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Geocentric Contextualized Mobile Learning with the Engineering Pathway Digital Library

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BACKGROUND

Mobile phones and digital tablets provide exciting opportunities for science and engineering learning in informal learning environments outside the classroom. We present research on using location-centric contextualized learning resources in the *Engineering Pathway* educational digital library that are relevant to the student's specific location and learning goals.

PURPOSE

The research was designed to first understand effective means for location-sensitive search for relevant learning resources, then design and test possible prototypes for informal learning applications.

DESIGN/METHOD

This paper describes two studies: (1) user studies to identify natural and effective means for student navigation with informal location-sensitive mobile learning and (2) user studies of three prototypes that implemented solutions based on the navigation research. The navigation user studies were conducted on two middle and high school student groups at the University of California at Berkeley using observations and a card query experiment that was translated into information retrieval testing in the *Engineering Pathway*. These results were used to develop and test the *EP on the GO* iPhone augmented reality (AR) application under three conditions with nine undergraduate student participants in a between-subject design study. The participants were randomly assigned into three groups (AR view, digital map and a control paper map), with three people per group. Participants were followed by a researcher with a video camera recording their activities and comments using ethnographic research methods.

RESULTS

Based on recommendations from a navigation study, the *EP on the GO* prototype was designed to pull digital resources available from *EP* 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 establish personal connections with the educational material. We found that the AR view was good at orienting students in the right direction and guiding them to come close to the target object or location, compared to the digital map and the paper map groups. However, when the target was far away, the digital map seemed more comfortable to use, as users did not have to hold the device in front of the face all the time. The students also valued the mobile learning resources that supplemented their learning experience.

CONCLUSIONS

These observations led us to formulate a hybrid approach for future research that would combine a digital map and an AR view for geocentric mobile learning applications. In this approach, the system would start with the digital map to help the users navigate the bigger general space, but switch to the AR view when the target is near the user to further guide her/him closer to the target. This solution enables spatial navigation to move from a macro view (overview of the campus) to a micro view (particular part of the area experts would notice) in order to support location-sensitive student learning.

KEYWORDS
Mobile Learning, Educational Digital Libraries, Informal Learning

INTRODUCTION & PRIOR RESEARCH

Mobile technologies can enable easy access to educational content in a mobile context that can transform students' daily events into meaningful learning opportunities (Sefton-Green, 2003). Research on informal and mobile learning has shown improved scientific reasoning abilities (Gerber et al., 2001) and motivation by connecting personal sensory experiences to curricular materials (Roschelle, 2003). In contrast to traditional learning in classrooms, the mobile learning experience can be unique with its flexible access of digital information from a variety of devices that can provide a wide range of types of educational content, (e.g., online texts, interactive simulations, video clips of experts or demonstrations, tutorials, assessments). Instead of a linear and sequential lecture, mobile educational resources can be accessed and viewed flexibly at different lengths and at different times from almost any location – transcending both spatial and temporal boundaries.

In designing infrastructures for mobile learning, questions about what type of educational content to be delivered – when and how – with respect to the learner's context becomes important. Today's mobile devices are equipped with robust location sensors and wireless connectivity, making it possible for these devices to play an active role in delivering a personalized learning experience with context-relevant educational content. Thus, another opportunity for mobile learning is to help situate the learning in the learner's personal environment outside of the traditional classroom. The very location and physical environment could be an integral part of the learning experience. In contrast to traditional learning, mobile learning has the opportunity to translate the abstract and decontextualized knowledge presented in a classroom to personally meaningful learning experiences in real world scenarios.

Emerging mobile digital devices (e.g., audio players, smart phones and digital tablets) provide a wide range of platform opportunities for learning that include the ability to geo-tag and explore the physical environment (natural and built), augmented with multimedia educational resources (Economides & Nikolaou, 2008). Our prior work on the *Simple Machines in Your Life* used a PDA to engage elementary school girls in learning about the simple machines in their everyday surroundings (Ryokai et al., 2012). The *GreenHat* mobile augmented reality application helped students learn about bio diversity and sustainability issues in their natural environment using an interactive location-sensitive map on a smart phone (Ryokai et al. 2011). Database-driven mobile learning presents many challenges to the mobile user interface and the infrastructure of educational digital libraries; in particular, it is important to take into account: 1) location (e.g., address, geocentric coordinates), 2) type of location (e.g., school, home, parks, museums), and 3) learning goals (e.g., learning about nature in a field trip) (Hey et al., 2007). The next section describes the *Engineering Pathway* digital library and its infrastructure for mobile learning.

MOBILE LEARNING AND DIGITAL LIBRARY INFRASTRUCTURE

In order for mobile devices to provide the ability to remotely access context-relevant high quality educational resources that are untethered from the classroom, an infrastructure is necessary to store, serve, maintain and host these resources. Educational digital libraries, such as the *Engineering Pathway (EP)* (www.engineeringpathway.org), have many of the desirable features needed for a mobile learning infrastructure, such as database fields for educational levels, discipline and learning goals. Currently *EP* has approximately 17,000 learning resources catalogued with over 9,000 registered users and averages approximately one million page views a month.

The goal of *EP*'s Mobile Learning project is to extend the reach of engineering digital libraries to mobile learning experiences and applications. We are developing digital library infrastructures to support a range of mobile learning applications as well as the ability to enable the seamless transition between mobile and desktop settings. One of our research goals is to understand what information should be immediately available in the mobile setting, versus what information is best viewed from a larger screen in a stationary setting. Clearly one needs to consider the difference in screen size, memory, bandwidth and processing power. We also want to understand how mobile queries differ from desktop queries (Yndurain et al., 2012). Our prior 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.

Following best practices, we incorporated standard location information into the *Engineering Pathway* description of resources: Place Name, Street Address, City, State, Zip Code, Country and geocentric coordinates (latitude and longitude). Based on teacher feedback we also added Place Type (business, college/ university, K-12 school, landmark-built, landmark-natural, museum/ exhibit) to provide more context and distinguish the types of settings that might be useful for mobile learning. The resources (websites, tutorials, interactive simulations, case studies, etc.) were organized for browsing and specialized searches on *EP's* Mobile Learning community site (2012). Those tagged with full geocentric information were placed in the *EP on the GO* collection (2012) for use in our user studies described in the next section.

USER STUDIES

Two user studies were conducted to test software and user interface features for mobile learning applications: (1) user studies to identify natural and effective means for student navigation with location-sensitive mobile learning and (2) user studies of three prototypes that implemented solutions based on the navigation research.

Precision and Recall Experiments

Previous evaluation studies have shown that our search capabilities are effective for desktop learning applications (Robinson, 2008). We explore here the question of their effectiveness in a mobile learning context. Can students find the information they want that is relevant to their physical location-based context using our current search capabilities? Which location-sensitive fields in the catalogue records would be most useful to use in a mobile learning setting using a smart phone? As one of our use scenarios for mobile learning was associated with K-12 campus outreach visits, we used campus tours and demonstrations to study students' ability to make context-relevant searches over our educational digital library.

We conducted two separate experiments with different student groups on the campus of the University of California at Berkeley in the Summer of 2009. Group 1 consisted of female middle school and high school students who were part of the Geek Squad Summer Academy program of the Girl Scouts of America (Figure 1). The students were given two days of intense interactive sessions on computer hardware, multimedia, and campus demonstrations as part of a program to increase the number of women in computer science and engineering. Group 2 was composed of co-educational high school students as part of iDesign, a pre-engineering program with a focus on design and manufacturing in conjunction with the City College of San Francisco (Figure 2). Both groups were given 20-30 minute tours and demos at the following stops: (1) Culturally-Sensitive Sustainable Housing with the Pinoleville Pomo Nation; (2) Human-Powered Energy; (3) Rapid Prototyping Lab; (4) CITRIS (Center for Information Technology Research in the Interest of Society) Tech Museum.

So that the technology did not detract from the primary purpose of the outreach activity, we used paper cards to simulate a computer search. At each location, the students were given a paper card (Figure 3) and a pen, and asked to provide a question about demonstrations they visited and participated in. In addition to the question, they were asked to specify the location they were at, place name and place type to help us contextualize the question. The human tour guides then answered questions to give students feedback.

Figure 1: Geek Squad at human-power generation demonstration

Figure 2: Coed iDesign at CITRIS Tech Museum

Next, the results of the questions on the cards were used to formulate twenty-six suitable queries for our precision and recall experiment. *Precision* is defined as the percentage of relevant results in a search results list for a specific query. *Recall* is defined as the percentage of relevant resources in the database that are included in the search results. As the students were asked to write down questions, the queries needed to be modified to better simulate a database search. Two baselines were used: (a) noun and verb phrases were extracted from each of the 26 questions and (b) experts in database search modified the terms for effectiveness in a standard search engine (Lucene, 2012). We expected that if the students had performed the search queries themselves, the precision of their search results would be somewhere between these two extremes.

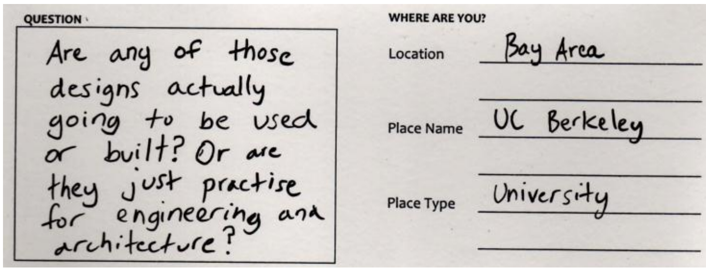

Figure 3: Query paper cards filled in by students visiting UC Berkeley in outreach program

Preliminary tests on both the noun/verb phrases and the expert search queries showed poor precision results, validating our hypothesis that location-sensitive cues are needed to improve relevancy of searches in mobile learning applications. To test what kind of cues would be most effective, we conjoined (Boolean AND) these search terms with combinations of place names, location, place type, and geocentric data. Nine case queries were conducted over the EP database as shown in Table 1.

As most desktop users rarely go beyond the top 20 in a list of search results, and mobile users only 10-15 (Jones, 2003), we limited our evaluation to the top 20 search results in each category to evaluate for relevancy precision. We randomly selected two queries to develop and normalize rubrics for evaluating relevancy on a five-point scale (Question 31: Is the green roof made of plants? Where will the solar panels be located? and Question 26: Why do they build places like that house community thing?). With three coders, 93% average inter-rater reliability was achieved. Once the protocol was validated, the rest of the database test queries were completed with one coder using the protocol over approximately 500 records for relevancy for each query. The results are shown in Table 1 for each of the nine query cases. The recall rate for relevant resources was close to 100% in all cases (almost all relevant resources were recalled), but the precision varied widely (e.g., not all of the resources recalled were highly relevant). Case 1 used the noun and verb phrases from the original student queries. Over 2,000 records were in the search results, whereas less than ten were highly relevant for each search. This case led to the lowest precision rate of 1.79 on a five-point scale. The precision greatly increased if the official location was conjoined with the noun, verb phrase, increasing the precision to 3.85 on a five-point scale.

Table 1: Precision and recall test results for different queries

(1. Noun, Verb Phrases; 2. Noun, Verb Phrases Conjoined with Official Place or Location; 3. Expert Search Terms; 4.Expert Search Conjoined with Place Names; 5. Expert Search Conjoined with Location; 6. Expert Search Conjoined with Type of Place; 7. Expert Search Conjoined with Official Place or Location; 8. Expert Search Conjoined with Official Location Type; and 9. Expert Search Conjoined with Geocentric Data: longitude/latitude)

Case #	1	2	3	4	5	6	7	8	9
Average Total # of Results	2,363.58	4.69	339.08	22.31	59.58	51.77	2.31	113.69	8.77
Average Precision	1.79	3.85	2.51	2.69	2.97	2.57	4.48	2.40	3.84
Standard Deviation	0.89	1.15	0.81	0.77	1.18	0.67	0.38	0.87	0.77

We expected the search results with the expert-modified search terms would have the highest level of precision. Interestingly, the search results with these queries did not have a high precision by themselves (Case 3) or when conjoined with the student terms for place or location (Cases 4-6). The precision did not increase greatly when official location type was added (in this case “university”), but it did increase dramatically when the official location was added (Case 7) where the precision was increased to 4.48, the highest on all of the tests. The next closest in precision was when the expert query was conjoined with geocentric data with the accuracy typically available on a smart phone (Case 9). The precision was lower than the case using the official location as three different tours were given in the same building with the same geocentric data.

User Studies with EP on the GO AR iPhone Application

The results of the precision study discussed in the previous section motivated us to use explicit location data in an application that could exploit the smart phone’s GPS and compass features, as well as multimedia displays and digital maps. The camera view was used to overlay information on educational resources in an augmented reality (AR) view (Figures 4 and 5). A subset of *EP* learning resources were curated for the specific geographic location. A folder of approximately 50 relevant learning resources from the *EP on the GO* collection around the UC Berkeley campus was included in the application. Due to the smaller screen size of the smart phone versus a desktop monitor and based on the prioritization of fields from our search study, fewer information fields were used in the mobile display (six fields: title, image, abstract, place, location and related links; examples are shown later in the paper in Figures 7-9) versus the desktop display (40 fields). As with our desktop view, *EP on the GO* users also had the ability to store resources in their personal workspace so that they could revisit a mobile experience at a later time.

The *EP on the GO* AR was developed as an iPhone application and was programmed in Objective-C for the iOS 4.2 operating system, utilizing the Cocoa framework for basic functionality as well as location, graphics and data management. We used the Wikitude AR API 1.1 to generate an augmented overlay view for the camera view. Based on the device’s line of vision in combination with its GPS coordinates and a distance parameter, the application displays all relevant thumbnails of learning resources from the given *EP on the GO* database (Figure 4). In other words, the query is automatically generated to display all relevant educational resources associated with the specific location. Depending on the user's position in the real world, these floating thumbnails are added to the augmented reality screen. A virtual radius additionally shows all available location-relevant resources not shown in the current field of view. When the user touches a floating thumbnail, further information becomes available, including the title, distance, a preview picture and a short description (Figure 5). By swiping over this preview window, the user is able to cycle through all learning resources within the designated distance parameter. Additionally, the user is able to access further information on the *EP on the GO* mobile website via the lower tab bar. Figure 5 shows an example of clicking on one of the thumbnails to see an expanded view of the Strawberry Creek tour option with expandable text and related resources. Users can click on the title or figure to play the video or other multimedia resources.

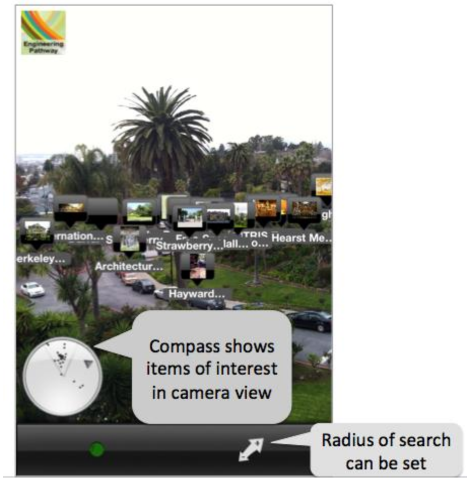

Figure 4: Screen shot from iPhone AR application

Figure 5: Screen shot from iPhone AR application: Strawberry Creek tour

We tested the *EP on the GO* iPhone augmented reality (AR) application under three conditions with nine undergraduate student participants in a between-subject design study. The participants were randomly assigned into three groups, with three people per group. Each participant was followed by a researcher with a video camera recording his/her activity. Each session took approximately one hour. In addition to evaluating the effectiveness of our *EP on the GO* features and information retrieval infrastructure, we studied the task of simple physical space navigation to contrast different types of interfaces: 1) paper map, 2) digital map, and 3) AR view (see Figure 6). The paper condition was designed to help contrast how individuals engage in way finding with digital tools in contrast to traditional paper-based media. In all three treatments, we kept the information content the same. The paper group used a booklet that was the same size as the mobile phone screen and used linked pages of screen shots from *EP on the GO* to replicate the hyperlinked educational content on the metadata displays available via the digital map and AR versions. In this study, we only included five learning locations as participants were asked to visit only three to five locations of their choice on campus.

The videos of the students were analysed for user behaviour, including head and hand positioning, user interface problems and queries on *EP on the GO.* The students were also interviewed afterwards with questions associated with navigation and effectiveness of the learning resources accessed. Query data and server logs were also analysed on *EP on the GO.* All three groups found the navigational features of *EP on the GO* to be effective in finding the right location and in finding links relevant to the intended learning experience. The learning resources associated with the five options provided enough information for the students to decide which locations were of interest to them. The paper map, the digital map and the AR views helped students navigate to the general location of interest. Students using either the digital map or the paper map spent a significant amount of time looking down at the digital map or paper booklet in their hand while walking around the campus and sometimes had difficulties orienting themselves once they reached the general area. In contrast, students using the AR view held their heads relatively upright as they browsed the digital information displayed/overlaid in their field of view (notice the difference between the three conditions in the way they hold their devices in Figure 6). The upright head positioning so that users always saw the environment while navigating may explain why the AR users were ale to navigate better once arriving at the target destinations.

Figure 6: Students using the digital map (left), paper map (middle), and AR (right).

In contrast to the paper and digital map users, the AR users used the tool until the very end of their spatial navigation. For example, one of the places the participants were invited to visit was the CITRIS technology museum used previously in the IR study (see Figure 2). For the paper and digital map groups, once they were inside the building, they did not look at the digital or paper map at all and used other information such as room numbers to finish their navigation. In contrast, the AR users used the AR tool until they could see the target area right in front of them. Even when the live GPS data were not available indoors, the compass data were still available so that the students could continue their navigation inside of the building. They were also able to compare information and images they saw in the educa-tional resources provided via the visuals they saw directly through the AR view to better orient themselves.

Figure 7: CITRIS Museum resources

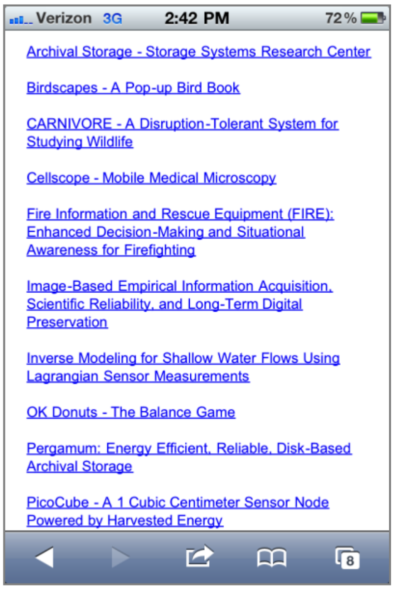

Figure 8: Related links on the CITRIS Museum resource

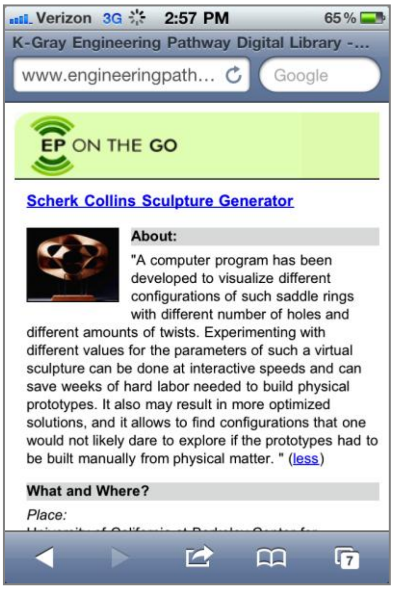

Figure 9: Example related link of Sculpture Generator made from 3D printing

Most users found enough information on the metadata and linked resources and did not feel the need for a full text search for other resources. Figure 7 shows a screen shot of the location-sensitive information shown for the CITRIS museum and Figure 8 shows some of the related links associated with the exhibits in the museum. Another useful feature, due to the small form factor of the iPhone, was the ability to expand and contract (Figure 9) descriptions. Some of the users commented that the descriptions were more helpful than those in the museum display as *EP on the GO* allowed them to go into as much depth as they wanted. For example, one student visiting the Blum Center for Developing Economies learned about the engineering design behind the Darfur Stoves project while she was there and appreciated that she could immediately follow the links on *EP on the GO* for her to be involved in the project and take actions. She explained that she would not have known about the project, or find ways for her to be involved in such projects, if she did not have this opportunity to visit this neighbouring building on campus and view the related links from *EP on the GO*. Another student visiting the Human Powered Vehicle exhibit explained that she was not only excited to learn more about “Human Centered-Design” but also to find related research projects happening on campus through related links.

CONCLUSIONS & FUTURE RESEARCH

Our goal is to bring digital library resources from the *Engineering Pathway (EP)* to mobile devices in order to enhance students’ experiential learning outside of the traditional school setting. Our *EP on the GO* prototype was designed to pull digital resources available from *EP* that were relevant to the learners’ ongoing activities in the physical world (both the natural and built environments), allowing them to make real world observations of science and engineering in their everyday environment and thus establishing personal connections with the educational material.

Representing the lower end of our target student population, our information retrieval study of middle and high school students showed that users unfamiliar with a location may not have the right cues to formulate an effective text-based query over a digital library to find relevant information. There appeared to be little difference in the lack of effectiveness over the span of age groups leading us to believe that college students would have similar difficulties. This study recommended better use of relatively precise location data such as GPS coordinates or other specific identifiers (e.g., QR codes, hash tags). The lower division college students tested with the automatic geocentric search had little difficulty in finding relevant local resources with this change. In addition, these “on the go” mobile users were much more likely to use curated links, as opposed to full text search, once they were viewing specific metadata. The automatically generated geocentric search, coupled with the related resource links seemed to adequately answer their questions based on our observations and post-test interviews.

Through our formative study with *EP on the GO* we made two important observations concerning how the user interface influenced the way individual users looked at the built and natural environment and navigated the space. First, the AR view was good at orienting people in the right direction and guiding people to come close to the target object or location for the learning resource, compared to the digital map and the paper map groups. Second, when the target was far away, the digital map seemed more comfortable to use, as users did not have to hold the device in front of the face all the time. One concern of the AR view is that holding the phone vertically in front of a user for a long period of time was not good ergonomics and thus could be physically demanding.

These observations led us to formulate a hybrid approach for future research that would combine a digital map and an AR view. In this approach, the system would start with the digital map to help the users navigate the bigger general space, but switch to the AR view when the target is near the user to further guide her/him closer to the target. This solution enables spatial navigation to move from a macro view (overview of the campus) to a micro view (particular part of the area experts would notice) that learners should become aware of. We will evaluate whether this hybrid approach has improved way finding at the start and improved engagement with the physical world during the actual learning experience.

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