

Off the Paved Paths: Exploring Nature With a Mobile Augmented Reality Learning Tool

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Abstract

Mobile augmented reality (MAR) is an increasingly popular technology for enhancing how people interact with and learn about the environment and objects in the physical world. However, little is known about what aspects of a MAR interface can enhance student learning and engagement. Building on field observations and interviews with experts, and formative studies on how mobile learners navigate spaces using different interfaces, we have designed, built, and evaluated the *GreenHat* MAR application to help students learn about biodiversity and sustainability issues in their natural environment. Our evaluation of the GreenHat MAR prototypes suggests that in comparison to a digital map on the same smartphone, MAR encouraged students to more carefully scrutinize physical field sites, and led them to make more personal discoveries to the subject matter being learned. We present the iterative design process, results from our studies, and discuss the implications for the design of mobile learning tools.

Keywords

Mobile augmented reality, mobile learning, sustainability, biodiversity, location-based information, expert perspectives.

Introduction

Today, more than a third of all adults and more than fifty percent of all college students in the U.S. have smart phones (Nielsenwire, 2012). Commercially available smart phones have enough processor and graphics engine power to run augmented reality applications, and network connectivity fast enough to download high resolution videos. In addition, they come with built-in GPS and motion sensors that can track the user's location reliably and run applications that are location-sensitive in real time. Because many students carry these powerful devices everywhere they go, providing educational material through mobile devices strikes us as a prime opportunity to reach the aspirational goal of "learning anytime, anywhere," which expands Weiser's vision (Weiser, 1991) of *ubiquitous computing* (ubicmp) to everyday educational contexts.

Mobile Augmented Reality (MAR)—which involves the dynamic overlay of digital information in the user's view through mobile devices—is an increasingly popular technology for enhancing how people interact with and learn about the environment and objects in the physical world. In MAR, mobile devices act as the "magic" lens through which people can see the world annotated or augmented with digital information (Bier et al., 1993). Information displayed in MAR is meant to be understood in conjunction with the dynamically changing physical environment mobile users are in. MAR keeps people connected to the physical world via their natural senses (e.g., smelling the air, hearing the ambient sounds, feeling the heat in the environment, etc.) while at the same time having access to, and interacting with, a wealth of digital information. This combination has the potential to be a powerful way for people to learn about the environment or physical objects in situ, in a way desktop computers or other types of stationary displays cannot accomplish.

To date, much of the effort made in the field of HCI and Ubiquitous Computing has focused on technical enablers of MAR (e.g., Billingham et al., 2001; Cheok et al., 2004; Gleue et al., 2001; Henrysson et al., 2005; Rekimoto, 1997; Viegas et al., 1996). However, many questions with regards to how MAR can be used to meaningfully support learning remain. For example, what type(s) of information or situation(s) would most benefit from MAR displays? In what ways can having access to digital information while being embedded in the real physical world contribute to users' understanding about the environment?

In this article, we investigate the potential role MAR technologies could play in engaging students in uniquely mobile and personal learning experiences by providing experts' perspectives and knowledge in situ (Goodwin, 1994), i.e., the way experts notice things and ask questions about the very environment students are standing in, so that even in the absence of experts, the students could actively investigate and learn about their environment. Using MAR and experts' videos on smart phones, we explore ways to draw students' attention to the physical environment they are immersed in, and actively engage them in the subject of sustainability and biodiversity in the specific context of their environment. We report on our iterative design process and evaluation of *GreenHat*, a MAR system that aims to help students engage with the natural environment from multiple expert perspectives (landscape architecture and conservation biology). The evolution of the prototype design was based on our observations of experts in the field, as well as individuals using the MAR tools in contrast to other mobile tools, such as interactive digital map tools, to navigate and learn about their environment. With multiple

iterations of our design of a mobile learning tool, we investigate MAR's role in enabling increased interaction with the physical environment.

Background

Mobile Augmented Reality

Mobile Augmented Reality (MAR) extends the Augmented Reality (AR) paradigm, which is to display digital information in the user's view via head-mounted displays or other displays, so that objects in the physical world and digital world appear to spatially co-exist (Milgram & Kishino, 1994). AR is often understood as part of the mixed reality continuum focusing on augmenting the real world with digital information, instead of bringing real-world information in virtual worlds (Azuma, 1993). Therefore, AR aims to supplement the real world, rather than creating an entirely artificial environment (Olsson et al., 2012). Through the use of location aware mobile devices, MAR can further broaden the interaction space of the traditional AR where the augmented interaction space is limited to a predefined area. In the following sections, we discuss aspects of MAR that can contribute uniquely to people learning about objects or environments in situ. Our goal is not to come up with a new taxonomy for MAR (useful taxonomies of AR have been proposed in the past (Normand et al., 2012; Milgram & Kishino, 1994; Mackay, 1998; Suomela & Leikoinen, 2004; Lindeman & Noma, 2007)), but rather to discuss MAR as a unique enabler for mobile learning that takes advantage of the context and manner in which people receive information with respect to their environment.

Mobility and Extended Interaction Spaces

MAR's extended mobility enables digital information to be displayed in more places away from the desktop, in the users' physical and personal world. This has opened up interesting opportunities for mobile learning. For example, a classic example of a MAR learning tool is ARCHEOGUIDE (Gleue & Dähne, 2001), which provided virtual reconstructions of the artifacts and buildings, and situated documentaries about historic places in the real environment. In this early MAR system, users wore a head-mounted display (HMD) and a backpack full of sensors and mobile equipment. *TimeWarp* (Herbst et al., 2008) was designed as a MAR game for exploring the history of a city. The game was based on the legend of the *Heinzelmannchen*, small elves of Cologne from medieval times. As the players searched for the virtual elves hiding at different street corners, they explored both the virtual reconstruction of historic buildings and the real locations in the city. *Science in the City AR* (Rothfarb, 2011) is a MAR tool developed by the *Exploratorium* museum, so that visitors can explore fog and weather phenomena in San Francisco. For example, the Golden Gate Bridge can be turned into an altimeter, with heights marked at different vertical points and scaled to actual size. Visitors can learn about factors that affect how fog moves into the areas by directly observing the height of fog at their location. Similarly, *ARWeather* (Heinrich et al, 2008) is a MAR system that provides simulations of a variety of weather conditions on the terrains and topology users are in.

In MAR systems, augmentable targets can be streets, buildings, natural areas and objects, even people and other moving targets. MAR enables the physical environment to be directly annotated and described in situ, guiding users to pay attention to particular parts of objects in their environment. Virtually any object in the user's environment could become an entry point to new information, i.e., "the world becomes the user interface" (Höllerer & Feiner, 2004; Wellner et al., 1993) and material for learning. This is a great

opportunity to design new educational technologies that aims to connect learning materials to student's personal life and experience beyond classroom. In contrast to traditional educational materials, MAR systems can provide students with ways to more directly and personally connect and interact with examples found in the real environment.

Multimodal (Multiple Senses) Interactions

In addition to its mobility, MAR is a unique enabler for mobile learning because of its multimodality. MAR enables people to view digital information overlaid in the physical environment they are immersed in, *in situ*, rather than being immersed in a virtual environment. Away from desktop, a user's body is highly connected with the physical world. Exploring the environment with MAR can include a variety of senses and modalities, such as multiple hands, eyes, body postures, audio, temperature, the sense of smell: some or all of which may be used to enhance the learning experience with MAR systems. For example, White and Feiner (2010) have developed botanical species identification and data collection systems that can run across a diversity of platforms including tablet PC and mobile phones running MAR. The system uses computer vision to help identify the botanical species the users encounter. With their system, users are invited to use the device as a lens through which they interact with and learn about physical specimens. The system supported users' engagement in the mobile learning activity through a variety of senses and modalities: visually (shape and colors), physically (feeling the texture and forms), and even olfactory senses (how difference species smell). *Immersive Tour Post* (Park et al., 2006) was designed as magic binoculars through which Korean tourists could experience historical sites in Korean cities. For example, tourists may observe virtual soldiers from the past, dynamically moving and roaring, overlaid onto the rampart where a famous war had taken place. Through the visual and auditory reconstruction of historical events that once took place at the very location they are standing in, the visitors had more direct and personal ways of learning about the architecture and history.

To encourage people to stay connected with their environment, Albrecht et al. (2011) have explored techniques that allow a user to hear the surrounding acoustic environment while adding virtual sounds to the auditory perception through acoustic-hear-through and microphone-hear-through. Veas & Kuruijff (2010) explored a variety of physical and ergonomic designs such as grip attachments and special belts for MAR so that people can comfortably use MAR devices while exploring nature, even in harsh weather condition such as in snow covered mountains. *Pileus* (Matsumoto & Hashimoto, 2009), on the other hand, is a MAR system in the form of an umbrella that displays information embedded in a city using metadata. The umbrella shows an interactive map and photo database related to the user's location, so that even in rain, the user can explore and navigate the city while utilizing context-sensitive digital information. From a head-mounted display to an umbrella, using visual and auditory augments, MAR gives people access to information dynamically in interaction with the environment, richly involving multiple senses, and keeping the personal connection people have with their environment. These examples illustrate the potential of MAR as a uniquely immersive learning tool, which can build on and engage through people's multiple senses, both in the physical and digital world.

Access to New Perspectives

Thirdly, MAR is an enabler of unique mobile learning because of its ability to simulate new perspectives directly in the user's environment. Through visually rich simulations and location sensitive media, MAR can provide people with new or alternative ways of

looking at the world. For example, *Human Pacman* (Cheok et al, 2004), a MAR game, turned regular urban streets into a grid on which virtual game characters can roam around, creating a hybrid digital and physical game playground. This project, though not designed as an educational tool, inspired UI designers to consider features of users' physical environment as an integral part of their augmented game experience.

A variety of MAR systems have explored ways of providing users with alternative views of their environment. The *see-through vision system* by Avery et al. (2008) allowed visualizations of occluded objects in an outdoor setting, textured with real-time video information. Their MAR system give people access to a kind of "x-ray vision," revealing the activities that happen inside of the building from outside, which is usually not possible. Similarly, an *underground visualization system* (Schall et al., 2009) gave users geospatial 3D models of the underground infrastructure superimposed on a construction site. The *MARCH* (Mobile Augmented Reality for Cultural Heritage) system (Choudary et al., 2009) was designed to help users identify cave drawings by overlaying experts' drawings on top of the surface of the cave. The *Earthquake AR* (Billinghurst & Grasset, 2010) explored how MAR can be used to visualize reconstructed buildings and show other earthquake related information on site after an earthquake disaster. After the earthquake at Christchurch New Zealand, people walked around the city with Earthquake AR, and saw life-sized virtual models of buildings in place of where the real buildings used to be.

It seems that people are willing to accept simulated views presented in MAR systems and build new and personal experience with it. Olsson et al. (2012) described that MAR can effectively evoke such experiences because of its visual and immersive way of visualizing information and by providing the user with a very immediate and intuitive way to interact with the information. In their study of people using MAR services in shopping centers, Olsson et al. found that people expect MAR services to be not just efficient, but also playful, inspiring, lively, and even provide positive surprises related to the current situation and location.

In summary, instead of being immersed in a virtual world, MAR enables people to remain connected with the physical environment they are in, and invites them to look at the world from new, alternative perspectives. Through rich multisensory simulations, MAR can project past, future, or new and alternative views on the user's environment. Access to this type of information, "seeing beyond what is," is important for learning, as learning happens by modifying or expanding the habitual framework of interpretation (Dewey, 1934; Csikszentmihalyi & Rochberg-Halton, 1981). We are not arguing that MAR alone can directly cause such conceptual changes in people, but rather, by presenting alternative perspectives in their everyday view, MAR could help facilitate this type of active perception of the everyday environment. MAR can holistically change the way we view our environment, and the way we interpret information presented in that context, which can lead us to ask questions we would not have asked before. In this article, we specifically investigate MAR's role in simulating such new views as "experts' perspectives" in mobile learning, on the subject of sustainability and biodiversity in the specific context of their environment. In the following sections, we provide a short overview of literature on mobile learning.

Mobile and Situated Learning

MAR's ability to extend the interaction space to places beyond the desktop, and provide unique learning experience that takes advantage of both digital and physical worlds is of

particular and timely interest to the mobile learning community. A number of studies have shown that 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 (Merdich et al., 1997; Sefton-Green, 2003; Yeh et al., 2006). Students with enriched informal learning environments have been shown to achieve improved scientific reasoning abilities (Gerber, 2001). Learning in context can improve student learning by allowing them to connect personal sensory experiences in the field to curricular materials (Bransford et al., 2000). 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.

In contrast to traditional classroom learning, mobile learning has the opportunity to take the abstract and decontextualized knowledge (often offered in the classroom) and apply it back to the real world scenarios the students are immersed in. Mobile learning can help *situate* the learning in the learner's personal environment outside of the traditional classroom. Situated cognition theory suggests that knowledge cannot be separated from the context in which it is embedded and learning results from students acting in apprentice-like situations in interaction with experts (Lave & Wenger, 1991; Brown et al., 1989). One of the primary challenges in scaffolding novices to become experts is helping them first develop a "professional vision" – being able to see the world from an expert's perspective (Goodwin, 1994). Goodwin identifies three key expert "practices": (1) *coding*, which transforms phenomena observed in a specific setting into the objects of knowledge that animate the discourse of a profession; (2) *highlighting*, which makes specific phenomena in a complex perceptual field salient by marking them in some fashion; (3) *producing and articulating material representations*.

Traditionally, field trips and fieldwork serve as opportunities for this type of situated learning where experts demonstrate a professional vision. Successful teachers motivate and situate the learning for the students. For example, a field biologist expert may guide students by demonstrating how she goes about engaging in scientific inquiry in interaction with the real forest (e.g., what she notices in the field and what kind of questions she asks about them), and then encouraging the students to try it out themselves. Such active learning with experts in interaction with the real environment is powerful, but experts might not always be available for the learners.

In absence of experts, can mobile technologies help scaffold novices by helping them see the world from experts' perspectives? If MAR can direct people's attention to particular parts of the physical environment by annotating the physical environment with digital information, can MAR direct people to look at the environment in certain ways that could be educational? Can a MAR view simulate the way experts look at the environment and make observations? Informed by the situated cognition theory, our goal is to explore MAR to simulate experts' perspectives and help learners engage in *apprenticeship in thinking* (Rogoff, 1990).

In the following section, we provide related technologies designed to support mobile learning.

Related Technologies

Increasing ecological awareness is an important area of research in the HCI and design community (Blevins, 2007). Previous work has leveraged ubiquitous computing (Liu & Milrad, 2010; Petropoulakis & Flood, 2008; Roschelle, 2003) and social networks to

promote ecologically friendly action (Mankoff, 2007), and enabled citizen science by using cellphones as a mobile sensing platform (Paulos et al., 2008; Kim et al., 2011). The *Explore!* mobile-learning system invited middle school students during a visit to an archaeological park to engage in an excursion-game, to help students acquire historical notions while playing, and to make archaeological visits more effective and exciting (Costabile et al., 2008). The *Ambient Wood* (Rogers et al., 2004) invited children to explore and reflect upon a physical environment that had been augmented with a medley of digital abstractions. Researchers have also developed smart phone- and tablet-based tools for automated identification of botanical species in the field (Leafsnap, 2012) as well as paper-based mobile tools for field biologists (Yeh et al., 2006). *Creek Watch*, an iPhone application and website, allowed volunteers to report information about waterways in order to aid water management programs (Kim et al., 2011). Applications have been developed to 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 tourist information (Benford et al. 2006; Bobrich & Otto, 2002; Soloway et al., 1999; *CyberTracker*, 2005; *Mobile Bristol Centre*, 2005). 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*).

Within HCI, augmented reality (AR) has been applied to a variety of educational and creative tools since the late 90's: from an AR "x-ray vision" tool for surgeons in training (Welch & Bishop, 1997), to *Magic Book* that has 3D virtual and animated content on real pages like a traditional "pop-up" book (Billinghurst et al., 2001), to Archeoguide that provides situated documentaries about historic places (Gleue & Dähne, 2001). State of the art technologies for such games include PTAMM, a parallel tracking and mapping system using multiple independent cameras and multiple maps (Castle et al., 2008). These technologies offer exciting ways of viewing the physical world, taking advantage of the additional digital information overlaid in the user's view. Most of these technologies (with the exception of PTAMM), however, rely on the presence of physical fiducial markers the system can identify in the desktop or indoor setting.

Our work builds on and contributes to these research efforts to support learning activities in increasingly diverse places yet increasingly personal ways. Despite a large body of MAR demonstrators and related research, our work is unique and novel in that it shows how MAR can be used to simulate experts' perspectives in natural settings. We investigate the potential of MAR as a learning tool in everyday environments, and how MAR can enable people engaging with nature in a way experts would, by simulating their perspectives.

Iterative Design and Prototyping

The work presented here is part of a larger research effort to bring high quality educational materials to students on the go, expanding the accessibility of educational resources available through a digital library called the *Engineering Pathway* (2012). Issues of organizing and accessing educational content using location sensitive metadata on mobile devices are discussed elsewhere (Ryokai & Agogino, 2012; Ryokai et al., 2012). In this article, we focus on user interface issues: how a specific type of user interface, MAR, can engage students in active scientific inquiry in natural settings, as experts would do. Our prototype, *GreenHat*, is one example of such an experimental mobile learning system.

The design of the GreenHat mobile learning tool involved an iterative process of building and evaluating several prototypes, both with and without MAR views. The current design of GreenHat incorporates a MAR view in conjunction with an interactive digital map as a space navigational tool. The decision to create such a hybrid system with MAR and a digital-map was based on lessons learned from our early prototypes. We have made two important observations that informed the final hybrid design. The first finding is that providing students with access to location information through videos and websites on a mobile device can engage students with the topic, but can also draw their attention away from the very environment they are learning about. In other words, even when the students are physically there, their attention towards the environment may not be there if the mobile content monopolizes their attention. The second finding is that the way information is presented to students determines how they look at the environment. For example, a MAR view (in contrast to a map view) can act as a directional tool to draw students' attention to specific parts of the physical environment (in a way experts might do), bringing the students closer to the physical target they are learning about, and lead the students to explore the site more.

In the following sections, we describe our iterative design process in several steps: 1) Our observation of experts in the field which led to our design goals for GreenHat, 2) Building and evaluating the first GreenHat prototype without any MAR view, 3) A formative study about how people navigate and learn about their environments using MAR in contrast to digital and paper maps. These steps explain why and how a MAR view was incorporated in our final prototype.

Step 1. Expert Observations & Design Goals

With the goal of designing a mobile learning tool to enhance student learning about issues of biodiversity and sustainability, we took advantage of our local environmental resources. We were fortunate to work on a campus built on a natural landscape with a creek running through it. However, as we learned later, the campus is faced with difficult issues of balancing landscape design and nature conservation. In order to understand the specific issues of sustainability and biodiversity on campus, the design team first reviewed material available through the campus' existing resources (e.g., websites and print media). The design team then took tours of the campus with experts, including conservationist biologists and a landscape architect, and conducted interviews and discussions with these experts.

Based on insights we gained from the tours, interviews with experts, and the mobile learning literature, we developed the following design goals for our system (also discussed in (Ryokai et al., 2011)).

Modeling the Way an Expert Explores the Environment: Observe the Environment From Experts' Perspectives

One of the first observations the design team made while in the field with the experts was that experts invited us to explore the parts of the campus we usually do not notice or enter. The experts walked around areas of the campus that were *off* the map and pointed out a variety of issues we neither knew of nor noticed. The areas the experts entered were not fenced off, nor were they far from the usual paved paths. Yet, they were far enough from the pavement (approximately 10-20 meters) so that if not pointed out by an expert, we would rarely notice them. For example, one of the experts took us just a few meters

from the usual paved paths to show us where a particular patch of lawn serves as a bio pollutant filter.

We also noticed that the experts' physical demeanor and engagement with the environment were different from ours while we walked on campus together. While being in the same environment, the experts' eyes were at a variety of locations, noticing things and asking critical questions about the environment. For example, experts carefully looked around the ground as we walked together (e.g., identifying native oak seedling sprouting where they could be damaged from human traffic), looked up the trees (e.g., identifying non-native ivy overtaking the light that the oak tree should get) and looked around the shrubs (e.g., identifying non-native squirrel species).

What, then, we wondered, is it like to experience one's familiar environment from multiple experts' perspectives? What kinds of things would experts notice? What kinds of questions would they ask? What kinds of observations would they make? In our mobile learning application, we wanted to trigger this kind of active observation about one's own environment. While an expert's availability is limited, mobile devices may be able to play a role in providing expertise "on demand" for learners, in the absence of direct conversations with human experts (Trondsen & Vickery, 1997). Based on the literature on expert vs. novice learning (Goodwin, 1994) and situated cognition theory (Lave & Wenger, 1991; Brown et al., 1989; Bransford et al., 2000), our goal is to simulate an experience for the learner as if they were taking a walk with experts in the natural environment.

Discover Unfamiliar Debates About Familiar Places: To Look at the Familiar Places With a New Perspective

While taking a tour of the campus with experts, we were also presented with unfamiliar debates about familiar places. For example, we discovered that one of the most beautiful and popular open spaces with a large lawn on the campus is the least sustainable. Lawns not only require a lot of water, but are also maintained with pesticides and lawnmowers; pollutants pour directly into the creek and kill animal and plant life in the water. The expert guided us away from the pavement we are usually on, and invited us to take a physically closer look at the creek and discover the murky unhealthy condition of the water right next to the lawn we usually enjoy. There, we were presented with two contentious issues: one having an open social space important for students on campus, and two, saving life in the creek. It is this type of unfamiliar debate about familiar places with which we wanted to engage the students. As our conservation biology expert commented: "One does not need to hop on a bus to Yosemite to learn about biodiversity." There are plenty of opportunities to provide situated learning on biodiversity right in students' back yard. In fact, learning in familiar places can make conservation issues even more personal to the student. We believe that presenting evidence and facts in a familiar physical environment to the learner provides a unique learning experience and an opportunity to "care, discover, and observe" (Brown et al., 1989).

Present Multiple Perspectives

We also noticed that experts were careful in expressing their opinions with respect to other perspectives. We wanted to avoid having biased or polarized views by supporting pluralism in perspectives. For example, a nature conservationist may have a mission to restore the landscape with native plants, but what constraints might the landscape architect have? Are there solutions that satisfy both perspectives? As part of the

educational design, we included educational resources and videos that represented the views of multiple experts.

Mobile and Beyond / Reflect

We also connected the mobile learning experience with the students' existing desktop learning experience. Learning "on the go" provides unique opportunities for the students to make observations in situ and discover relevant facts. However, certain behaviors such as typing long notes or browsing large collections of digital library resources are not ideal on a mobile device with a small screen and a tiny or virtual keyboard. Our goal is to support uniquely "mobile" learning experiences, but at the same time not limit the experience to mobile devices only. After the trip, the students should be able to reflect and expand on their activities by visiting their personalized online map on a web interface. Therefore, the GreenHat web interface was designed to invite them to further explore relevant keywords, edit their entries, browse and comment on others' entries, and visit relevant online resources.

Educational Content

The educational content for our prototype was chosen based on the observations and interviews we made with experts. The final locations and topics to be learned with GreenHat prototype were selected so that they are manageable during a tour a student could take on foot in about one hour. Table 1 with the map and descriptions presents the topics and questions presented at each area.

Step 2. First Study With GreenHat Mobile Tool

The first GreenHat prototype was built on an Android G1 Dev smart phone with a built-in GPS. The curated content (see Table 1) was delivered on the phone in a combination of video, images, and a location-sensitive map. The map first indicated the user's current location with respect to a specific area (Figure 1, left). Once the user reached his/her destination, the phone initiated a video of the expert discussing an issue specific to the area (Figure 1, right). In this first prototype, we did not see the need to incorporate the MAR view as we felt that the locations of experts' discussion were clear on the map and also in the video of experts explaining and pointing at the environment.

We evaluated our first GreenHat system with 12 undergraduate students outdoors. Each student spent approximately one hour exploring the five locations on campus with our first GreenHat prototype. At each location, the students wrote their responses to the topic question on the phone using the phone's keypad. We followed each student with video cameras and field notes. The results of this study was presented elsewhere (Ryokai et al., 2011). Here we focus on the findings that motivated us to develop new design with MAR view.

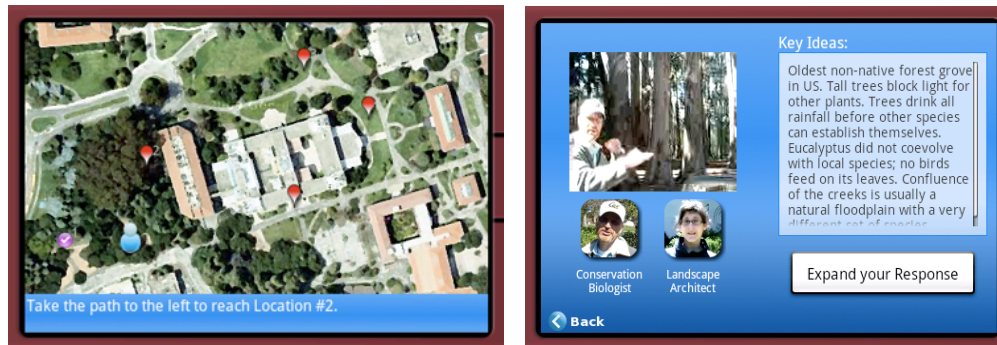
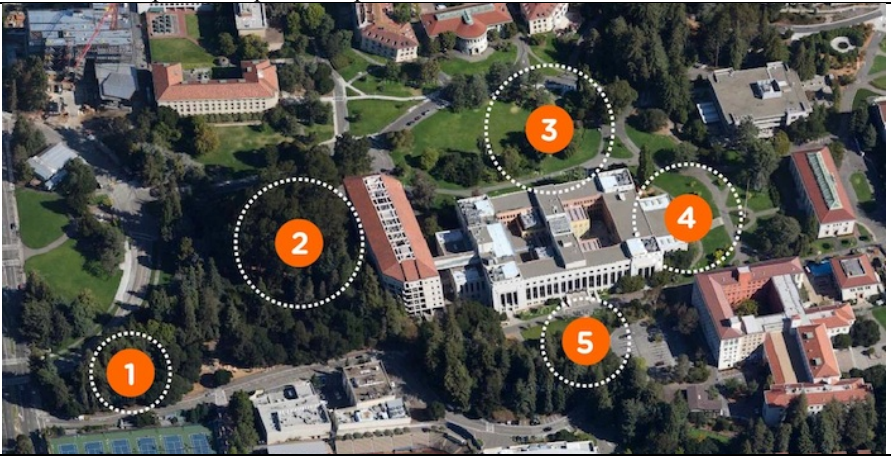
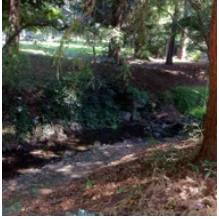

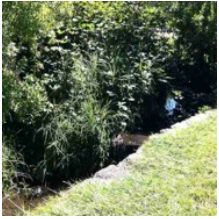




Figure 1. Screenshots from the first GreenHat prototype without any MAR view. On the left is shown the interactive location-sensitive map, and on the right experts' demonstrative videos with key concepts in text.

Table 1. The topics and questions presented at each area.

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| <p>1. Ivy at the Strawberry Creek Students are invited to look at the two banks of the creek – one with ivy (luscious green area), and one without (brown area). In the videos, the conservationist 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. The students are asked which side of the creek they prefer and why.</p> |  |
| <p>2. Eucalyptus Grove Students are invited to step into the eucalyptus grove. The conservationist biologist explains that the eucalyptus trees are non-native species and they do not give other native species space to grow. The landscape architect explains they are a fire hazard, but they have been part of the campus for more than a century. Students are asked whether the grove should be cut down or kept.</p> |  |
| <p>3. North Lawn Students are invited to look at the lawn that comes close to the creek. The biologist explains that maintaining the lawn is unsustainable and pollutes the creek. The landscape architect explains the lawn brings people together and closer to the creek/nature. Students are asked to think about the advantage and disadvantage of the lawn on campus.</p> |  |
| <p>4. Oak Seedlings Students are invited to identify native oak tree seedlings sprouting among the landscaped area. The biologist explains the seedlings can be transplanted given the right care. The landscape architect explains the seedlings are interfering with the committed landscape and transplanting them would be expensive. Students are asked whether the seedlings should be pulled out or replanted.</p> |  |
| <p>5. Filtering Lawn Students are invited to look at the lawn designed to serve as a bio filter in conjunction with a nearby detention pond. The biologist explains how this patch of lawn has a useful function but still uses too much water to be maintained. The landscape architect explains the lawn functions as a social place for students and connecting them to the rest of the campus. Students are asked how this lawn compares with the North Lawn they saw earlier.</p> |  |

Lessons Learned

The students using the first prototype of GreenHat outdoors navigated between each of the five locations on campus, and learned about each site by watching the facts provided by experts in the videos. However, we observed that the students did not seem to physically come *close enough* to investigate the area. They were quite often at the periphery of the actual site. For example, while near the Eucalyptus Grove (stop 2), the students watched it over the fence as opposed to stepping into it (see pictures in Figure 2). At this site, it was important for them to step into the grove and directly observe why Eucalyptus trees leave no space for other species to thrive. Yet, instead of stepping into the grove as experts were doing in the video to make their observations, the students using our first GreenHat prototype stayed on the paved path they were on, and learned about the facts from the paved path. This motivated us to redesign the user interface design so that it could invite the students to physically come closer to the target site and more directly explore the area.



Figure 2. Students using the first GreenHat system remained on the paved path and were engaged more with the phone than the environment.

Secondly, the students spent more time looking at the mobile device for navigating with the map and watching the experts' videos (approximately 5 minutes of videos at 5 different locations), compared to the short amount of time spent to look at the actual environment (between 12 to 31 seconds). The students were physically present at the five locations, but they seemed more engaged with the mobile phone than with the physical sites. This motivated us to redesign the user interface so that it would shift the students' perspective, away from the device, and more towards the environment. After all, the students were there to learn about the physical location, not just to interact with the mobile device.

Given the background research in MAR, we speculated that an augmented reality (AR) view could be incorporated on our device to direct the students' attention towards the environment, while still providing context-sensitive information on top of the physical view. However, we did not know, how much of the MAR view should be incorporated in our system. Should the MAR view be used the whole time the students are in the field? If part time, when should the system switch to the MAR view? Before redesigning the system, we needed to have a better understanding of how MAR could be effectively incorporated in our mobile learning activity. We designed our second study to explore UI issues associated with MAR for our application.

Step 3. Studying Navigational Differences Between Paper, Digital Map, and MAR UIs

Morrison et al. (2009) studied how people used a MAR view on a paper map, versus a digital map in a setting where multiple users shared one device. Their study was based on MAR views on a paper map and not in the environment. Therefore, we needed to further investigate the potential of engaging users with the physical environment using the MAR versus digital map view. In order to study how different interfaces affect the way individuals navigate and look at the physical world, we conducted a formative study with the task of simple physical space navigation to contrast different types of interfaces: 1) paper map, 2) digital map, and 3) MAR view. 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. For example, the paper group used a booklet that was the same size as the mobile phone screen and used linked pages to replicate the hyperlinked educational content available via the digital map and MAR versions.

Unlike Morrison et al.'s study in a group map navigation, this was an individual user study. Participants were asked to visit three to five locations of their choice on campus using a navigation tool in three respective types: digital map, paper map, and MAR. The goal was to investigate the different affordances provided by the three interfaces, how individuals used the tool, and how the tool influenced the way people oriented themselves and navigated the physical space.

A total of nine undergraduate students participated in this between-subject design study. The participants were randomly assigned into three groups, with three participants per group. At the beginning, each participant received basic instructions of the navigation tool. Then, each participant was asked to choose three to five locations of their choice on campus using the navigation tool. A researcher followed each participant with a video camera recording the participant's activity on the go. Each session took approximately one hour.

Results

The digital map users held the device in one hand, looked down at the device for a significant amount of time while walking around the campus. Their eyes moved between looking down at the device and up at the environment. The digital map view seemed effective in guiding the users to the general location, but once they were close to the target location, they sometimes had difficulties orienting themselves, e.g., towards the right entrance of the building.

The paper map users also looked down at the paper for a significant amount of time while walking around campus. Similar to the digital map group, the paper map users often shifted between looking down at the paper map and looking up at the environment. Because they worked with the paper document spanning multiple pages (the map was on one page, but the related educational information about the locations they visited were on separate pages), they used two hands to hold the paper document, sometimes using fingers to mark the pages they wanted to remember.

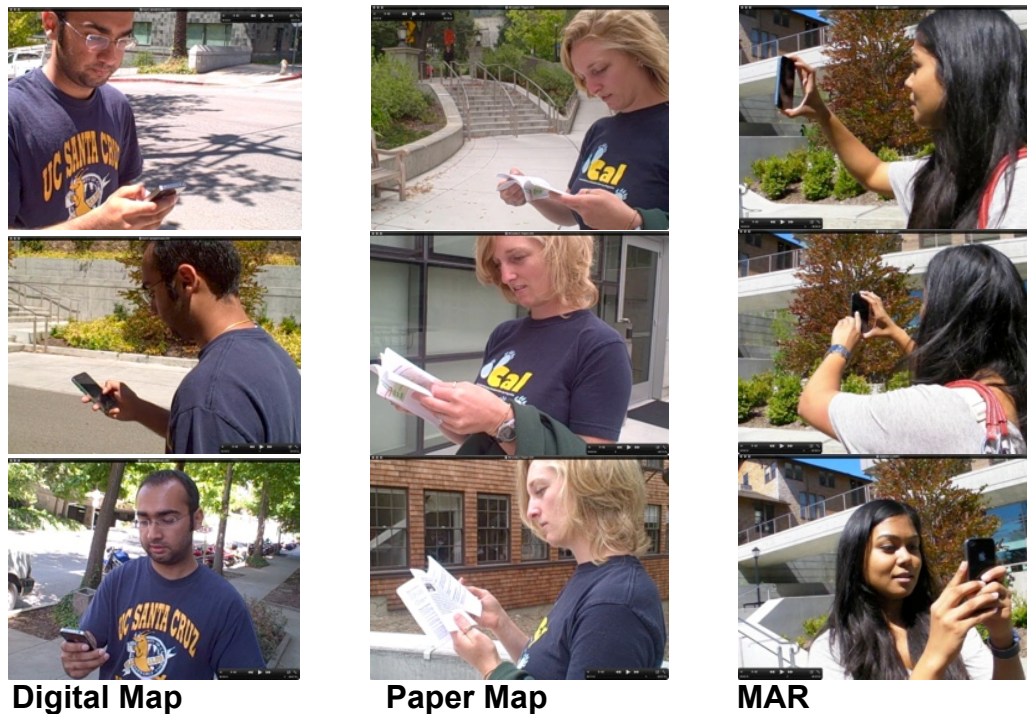


Figure 3. Students using the digital map (left), paper map (middle), and MAR (right).

The MAR users, in contrast to the paper and digital map users, held their phone in front of their faces, looking at the environment through the MAR view. Therefore, in contrast to the paper and digital map users, individuals' heads were 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 3). The MAR users sometimes used two hands, one to hold the device in front of their face and the other to touch the items on the screen (see Figure 3 third column). In contrast to the paper and digital map users, the MAR users also used the tool until the very end of their spatial navigation. For example, one of the places the participants were invited to visit was a technology museum located inside a nearby campus building. 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 MAR users used the MAR tool until they could see the target area right 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 educational resources provided via the visuals they saw directly through the MAR view.

From the beginning of their tour, the MAR users held the phone upright in front of their face and oriented themselves and navigated the environment through the camera view until they reached the final destination. The MAR users diligently followed the target displayed in their MAR view, but perhaps too diligently. Holding the phone vertically in front of them all the time is physically demanding and not ergonomic, particularly for extended periods of time.

In summary, through this formative study, we made two important observations concerning how UI influenced the way individual users looked at the environment and navigated the space. First, the MAR view was good at *orienting* people in the right

direction and guiding people to *come close* to the target object or location, 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. These observations led us to consider a hybrid approach that combines a digital map and a MAR view. In this approach, the system starts with the digital map to help the users navigate the bigger general space, but switches to the MAR 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.

Green Hat: Current Design

The design of our current interface reflects the observations made in our previous two studies, mentioned in the previous sections. Specifically in this third study, our goals were to 1) invite students to closely approach the site *physically*, 2) invite students to *look at the environment more*, and 3) investigate how these design features change the way students learn about sustainability and biodiversity issues. Two main implementation improvements were made for the current prototype:

1. Hybrid Digital Map and MAR Navigation

Based on our observations of how people navigate the physical environment with a MAR vs. digital map, we designed a hybrid navigation system that switches between the MAR and map views automatically. This was for two reasons. One, so that the user does not have to hold the phone in front of their face and explore the environment through the camera view during the entire expedition (as observed in the MAR group in the last study). Two, so that once the user is close to a target, the MAR view can further invite the user to take a closer look, in a way experts would do. We automated this switch between the two modes, as the users may not know when to switch from the digital map to the MAR view. Our goal was to redesign GreenHat to prompt the user's attention to the environment similar to how experts would. For example, an expert may ask a student to follow him to a certain location, but once they are near the location, he may more directly point at a particular part of the environment and say, "Come take a closer look at *this!*" In our system, this is where the navigation automatically switches from the digital map to the MAR view.

Technically, the system was designed to switch to the MAR view when the user enters inside of a specified radius of the location. For example, at the North Lawn (Area 3 in Table 1), the system first shows the area on the digital map to guide on the regular path, but then it switches to the AR view so that the system can show specifically which orientation the user should be facing and find the specific area of the creek or vegetation the expert is talking about. This timing was based on the tour we took with the experts and their timing when they went off the paved road and went into the area. Figure 4 shows the final areas. When the user is within the red circles, the AR view is shown. Outside of the red circles, the system is in the digital map view.

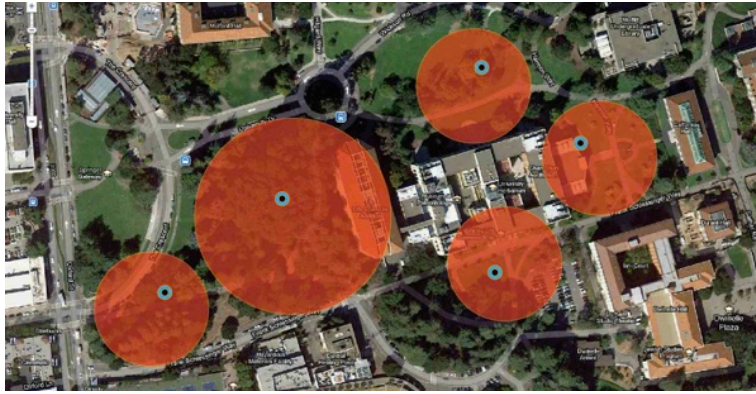


Figure 4. Showing areas, red circles, where MAR was activated.

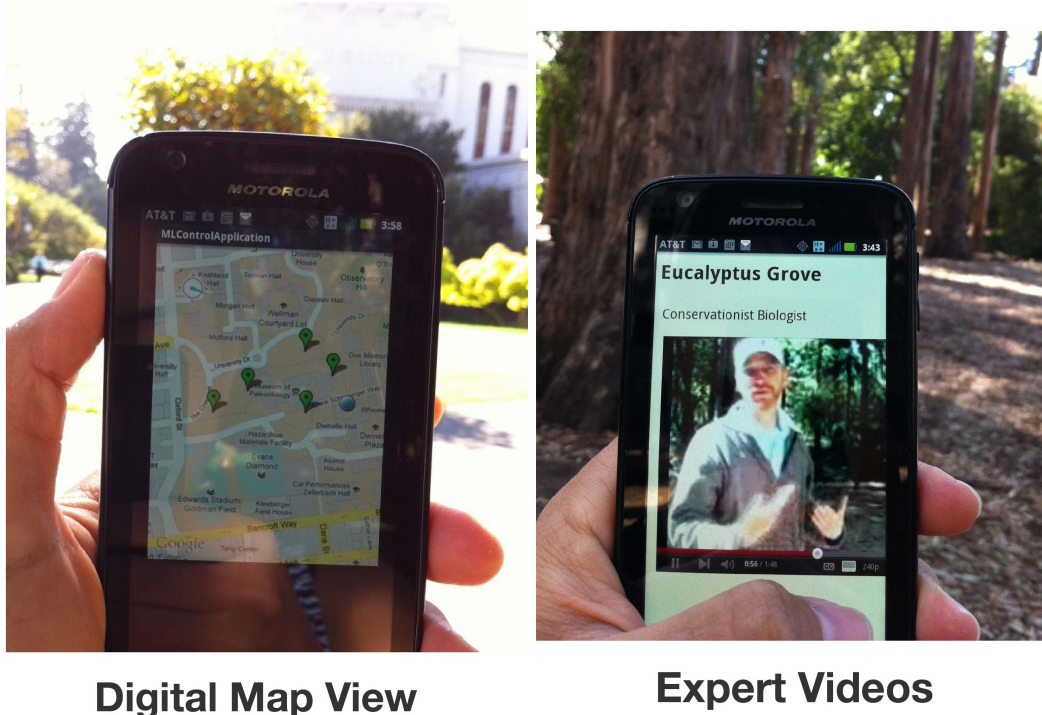
2. Mobile Augmented Reality Interface Design

Once the participant is within the active MAR area, i.e., within 30 meters radius of the target except for the Eucalyptus Grove, which has a larger radius (Figure 4), the phone automatically switches to the MAR view and the user uses the phone as an additional lens to look at the environment. Yet at any point, if the user wishes to, the user can hit the “MAR View” or “Map View” button to switch manually. Figure 5a shows an example MAR view. The MAR view shows the target as a thumbnail image in the user’s field of view via camera view. The navigation icon shows how far away the user is to the target within the 30 meters range, as well as the orientation.

While the target is shown, a dialog box is also shown at the bottom of the screen with text information about the area. The link, “Learn More” takes the user to a webpage with videos of the experts and related links to the mobile digital library *Engineering Pathway*. To go back to the main application from the webpages, the user hits the back button on the phone.



Figure 5a. The image shows the MAR view where thumbnails and descriptions are shown in the viewfinder.



Digital Map View

Expert Videos

Figure 5b. Left image shows the digital map view. Right image shows experts' video view.

Technical Implementation

The mobile application consists of an Android application in which the main Map View resides. In this Map View, there are two overlays, one for tracking the user's location and one for indicating the learning locations for the user. The application listens for proximity alerts from the GPS location service. Every time the user is within a certain radius of a learning location, the GPS sends out a notification to the Android application. The radius for each location is statically determined from a predefined dictionary of the location coordinates and a corresponding radius for those coordinates. This notification in turn triggers the call to the Layar AR application (Layar, 2012), which then displays the learning location inside the MAR View.

Study of Current Design

The goal of this third study was to investigate the effects of the interface design associated with the MAR view. Specifically, we were interested in evaluating features that facilitate greater engagement with the environment and greater exploration of learning resources. Our hypotheses were: 1) the MAR group will explore the area more, and 2) more time spent on engagement with the physical environment and reviewing educational resources will lead to deeper engagement with the learning topic.

In order to contrast the interface, we designed a control interface that had all the same information for navigating and learning about the environment except for the MAR view. The user experience for the control group was the same except that the phone never switched to the MAR view. Therefore, the control group was unaware of the existence of the MAR view, and used the digital map to navigate the environment. The control group's UI had a resizable digital map so that they could zoom in and out on the precise target locations, with clickable location markers that linked to related learning resources.

The number of clicks involved in getting to the learning resources was the same for both groups.

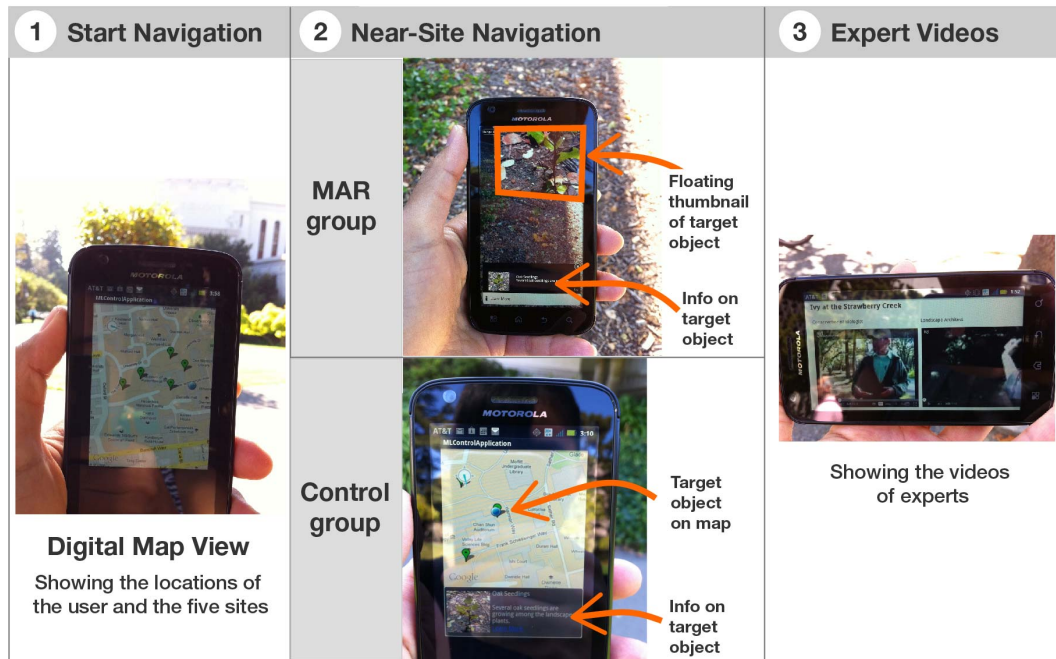


Figure 6. Both MAR group and Control group started with the digital map view. Once they were near the target site, the MAR group’s screen switched to the MAR view with a picture of the target object and the description on the bottom. The control group’s screen showed the same amount of information as the MAR group with a picture of the target object and the description but without the MAR view. Both group then accessed the same expert videos.

Method

A total of 20 college students participated in the study with the *between-subject* design. Ten participants in the experimental group used the MAR tool, and ten participants in the control group used the digital map. The participants were randomly assigned into these two groups.

Both the MAR and control groups were first given a short survey asking about their prior knowledge of issues related to sustainability and biodiversity on campus, as well as a brief amount of background information (academic year, department). Both groups were then given the same introduction to the device, along with an explanation of the study procedure. They were instructed to visit five locations on campus using the phone and watch the videos of two experts: a conservationist biologist and a landscape architect. Upon finishing the videos, they were given a piece of paper with a question about the location with plenty of space to write their response. They were instructed to write their answer on the paper with a pen. We decided to use a regular pen and paper as it was difficult for many people to type their answers using the phone’s keyboard in our first study. Sample questions are in Table 1. Once they completed their tour, they were given a post-test questionnaire.

All the participants were asked to wear a small GPS tracking device (Qstarz BT-Q1000eX professional data logger GPS, 1x2x0.5 inches in size, tracking the location at 1Hz rate, with receiver sensitivity of -165dBm and AGPS fix support) that recorded time and coordinates of the participant throughout the study.

An experimenter followed each participant with a video camera to record the activity on the go. Both groups were told that they were free to move around at their own pace and were not given any time limit to complete their task.

Results

All 20 participants completed visits to all five locations specified on the phone. The participants spent an average of 64 minutes in the field with the phone (ranging from 41 minutes to 97 minutes). Video and GPS tracking data documenting their journeys, along with survey answers, were collected.

Physical Explorations

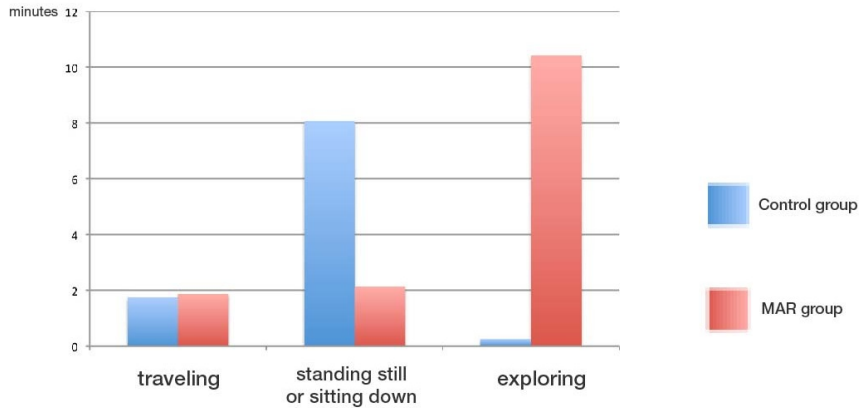
We were interested in how students in each group explored the area, both in terms of the time spent and the degree of coverage. The data from the GPS trackers worn by the participants in both groups revealed both the amount of time each participant spent and the nature of physical explorations they engaged during their session.

| | MAR group | Control group |
|-------------------------|------------------|----------------------|
| Average Distance | 1,241 meters* | 825 meters* |
| Average Time | 73 minutes* | 55 minutes* |

Table 2. Showing the average distance and time for the MAR group and the control group.

The average value of the total number of distances and time for the MAR group were significantly more than the control group, with a p value of less than 0.001 for distance and 0.007 for average time. We used independent-samples t-test (two-tailed) for comparing the values for “distance” and “time” for each group. For “time,” there was a significant difference between MAR ($M=72.90$, $SD=12.33$) and Control ($M=54.90$, $SD=12.52$); $t(18)=3.239$, $p = 0.007$, $d = 1.44$. For “distance,” there was a significant difference between MAR ($M=1241.20$, $SD=250.92$) and Control ($M=825.30$, $SD=109.56$); $t(18)=4.803$, $p < 0.001$, $d = 2.14$.

We further studied how the individual participants physically moved during their session. By looking at the video records of each participant’s session, we coded for 1) the time spent to find and travel between the five locations, 2) the time spent standing still or sitting down in the field (watching videos or browsing related information), and 3) the time spent on exploring the site. The results are shown in the Graph 1. While there was no significant difference between the amount of time MAR group and Control group spent traveling between five locations (MAR group: $M=1.88$, $SD=0.63$; Control group: $M=1.75$, $SD=0.51$; $t(18)=0.487$, $p = 0.632$), the MAR group spent significantly longer time exploring each of the five locations compared to the control group (MAR group: $M=10.43$, $SD=1.02$; Control group: $M=0.25$, $SD=0.19$; $t(18)=30.686$, $p < 0.001$). On the other hand, the Control group spent significantly more time standing still or sitting down in the field while watching videos or browsing related information (MAR group: $M=2.13$, $SD=0.49$; Control group: $M=8.07$, $SD=0.72$; $t(18)=-21.43$, $p < 0.001$).



Graph 1. Showing how the two groups spent their time in the field.

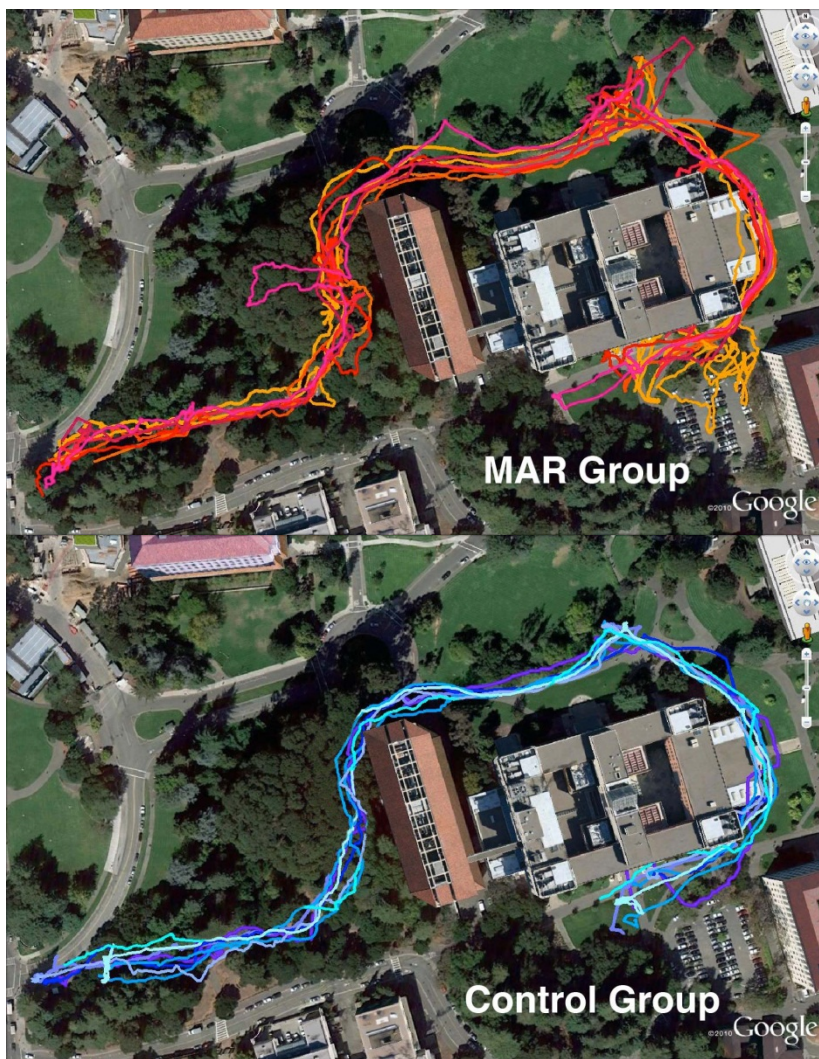


Figure 7. The results of the GPS traces. The top shows 10 lines from the MAR group. The bottom shows 10 lines from the control group. Note that the bluish traces from the Control group (bottom) are more direct, compared to the reddish lines from the MAR group (top) which describe more detours.

Figure 7 shows the results of all the GPS traces from all 20 participants. Figure 8 shows a close-up view of one of the five areas, “North Lawn,” and paths created by the two groups. The left figure shows the traces created by the MAR group. The right figure shows traces created by a participant in the control group. These lines provide a closer

view of how and how much the participants in the MAR group (shades of red) explored the area compared to the participants in the control group (shades of blue).

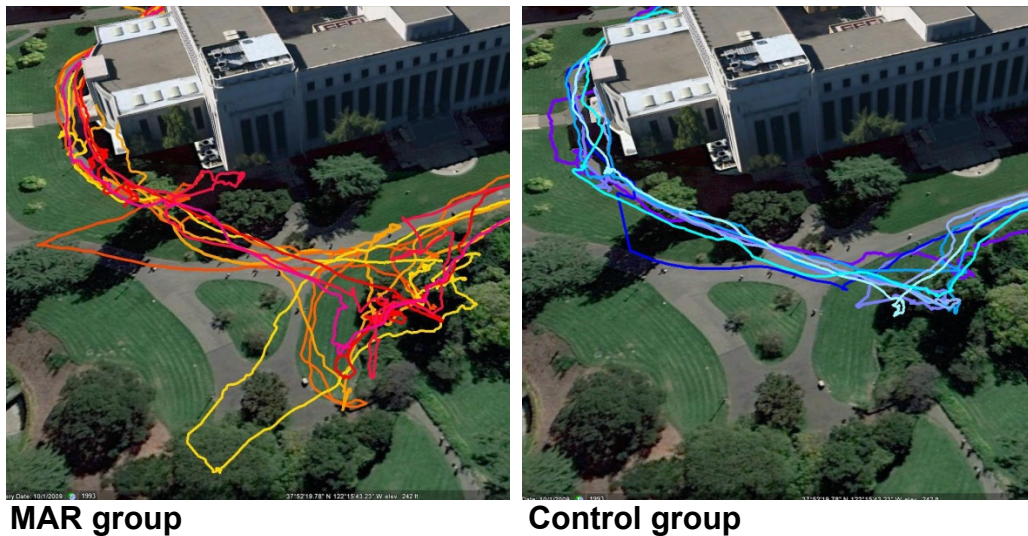


Figure 8. A close-up view of the GPS traces of “North Lawn” (stop 3): on the left (MAR group, reddish traces), the students clearly moved around the area more than on the right (control group, bluish traces), where the students go directly to the targets, and then move on.

As shown in Table 2 and Graph 1, the MAR group spent more time exploring in the field than the control group. A closer look of the GPS traces at each of the 5 locations (such as Figure 8) reveals that the time difference between the groups came from the MAR group’s time spent exploring the 5 locations, and not the time spent on way finding. In other words, there was relatively small variation in the way all students moved *between* the five locations: the GPS traces *between* each location are relatively straight for both groups. However, the traces varied greatly for the MAR group *within* each of the five locations compared to the control group. Once they reached the site, the participants in the MAR group moved around and explored the site more thoroughly compared to the control group.

Nature of Exploration

The physical demeanor in exploring each site was different between the groups. Reviewing the video recording of each participant’s session revealed additional details about the manner in which the participants in the two groups engaged with the environment. The control group with a digital map tended to settle at one spot once they got to the target location and looked at the expert videos by standing still or sitting (see photos in the left column of Figure 9).

In contrast, the MAR group actively explored the physical site once they arrived at the target location (photos in the right column), walking around the bushes to see what was behind them, leaning over the creek to see what was inside the water, squatting down to find seedlings in the ground, and sometimes touching the plants and trees, and picking up leaves and branches. These behaviors were similar to what we have observed the experts do: engaging in closer inspections and interactions with the natural environment. While the control group tended to focus on watching the videos of experts from one location, the MAR group went back and forth between watching the videos and investigating the natural environment.



Figure 9. Students at the North Lawn (Stop 3). The control group (shown in the first row) tended to settle at one point by standing still or sitting. The MAR group (shown in the second row) tended to come closer to the site and exploring the site from different angles.

Learning

At the beginning of the study, the participants in both groups were asked about how much they knew about the issues of biodiversity and sustainability on campus and how much they personally cared about them using Likert scale of 1 to 5. In order to measure whether the experience of learning about the issues in nature with the tool changed their knowledge, they were asked the same question again at the end of the study. Both groups increased their reported rating of their knowledge about the issues. The score increased 2.12 points (SD=0.993) for the MAR group and 1.75 points (SD=0.408) for the control group. There was no significant difference between the groups ($t(18)=1.107, p = 0.283, d = 0.46$) for participants' own perceived learning. This can be interpreted as evidence that perceived learning experience was equally positive between the MAR group and control group, and that both groups felt that they had learned something from the experience. However, further qualitative analysis suggested apparent differences in the degree of engagement and personal integration of knowledge.

We compared the quality of each group's answers to the open-ended question about the five locations. Both MAR group and control group produced similar amount of textual answers, measured by number of words (MAR group: $M=107.30, SD=14.29$; Control group: $M=94.60, SD=20.23$; $t(18)=1.621, p = 0.122$), however, the quality of their answers was different.

In responding to the question at each location, the MAR group presented evidence provided in the expert videos as well as other reasons not mentioned in the videos such as their personal feelings and observations made in situ. The followings are some of the responses by the participants in the MAR group to the question whether or not we should cut down the eucalyptus grove, which was asked at the second site, Eucalyptus Grove:

MAR1: It has become “native” over time and is a place for relaxation and solitude – I saw several people enjoying its shade and quiet while here. If it gets cut down it will likely not be replaced by more natural settings; I imagine it will become the site of a new building or facility.

MAR2: Tricky question! [...] As a student, my time here is so short at UC Berkeley that if the grove were to be cut down I would probably only witness the destruction rather than the new growth. [...]

MAR3: Let’s cut the half [of the grove] that’s close to the building to avoid fire hazard. We can preserve the other half since it’s been around for a while as a nice area of “contemplation.” I once heard one person practicing trumpet here and I thought that was nice. [...]

MAR4: I think there should be a public meeting where both sides get to present their side followed by a vote from current students, faculty, staff as well as alumni. That would be the most democratic way to decide.

The control group seemed to give explanations based more on the video description, with little evidence of personal integration of this information:

CONTROL1: They have been here almost a century and the experts didn’t say anything that the trees here caused death or injury to people. And even if it’s vulnerable to fire, no cases reported or mentioned by the experts.

CONTROL2: It’s a fire hazard – can have a cumulative effect when exposed to a flame. Proximity to LSA building is a danger (as mentioned by experts).

CONTROL3: Primary because it’s not safe for surrounding buildings. Eucalyptus trees are perfect ignition for fire and hence a hazard (as mentioned by experts). [...] The compelling reason for me is because of fire safety.

CONTROL4: Replacing the grove with other types of plants does not guarantee that the species the biologist wanted to revive are still around to take advantage of the change.

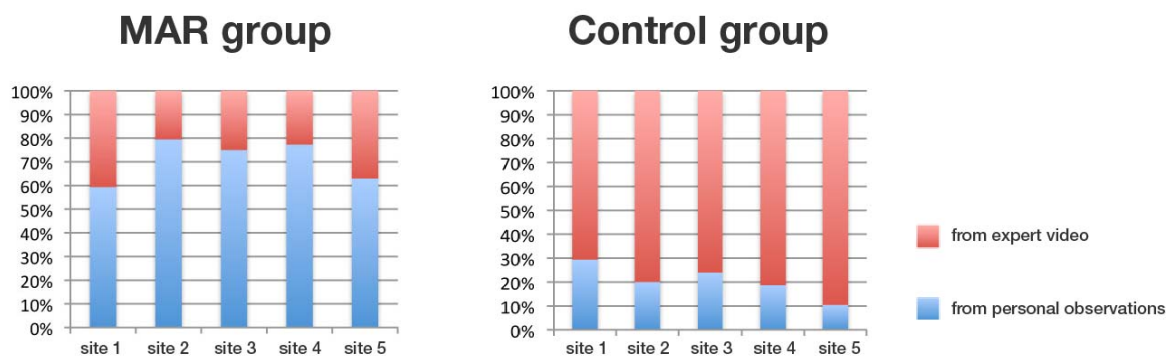
Between groups, we have compared the number of clauses in their answers that relate to 1) what experts have discussed in their videos and 2) the students’ personal observations in the field. The unit of analysis was *clause* where a clause was defined as the smallest grammatical unit that can express a complete proposition. A typical clause in English contains minimally a subject and a predicate. A sentence can have multiple clauses. For example, the following sentence contains two clauses (underlined): “The lawn is near the creek and the willow tree provides the shade.” In our analysis, a clause that relates directly to any concepts mentioned by experts in the video or a clause that contains explicit relation to the expert videos, such as “experts said that ...” was treated as one entry referring to the videos. Clauses that have no association with facts mentioned in the expert video (e.g., “I saw people leaving garbage at this side of creek...”) were treated as personal observation. Two coders have independently looked at the data, with a resulting Krippendorff’s alpha measurement of intercoder agreement level of .67 (where agreement levels of $\alpha > .55$ is considered satisfactory).

While both groups’ answers were informed by what they learned from the video, MAR group, in addition, included significantly more personal observations in their answers than the control group (MAR group: $M=14.70$, $SD=3.86$; Control group: $M=2.40$,

SD=1.77; $t(18)=9.15, p < 0.001$). The control group made more references to the expert videos than the MAR group (MAR group: $M=6.40, SD=2.06$; Control group: $M=9.80, SD=1.87$; $t(18)=-3.85, p = 0.001$). The mean values reflect the number of clauses in the participants answers.

The Graph 2 shows the percentages of coded answers in reference to personal observations (blue) versus expert videos (red), the two groups made for each of the five locations.

We believe this difference between how the two groups responded has an important implication for learning. In forming their answers, the MAR group did not simply repeat what was described in the video, but they were able to produce their own observations in the field. The MAR group's active engagement with the environment seemed to have led to a higher production of their personal observations in the field.



Graph 2: Showing the percentages of coded answers in reference to personal observations (blue) versus expert videos (red), the two groups made for each of the five locations.

Discussions

Both groups were told they were free to move on their own pace and spend as much time exploring each of the five areas. While both groups visited all five areas, the MAR group spent a significantly greater amount of time exploring, and moved more at each location. Why were there differences between the two groups in terms of the amount of time and exploration of physical locations? What made the MAR group explore more than the control group once they were there? We believe it involved a two-step process: First, the MAR interface made it more inviting for the students to come within close, physical proximity of the actual site. Secondly, this physical proximity to the site (compared to the control group)—in conjunction with the video of experts at the site—encouraged students to more fully immerse themselves in their exploration (e.g., because of the sound, smell, or other physical conditions of the creek).

For the first step of inviting students closer to the site, we believe that the MAR view directed the participants' eyes more towards salient aspects of the physical environment, as opposed to focusing solely on the information on the mobile device. Once they were near the area of investigation, the participants in the MAR group held their device *over* their physical view, like an extra lens through which they could look at their environment to discover more details. We believe this method of accessing digital information—augmenting the natural view, instead of taking their eyes off of it—helped students engage with the environment more. Applying Goodwin's (1994) concept of "professional vision," MAR view seemed to help *highlight* specific phenomena in a perceptual field.

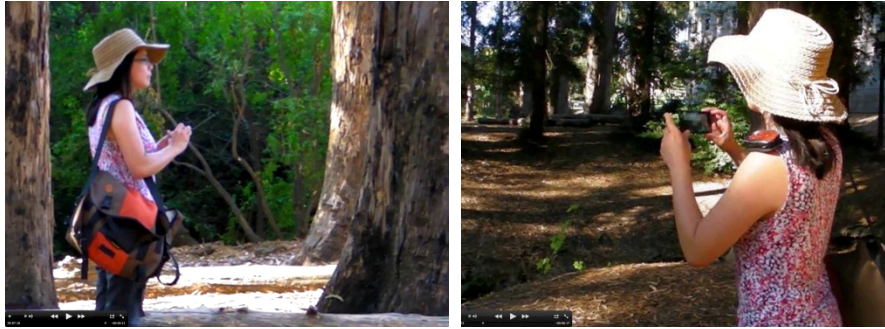


Figure 10. Using GreenHat MAR system, students engaged with the environment (left) as well as the educational content on the phone (right).

For the second step of being at the site, the MAR group was brought closer to the specific area they were invited to investigate than the control group. In that process of being closer to the target, they seemed to interact with nature more. For instance, at the third site, North Lawn, the closer one gets, the closer one can actually hear the sound of the creek, see the condition of the creek, or even smell the creek. The MAR group also made more personal discoveries, such as “the water quality I see here...” more so than the control group. MAR was successful at physically getting people closer to the site of investigation and as a result, people explored more.

In contrast to in-class or desktop learning environments, mobile learning is a multi-sensory experience (e.g., the movements, noises, air, temperature, shadows, and even the smell of the outside environment, etc.). MAR successfully directed students’ attention towards the natural environment, taking advantage of the natural setting to improve the learning experience.

Limitations and Future Work

One of the major technological challenges we faced was to achieve a high degree of precision for the location fix and the AR view. With all the AR platforms that we evaluated, the location fix on the AR view decreased in precision as the distance between the location of interest and the subject became smaller. After testing several platforms, *Layar* (Layar, 2012) performed the best in terms of consistent location fix on the camera view and precision of the location fix in the camera view. In order to increase the registration precision for future prototypes, we are considering a vision-based approach, using the built-in camera and a PTAM algorithm (parallel tracking and mapping), which will enhance the inertial and magnetic sensors already in the phone.

Future work will also look at the cognitive aspects of learning in greater detail. We will explore whether increased physical interaction such as touching, smelling and hearing the creek can motivate a more in-depth scientific inquiry for the learners.

Conclusion

Bringing the lessons to nature, and learning about “nature in nature” can be a powerful learning experience. In our experiment, MAR was successful at bringing students into *off-the-map* areas where they usually would not venture. Compared to a digital map, MAR invited students to come closer in proximity to the physical areas of investigation and to concentrate on the environment more than the mobile device. As a result, MAR inspired students to explore the area more thoroughly, and provoked more personal and contextual observations.

Our contribution comes from the features we incorporated into the MAR view to effectively simulate experts' perspective in sustainability and biodiversity learning. That is, our system was a combination of 1) a MAR view that draws students' attention to salient parts of the physical environment that experts might attend to, and in turn invites the students to come closer and investigate the area, and 2) delivers curated videos of experts discussing sustainability issues about the very location the students were immersed in. This combination of features provided accessibility of educational content, location/context-sensitivity, and an effective means to connect experts' views.

We have shown that MAR can support the development of expert perspectives by prompting students with context-relevant information, interactively engaging the student with multiple forms of information and inquiry, and connecting their experiences to the natural world. We contribute to the design and the evaluation of an interface that invites people to explore the natural environment, and increases their willingness to go into the wilderness off the paved path to explore and learn personally.

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