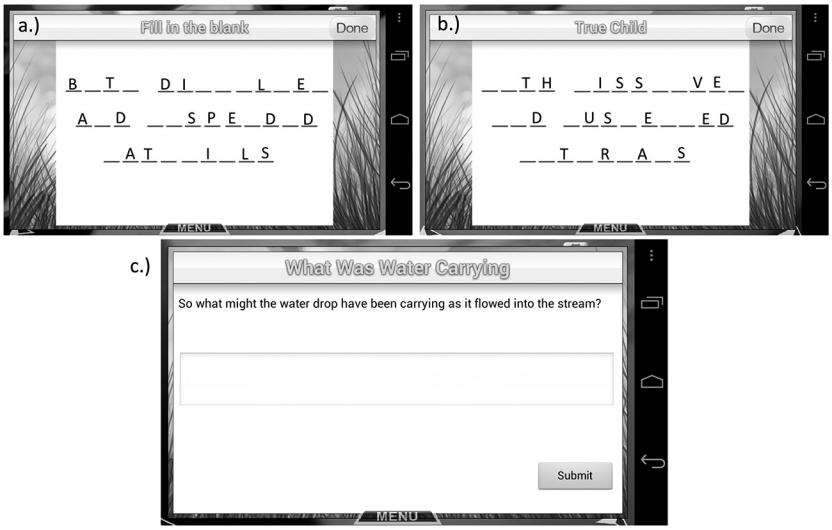


FIGURE 8.10 Fill-in-the-blank puzzle delivered to students following the "unseen" (a) and "seen" pathway (b). At the end of the experience, an open-ended question (c) provided a space for them to enter the answer to the fill-in-the-blank puzzle and receive feedback.

Klopfer, 2008), and follows from theories of group learning that support cooperative learning.

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 four classes of eighth-grade students (ages 13–14 years) in a relatively high-socioeconomic-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, Kamarainen, Tutwiler, Grotzer, & Dede, 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 three-dimensional 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 8.5) was implemented with teacher B with four classes (n = ~80) and the place-independent version (Follow the Flow) (Figure 8.3) was implemented with one 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 AR application and design may support contextualization, so we limit our reporting to the aspects of the experience relating to the use of AR by the students.

Throughout the field implementation of the 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 interrater 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 eight classes, we documented 20 responses to the "What did you think?" prompt (11 from Follow the Flow, and nine from Take a Tour). A further six 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 do 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 Table 8.1. 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).

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 Figure 8.11 were not statistically significant.

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.*

TABLE 8.1 Summary of the codes identified to characterize emergent themes, examples of each, and 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 exact places and seeing it in real life and it's better because you remember it more."	25%
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's like a 3D image of a duck, but it is not actually there. It is kind of cool actually. It actually looks very realistic but in like 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%

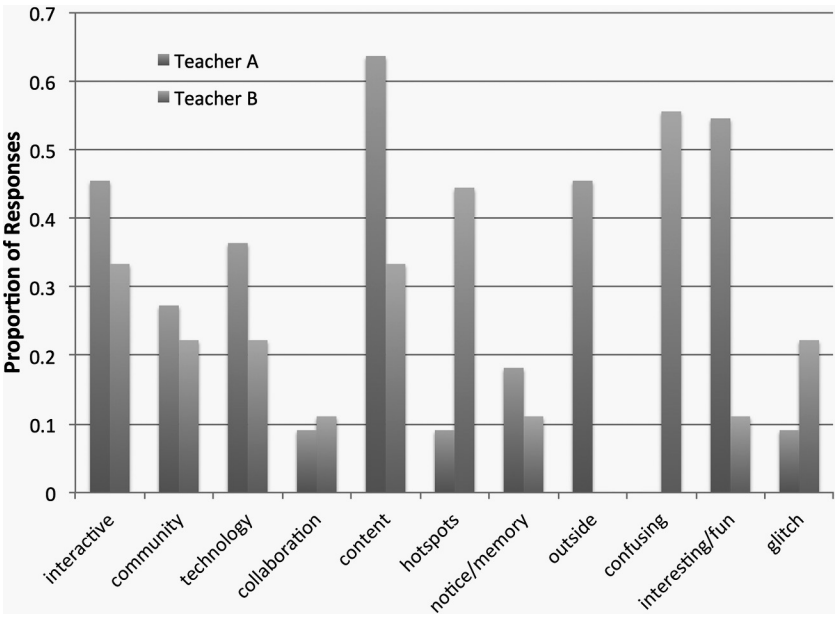


FIGURE 8.11 Comparison of the frequency of the occurrence of each code across the two experiences. The differences between the two groups were statistically significant in the cases of "outdoors" and "difficult/confuse" only.

These students also highlight the value of the augmented information that was delivered during the experience. Students refer to the mobile devices and AR 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.*

The comments above emphasize the relationship between experience, engagement, and learning and suggest that the mobile AR 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 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 teachers independently 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 & 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 earlier in this chapter, a number of affordances of mobile technologies and AR 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 et al., 2004a). 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 three of the four instances when 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 might not be activated as intended. Such incidents reveal weaknesses in both the technology and the design. Even in this high-socioeconomic-status 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 (Liu, Tan, & Chu 2009; Shih, Chu, & Hwang, 2011) 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 learners, 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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References

Barab, S., Pettyjohn, P., Gresalfi, M., Volk, C., & Solomou, M. (2012). Game-based curriculum and transformational play: Designing to meaningfully positioning person, content, and context. *Computers & Education*, *58*(1), 518–533.

Bouillion, L.M., & Gomez, L.M. (2001). Connecting school and community with science learning: real world problems and school–community partnerships as contextual scaffolds. *Journal of Research in Science Teaching*, *38*(8), 878–898.

Bressler, D.M., & Bodzin, A.M. (2013). A mixed methods assessment of students' flow experiences during a mobile augmented reality science game. *Journal of Computer Assisted Learning*, *29*(6), 505–517.

Brown, J.S., Collins, A., & Duguid, P. (1989). Situated cognition and the culture of learning. *Educational Researcher*, *18*(1), 32–42.

Brown, E., Sharples, M., Clough, G., Tangney, B., Wishart, J., Wijers, M., . . . & Polmear, G. (2010). *Education in the wild: Contextual and location-based mobile learning in action*. Nottingham, UK: Learning Sciences Research Institute, University of Nottingham.

Churchill, D., & Churchill, N. (2008). Educational affordances of PDAs: A study of a teacher's exploration of this technology. *Computers & Education*, *50*(4), 1439–1450.

Cordova, D.I., & Lepper, M.R. (1996). Intrinsic motivation and the process of learning: Beneficial effects of contextualization, personalization, and choice. *Journal of Educational Psychology*, *88*(4), 715–730.

Davies, M.M. (1996). Outdoors: An important context for young children's development. *Early Child Development and Care*, *115*(1), 37–49.

Dunleavy, M., & Dede, C. (2013). Augmented reality teaching and learning. In M.J. Bishop & J. Elen (Eds.), *Handbook of research on educational communications and technology* (4th ed., Vol. 2). New York: Macmillan.

Dunleavy, M., Dede, C., & Mitchell, R. (2009). Affordances and limitations of immersive participatory augmented reality simulations for teaching and learning. *Journal of Science Education and Technology*, *18*(1), 7–22.

Falk, J.H., & Dierking, L.D. (2000). *Learning from museums: Visitor experiences and the making of meaning*. Lanham, MD: Altamira Press.

Greeno, J.G. (1998). The situativity of knowing, learning, and research. *American Psychologist*, *53*(1), 5.

Grotzer, T.A., Powell, M., Kamarainen, A.K., Courter, C., Tutwiler, M.S., Metcalf, S., & Dede, C. (2014). Turning transfer inside out: The affordances of virtual worlds and mobile devices in real world contexts for teaching about causality across time and distance in ecosystems. *Technology, Knowledge, and Learning, 19*(3).

Gunckel, K.L., Covitt, B.A., Salinas, I., & Anderson, C.W. (2012). A learning progression for water in socio-ecological systems. *Journal of Research in Science Teaching*, *49*(7), 843–868.

Hodson, D. (2003). Time for action: Science education for an alternative future. *International Journal of Science Education*, *25*(6), 645–670.

Holden, C.L., & Sykes, J.M. (2012). Leveraging mobile games for place-based language learning. *Developments in Current Game-Based Learning Design and Deployment*, 27.

Klopfer, E. (2008). *Augmented learning: Research and design of mobile educational games*. Cambridge, MA: MIT Press.

Klopfer, E., Sheldon, J., Perry, J., & Chen, V.H. (2012). Ubiquitous games for learning (UbiqGames): Weatherlings, a worked example. *Journal of Computer Assisted Learning*, *28*(5), 465–476.

Klopfer, E., & Squire, K. (2007). Environmental detectives—the development of an augmented reality platform for environmental simulations. *Educational Technology Research and Development*, *56*(2), 203–228.

Klopfer, E., Squire, K., & Jenkins, H. (2002). Environmental detectives: PDAs as a window into a virtual simulated world. In *Proceedings of the IEEE International Workshop on wireless and mobile technologies in education* (pp. 95–98). IEEE.

Liaw, S.-S., Hatala, M., & Huang, H.-M. (2010). Investigating acceptance toward mobile learning to assist individual knowledge management: Based on activity theory approach. *Computers & Education*, *54*(2), 446–454.

Liu, T.Y., Tan, T.H., & Chu, Y.L. (2009). Outdoor natural science learning with an RFID-supported immersive ubiquitous learning environment. *Journal of Educational Technology and Society, 12*(40), 161–175.

Lonsdale, P., Baber, C., & Sharples, M. (2004). A context awareness architecture for facilitating mobile learning. In J. Attewell & C. Savill-Smith (Eds.) *Learning with mobile devices: Research and development* (pp. 79–85). London: Learning and Skills Development Agency.

Looi, C.K., Seow, P., Zhang, B., So, H.J., Chen, W., & Wong, L.H. (2010). Leveraging mobile technology for sustainable seamless learning: a research agenda. *British Journal of Educational Technology*, *41*(2), 154–169.

Metcalf, S., Kamarainen, A., Tutwiler, M.S., Grotzer, T., & Dede, C. (2011). Ecosystem science learning via multi-user virtual environments. *International Journal of Gaming and Computer-Mediated Simulations (IJGCMS)*, *3*(1), 86–90.

Naismith, L., Lonsdale, P., Vavoula, G., & Sharples, M. (2004). *Literature review in mobile technologies and learning*. Bristol, UK: Futurelab.

Parker, L.E., & Lepper, M.R. (1992). Effects of fantasy contexts on children's learning and motivation: Making learning more fun. *Journal of Personality and Social Psychology*, *62*(4), 625.

Perry, J., & Klopfer, E. (2014). UbiqBio: Adoptions and outcomes of mobile biology games in the ecology of school. *Computers in the Schools*, *31*(1–2), 43–64.

Perry, J., Klopfer, E., Norton, M., Sutch, D., Sandford, R., & Facer, K. (2008). AR gone wild: two approaches to using augmented reality learning games in Zoos. In *Proceedings of the 8th International Conference for the Learning Sciences,* Vol. 3 (pp. 322–329). International Society of the Learning Sciences.

Price, S., & Rogers, Y. (2004). Let's get physical: the learning benefits of interacting in digitally augmented physical spaces. *Computers & Education*, *43*(1), 137–151.

Rogers, Y., & Price, S. (2008). The role of mobile devices in facilitating collaborative inquiry in situ. *Research and Practice in Technology Enhanced Learning*, *03*(03), 209.

Rogers, Y., Price, S., Fitzpatrick, G., Fleck, R., Harris, E., Smith, H., . . . & Weal, M. (2004). Ambient wood: designing new forms of digital augmentation for learning outdoors. In *Proceedings of the 2004 Conference on Interaction Design and Children: Building a community* (pp. 3–10). New York: ACM.

Sharples, M., Taylor, J., & Vavoula, G. (2005). Towards a theory of mobile learning. *Proceedings of mLearn 2005*, *1*(1), 1–9.

Shepardson, D.P., Wee, B., Priddy, M., Schellenberger, L., & Harbor, J. (2007). What is a watershed? Implications of student conceptions for environmental science education and the national science education standards. *Science Education*, *91*(4), 554–578.

Shih, J.L., Chu, H.C., & Hwang, G.J. (2011). An investigation of attitudes of students and teachers about participating in a context-aware ubiquitous learning activity. *British Journal of Educational Technology*, *42*(3), 373–394.

Squire, K. (2009). Mobile media learning: multiplicities of place. *On the Horizon*, *17*(1), 70–80.

Squire, K. (2010). From information to experience: Place-based augmented reality games as a model for learning in a globally networked society. *Teachers College Record 112*(10), 2565–2602.

Squire, K. (2011). *Video games and learning: Teaching and participatory culture in the digital age. technology, education – connections (the TEC series)*. New York, NY: Teachers College Press.

Squire, K.D., & Jan, M. (2007). Mad city mystery: Developing scientific argumentation skills with a place-based augmented reality game on handheld computers. *Journal of Science Education and Technology*, *16*(1), 5–29.

Squire, K., & Klopfer, E. (2007). Augmented reality simulations on handheld computers. *The Journal of the Learning Sciences*, *16*(3), 371–413.

Traxler, J., & Kukulska-Hulme, A. (2005). Evaluating mobile learning: Reflections on current practice. In *mLearn 2005: Mobile technology: The future of learning in your hands*. South Africa: Cape Town.