International Journal of Engineering Education Vol. 28, No. 5, pp. 1119–1126, 2012
Printed in Great Britain

0949-149X/91 $3.00+0.00

Mobile Learning with the Engineering Pathway Digital Library*

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There are exciting new opportunities for mobile learning in structured and semi-structured out-of-classroom activities using inquiry-based or project-based pedagogies. We present ongoing research on mobile access to context-relevant digital library resources using mobile interfaces. This project leverages the *Engineering Pathway*, a digital library of high-quality teaching and learning resources for applied science and math, engineering, computer science/information technology and engineering technology for K-12, higher education and beyond. We build on a previous user needs analysis of teachers, parents and students involved with mobile learning and present two mobile prototype applications that address these needs. *Simple Machines in Your Life* use a PDA to engage elementary school girls in learning about the simple machines in their surroundings. *GreenHat* uses a GPS-enabled Smartphone to encourage exploration of the natural environment through expert's perspectives. These two cases evaluate the benefits of technological features and their limitations. Lessons learned and recommendations for future improvements are summarized.

Keywords: mobile learning; engineering education; mobile devices; digital library, mobile library; science education

1. Introduction and prior research

Mobile learning provides the opportunity to transform informal and semi-structured field experiences into meaningful learning opportunities that contribute to a student's overall education [1–3]. Learning can be 'mobile' with respect to 1) time (e.g., it happens during the day, school days or on weekends), 2) space (e.g., at school, at home, at parks), and 3) areas of life (e.g., for school or hobby or leisure) [4–7]. Students with enriched informal learning environments have been shown to achieve improved scientific reasoning abilities [8]. Learning in context can improve student learning by allowing them to connect personal sensory experiences on field trips to curricular materials [9]. These out-of-classroom learning experiences can engage students in the synthesis of science and technology and help develop their inquiry skills through active location-sensitive discourse with peer learners.

Emerging mobile digital devices provide a wide range of platform opportunities for learning. Early successes include using the popular iPod [10] media player to provide educational media outside of the classroom to students anywhere, anytime [11]. In addition to using the iPod for audio and video replay of lectures and talks, the iPod and other portable media players have been used for language learning, such as with elementary school students in learning vocabulary or the alphabet with material they can listen to at home.

Previous work has also leveraged ubiquitous computing [12–14], or social networks to develop collaborative inquiry skills [15, 16] promoting ecologically friendly action [17], or enabling citizen science by using cell phones as a mobile sensing platform [18, 19]. The *Explore!* mobile-learning system invited middle school students during a visit to an archaeological park to engage in an excursion-game, whose aim was to help students to acquire historical notions while playing and to make archaeological visits more effective and exciting [20]. *NatureTalk* aimed to enhance creativity by helping children capture, geo-tag, and explore sound [21]. Researchers have also developed paper-based mobile tools for field biologists [3]. The *Ambient Wood Project* [22] invited children to explore and reflect upon a physical environment that had been augmented with a medley of digital abstractions.

Recent applications have been developed that leverage the mobility of new devices to access learning content and resources by location, for example using GPS technology to identify landmarks, habitats, animal sightings, and even tourist information [23–26]. Although not specifically designed for educational context, commercial mobile applications also take advantage of a variety of non-text based search techniques (e.g., WikiMe, Google Goggles, Yelp AR).

Mobile technologies can transform the way students access educational content in a mobile context, and transform their daily events into meaningful learning opportunities in interaction with the personal and physical world. In a previous paper, we conducted a study to understand the needs of potential mobile learning users—teachers, students and parents—with regard to out-of-the-

* Accepted 4 March 2012.

classroom activities, new technologies, and the constraints and opportunities of using mobile devices [27]. This user needs study resulted in infrastructure design principles to support appropriate, robust and sustainable mobile digital library services. It also provided a guide for educators when developing educational resources and activities to be used by and incorporating mobile devices. Some of these guidelines were specific to K-12 teachers, such as those associated with educational standards, teacher preparation, access and mobile learning logistics. In this study, we focus on the following design principles applicable to both K-12 and higher education:

1. *Connect*—Activities and content covered in out of the classroom activities must be, in some way, connected back to a student's classroom experience/environment/curricula.
2. *Contextualize Access*—Establish a personal connection to allow students to develop a relationship to the educational material from his/her perspective, the aim being to motivate and inspire educational curiosity.
3. *Capture*—New technologies should provide capabilities to capture data and notes while away from the classroom.
4. *Multimodal*—Whenever possible, activities and resources should provide learning opportunities that are accessible for a range of different learning styles: visual, auditory and kinesthetic.

In this paper, we present and evaluate two implementations that embody these design principles with the goal of developing mobile applications that use contextually-relevant digital library resources in the *Engineering Pathway*.

2. Mobile learning and digital library infrastructures

In order for mobile devices to provide the ability to access remote high quality educational resources untethered from the classroom, an infrastructure is necessary to store, serve, maintain and host these resources. Within the domain of science, technology, engineering, and mathematics (STE&M) education digital libraries, such as the *Engineering Pathway* (EP) [28] digital library or the National STEM Education Digital Library (NSDL) [29], are quickly becoming mainstream tools, addressing this need at a range of educational levels [30]. These digital libraries provide educators with access to digital resources and allow educators and students to share resources, comment on resources and interact as a community. As of year-end in 2011, EP had 16,855 learning resources cataloged with over 9,000 registered users and averaged approximately one million page views a month. The cumulative number of views and downloads for specific EP resources was approximately nine million and 860,000, respectively. A 'view' is defined as viewing the catalog record; a 'download: is defined as linking to the actual resource or downloading a document, file or executable. The goal of the *Engineering Pathway*'s Mobile Learning project is to extend the reach of engineering digital libraries via mobile learning [31, 32].

As a first step, we identified a wide range of high quality mobile learning resources that were catalogued into the *Engineering Pathway* in order to provide instructors, parents and students tutorials, interactive simulations, case studies, tools and other educational material designed for field trips and other mobile learning opportunities. The resources are organized for browsing and specialized searches on the *Engineering Pathway*'s Mobile Learning community site [33]. We also added metadata fields for capturing geocentric information for each resource in the *EP on the GO* collection [34] to support our design experiments on the UC Berkeley campus.

3. Prototype development and testing

This paper presents and evaluates the following two prototypes that build on our design principles for mobile learning for different target populations and devices:

1. *Simple Machines in Your Life* (with elementary school students using PDAs).
2. *GreenHat: Exploring the Natural Environment Through Experts' Perspective* (with college students using Google Android Smartphone's).

In these studies we followed a user-centered evaluation approach that used ethnographic observations and qualitative data to understand user behavior [35, 36]. As the first study had specific learning goals, a pre- and post-test of knowledge of simple machines was also evaluated. The digital library resources used were curated to embody our recommended design principles. The first prototype with simple machines content was performed in 2007, using a PDA to engage elementary school girls in learning about the simple machines in their surroundings. *GreenHat* used a location sensitive Smartphone application in 2010 to support exploration of the natural environment through expert's perspectives.

4. Simple machines in your life

The goal of the *Simple Machines* prototype was to test the use of mobile devices to enhance pre-engineering education at the elementary level and technology literacy for all students [37]. At this early stage, students learn the fundamental building blocks of engineering through math, science and technology learning [1, 38]. During these early years, pre-engineering education often consists of real world observations of scientific principles as embodied in everyday technologies, enhanced by experiential learning exercises outside of the traditional school setting. Datta & Agogino [31] used Hewlett-Packard PDAs in an after-school program designed to encourage girls in science, technology, and engineering and increase their confidence in understanding technology in their everyday environment. These workshops were conducted in 2007 with TechBridge [39] in a school in a lower income neighborhood with primarily black and Latina fifth grade girls from two different elementary schools. We implemented our mobile learning design principles in the following manner.

- *Connect:* The PDA was used to connect the classroom lecture and hands-on activities associated with simple machines with relevant digital resources available from the *Engineering Pathway*.
- *Contextualize Access:* At any point, the student could query the system to learn more about three simple machines (lever, pulley and inclined plane) and see relevant examples.
- *Capture:* The students were given the opportunity to use digital cameras to capture examples of simple machines in their playground or school and annotate to show how the simple machines moved.
- *Multimodal:* The PDA implementation used context-sensitive images, annotations and text from the *Engineering Pathway* digital library.

After a short lecture with hands-on demonstrations, PDAs were given to teams of fifteen girls to walk around their school and identify and photograph examples of simple machines. The students worked in two-person teams to label the simple machines and explain how they worked using the Pocket Paint™ program, which allowed them to draw on the pictures. The PDAs had a mock-up of a simple machine digital library (Fig. 1) that they used to help in their identification and to generalize their knowledge of simple machines beyond the examples given in the short in-class activity.

The *Simple Machines in Your Life* workshop was designed to motivate students to consider engineering as a career by demystifying the engineering around them in familiar settings. The camera feature on the PDA allowed them to capture the image of the simple machine they observed and software overlays allowed them to annotate and describe the motion. The interface made rich use of images to help the elementary students in the identification. The students were able to connect to the lecture material on simple machines to additional information on the digital library in the PDA. Therefore, the technology helped the students contextualize with real life examples in their everyday life [31].

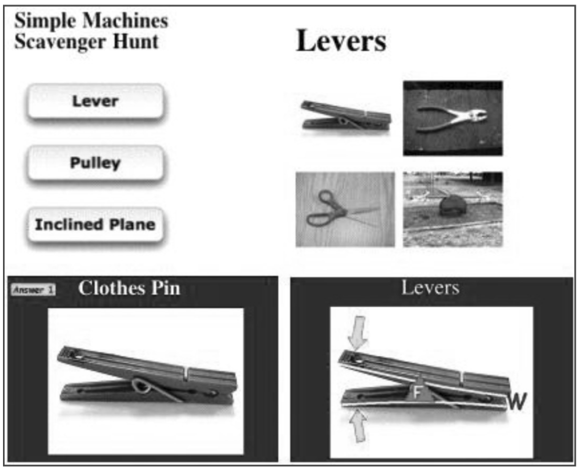

Fig. 1. Screen Capture of the *Simple Machines* Digital Library on a PDA.

A pre- and post- worksheet was used to assess learning improvements. This worksheet contained fill-in-the-blank and matching questions and was designed to test the students' ability to recognize definitions, applications, and examples of simple machines. This worksheet contained pictures to be labeled and was designed to test the students' ability to identify examples of simple machines. It turned out that the students' knowledge of simple machines was at a level that very few could successfully complete any of the questions in the pre-test (with an average score of less than one point on a six point scale). In fact, the instructors stopped the pre-test as it became apparent that it was too discouraging for the students. After the workshop there was a dramatic increase in the students' knowledge of simple machines (the average score was a 5.1 on a 6 point scale, with standard deviation of 1.1).

Using our design principles, the PDA module also allowed the students to personalize their knowledge and take the annotated images home with their families. A second day of the workshop was held to go over the home experiences and integrate the simple machines topic with career opportunities in engineering. The students were asked to reflect on their experiences in their notebooks. All of the reflective comments were enthusiastic; the following quotes from a student, teacher and administrator illustrate some of the positive features they found with the technology [31].

> *It was fun to use the PDA. It [was] fun to take pictures and [look] for levers, pulleys, and inclined planes.*—Student with Techbridge

> *Technology definitely is a plus. It grabs their attention and makes the recording of information engaging and more efficient. [The activity] leant itself well to collaboration and using the space around us to learn new ideas. They were learning something new about familiar objects and using new technology.*—Diana Barba-Velez, Instructor at TechBridge

> *Clearly your lesson taught the girls a lot about simple machines and did so in a fun, engaging manner. I loved watching the girls' excitement when it was time to identify the simple machines in the photos they took–they were so eager to demonstrate what they had learned. It was also nice to see that after the formal lesson was finished that the girls continued to spontaneously identify simple machines around them. Hopefully, the pictures you gave the girls to take home will generate some conversations with their families about your lesson and about engineering.*—Linda Kekelis, Project Director of TechBridge.

The *Simple Machine in Your Life* prototype, using PDAs, highlighted the importance of connecting the engineering principles to learner's personal and physical environment, and invited the students to actively observe the real world.

The experiment with PDAs, however, highlighted limitations of the technology available in 2007. Although most of the girls were excited by the technology, a few felt intimidated. The instructors felt that too much time was required to teach the students to use the device and software. There were also many technological problems with transitions between tasks. For example, the photographs had to be transferred manually for printing. Most of the students had difficulty navigating the software and performing useful searches.

Fortunately, the accessibility of mobile devices with improved user interfaces and seamless connections has solved many of the problems that were identified in this 2007 study. A recent study has shown that over one-third of adults have Smartphone's and they project two-thirds will by 2015 [40]. The *GreenHat* prototype described below addressed the same four design principles for mobile learning with digital libraries, but was able to use more advanced Smartphone technology.

5. GreenHat: Exploring the natural environment through experts' perspective

GreenHat used the mobile learning design principles to help students engage with the natural environment with multiple expert perspectives (landscape architecture and environmental science). By connecting these experts' analyses with the students' everyday landscapes, the goal was to motivate students to look at their environment from a new perspective, and develop their opinion on location-sensitive controversial conservation issues. Videos of different experts drawn from the *Engineering Pathway* were used to prompt novices with context-relevant information, interactively engaging the student with multiple forms of information and inquiry, and connecting their mobile experiences with the greater community discussion.

The *GreenHat* system consists of *GreenHat Mobile*, an application that runs on a GPS-enabled Smartphone (e.g. Android, iPhone), and *GreenHat Web View*, a website that aggregates data from multiple users [41]. We implemented the mobile learning design principles in the following manner.

- *Connect:* Using *GreenHat Web View*, collaborating students can view a common map that marks where each student has been, their observations at those locations, and frequently used tagging terms. This view enables collaborators to start conversations centered around each others' field observations.
- *Contextualize Access:* At any point, the student can *query GreenHat Mobile* for more information and request *GreenHat Mobile* to alert them when they are near interesting opportunities to learn about biodiversity. As the student continues to use the system, *GreenHat Mobile* prompts further mobile exploration by highlighting locations tagged with commonly used terms.
- *Capture:* Using *GreenHat Mobile*, students document personal observations in the field through text, photos, and audio capture. In addition to automatically-generated time and location metadata, students can add tags to group information. Users' past tagging activity can also be used by *GreenHat Mobile* to suggest additional content.
- *Multimodal:* Both *GreenHat Mobile* and *GreenHat Web View* used context-sensitive images, expert videos and text articles cataloged in the *Engineering Pathway* digital library.

We studied mobile learning situations offered by *GreenHat* by comparing our contextual observations of *GreenHat Mobile* users against those using a desktop version of the same program. Nineteen graduate and undergraduate students at the University of California at Berkeley participated in our study: twelve students participated in the *GreenHat* Mobile group and seven in the *GreenHat* Desktop group. Each student in the *GreenHat* Mobile group was given approximately one hour and a half to explore five locations on campus with the *GreenHat* prototype (Fig. 2). At each location, the students were first asked to respond to a multiple-choice topic question about the location (e.g., 'Which side of the creek looks more natural? The side covered with ivy or the side without ivy?') (Fig. 3).

Fig. 2. Screenshot of Interactive Location-Sensitive Map in the *GreenHat Mobile* Prototype.

Fig. 4. Screenshot of Expert Videos with Key Concepts in Text in the *GreenHat Mobile* Prototype.

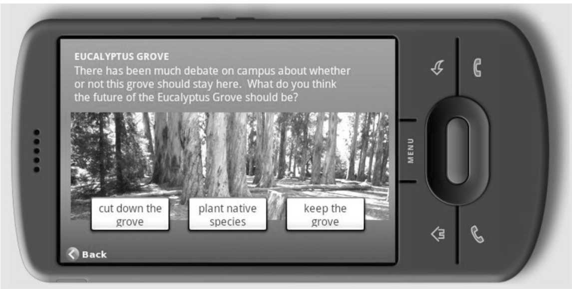

Fig. 3. Screenshot of Example Multiple-Choice Thought Questions in the *GreenHat Mobile* Prototype: *There has been much debate on the campus about whether or not this grove should stay here. What do you think the future of the Eucalyptus Grove should be?*

Next, the students viewed videos of each expert at the location discussing the issues surrounding the controversy (e.g., the biologist explains that ivy is a non-native species that takes over where native species grow, so removing the ivy gives the native species a chance to re-sprout and thrive. The landscape architect explains that removing the ivy is labor intensive and expensive, as well as causing possible land erosion) (Fig. 4). Finally, the students were asked to respond to the topic question again, writing their rationale on the phone using the phone's keypad. We 'shadowed' each student with video cameras and field notes. After the tour, we asked a set of open-ended questions such as 'How was your experience in learning about Strawberry Creek?' [41]. The seven students who participated in the *GreenHat* Desktop condition had access to all the same digital material as the *GreenHat* Mobile condition (e.g., expert videos, campus map, key concepts in text) but received these materials on the desktop computer in a room. In both conditions, the students explored five different locations on the campus, following the multi-step inquiry, and with the same time allocation.

Our evaluation of the *GreenHat* prototype with college students showed that having access to multiple experts' perspectives in the physical environment, i.e., how the experts would look at and interrogate the very environment the students stand, encouraged the students to actively observe the physical environment and provided more contextual evidence in forming their responses. For example, a student in the mobile condition wrote, 'The lawn seems more functional on *this side and further removed from the bustle of students walking to and from class*' (providing his observation in situ). Another student in the mobile condition wrote, 'I actually like hearing the *sound* of the creek and being able to *sit on the grass and see the creek at the same time*' (taking her personal experience into account). We did not see any of these types of comments from personal observation in the desktop condition. In describing their answers, the desktop group quoted directly from the video, e.g., 'In both videos, experts explained [. . .].'

Some of the connections the students made with their environment happened outside of the prompts made by *GreenHat* in the mobile condition. As they walked between locations on campus with *GreenHat*, four students voluntarily pointed out the specifics of the environment they just learned to observe (e.g., 'Oh, that's the ivy I just learned about!' pointing at the non-native ivy species found outside of the previous area). During the post-study interview, all twelve mobile condition students described that they would now look at their campus differently. Three students further described that they have 'learned to be more skeptical' and questioning what they see.

All twelve students in the mobile condition reported that the experience of going through their campus and learning about debates on sustainability and biodiversity was 'personal.' They described that it would not be the same experience if they had learned about the same issue at a desktop, as they would not be as 'immersed in the environment' as they were. For example, the students learned that the design of a particular creek side garden with lawn is highly un-sustainable (due to pesticides and energy to run lawn mowers). However, at the same time, they were there on a sunny day to observe their fellow students enjoying the green lawn during breaks between classes. They were encouraged to consider multiple aspects of the sustainable design challenge.

The students in both the *GreenHat* Mobile and Desktop groups watched a total of 25 minutes of videos (watching approximately 5 minutes of videos at 5 different locations). None of the students in the Desktop condition complained about the video length, but several of the students in the *GreenHat* Mobile group reported that the videos seemed too long for mobile learning. We plan to edit the videos so that they can be viewed in smaller chunks and also allow the students to save the point where they paused their video and continue watching it later.

6. Discussion and future research

Although our research on integrating mobile learning and educational digital libraries spanned different mobile platforms and age groups, the design principles obtained from prior user studies [27] served us well: *Connect*, *Contextualize Access*, *Capture*, and *Multimodal*. However, there were lessons learned in terms of the details of the different implementations. For example, our *GreenHat* Mobile study revealed that in a true 'on the go' situation, students may not be interested in reading long articles or watching long videos on a small handheld device. They were interested, however, in being able to retrieve the educational material they were exposed to in mobile situations later on while in a stationary setting. We also observed that the mobile learners had to go back and forth between looking at the information on the small screen and looking at their physical environment, actively studying and looking for evidence in the physical world. Other mobile learning researchers have observed the same problem [42].

We are continuing to develop tools for the seamless transition between the mobile and desktop settings as well as the connection between our prototype systems with the community of learners. Our research raises the question of what information should be immediately available in the mobile setting, versus what information is best viewed from a larger screen in a stationary setting. In regards to our mobile learning infrastructure, our research indicates that a mobile learning tool must provide just enough information on the screen so that the learner can spend quality time exploring the physical world, recognizing that too much information on the mobile device can detract the learners' engagement with the physical world. When the student returns to the stationary setting, these materials should be easily accessible in a desktop environment in an organized and personally meaningful way. As more mobile learners in the field collect field notes or images, these new resources should be added to the digital library collection as well.

Future research will focus on more natural ways to locate context-sensitive motivational and relevant learning resources. We will be evaluating the comparative advantages of using augmented reality [43] on a smart phone with the same information from a similar view using Google maps [44, 45]. Both the augmented reality and the Google maps prototypes will be compared against a traditional paper-based map book with similar resources.

7. Conclusions

This paper summarizes our ongoing research and prototype evaluation for a mobile digital library infrastructure to support learning using mobile devices. Mobile technologies can contextualize learning resources to make them relevant to the immediately visible environment. They can support the development of expert perspectives by prompting novices with context-relevant information, interactively engaging the student with multiple forms of information and inquiry, and connecting their mobile experiences with the greater community discussion. We contribute to the design of a mobile learning experience that takes advantage of access to multiple experts and context-sensitive information in the learner's immediate physical environment. The two research prototypes, *Simple Machin*es *in Your Life* and *GreenHat,* were designed to bring digital library resources from the *Engineering Pathway* to mobile devices in order to enhance students' experiential learning outside of the traditional school setting. Using mobile learning design principles from a previous study, these prototypes were able to pull digital resources available from the *Engineering Pathway* that were relevant to the learners' ongoing activities in the physical world, allowing them to make real world observations of science and technology in their everyday environment and thus establishing personal connections with their activity and the educational material. The media in both *Simple Machin*es and *GreenHat* were context- and geo-sensitive (e.g., maps, images, and videos; both the ones already in the *Engineering Pathway* and others captured by the learners in the field). *Simple Machin*es encouraged the learners to directly connect a lesson on engineering principles of simple machines to their personal and physical environment. *GreenHat* engaged the students with the physical environment and encouraged them to provide more contextual evidence of issues associated with sustainability and environmental science.

Acknowledgements—We wish to thank Google, HP, Ricoh Innovations, the California Discovery Grant and the NSF NSDL program for funding and intellectual collaborations. We also thank Michael Manoochehri, Robert Kowalski, Jennifer Wang, Ian Leighton, Christy Pratt, Elizabeth Goodman, Tim Pine, Danielle Christianson, Arielle Simpson, Sohyeong Kim, Arezu Aghaseyedjavadi and Frances Yan for their help in user testing and insightful discussions. This research was partially supported by NSF Grant #0840790.

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