EcoMOBILE: Integrating augmented reality and probeware with environmental education field trips

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Highlights

1. We designed an experience integrating augmented reality and environmental probes.
2. This combination of technologies had benefits for both teachers and for learners.
3. Gains were revealed on both affective and content dimensions of learning.
4. These technologies facilitated student-centered instructional practices.
5. EcoMOBILE promoted science understanding more than previous field trips without AR and probeware.

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Abstract

Positioned in the context of situated learning theory, the EcoMOBILE project combines an augmented reality (AR) experience with use of environmental probeware during a field trip to a local pond environment. Activities combining these two technologies were designed to address ecosystem science learning goals for middle school students, and aid in their understanding and interpretation of water quality measurements. The intervention was conducted with five classes of sixth graders from a northeastern school district as a pilot study for the larger EcoMOBILE project, and included pre-field trip training, a field trip to a local pond environment, and post-field trip discussions in the classroom. During the field experience, students used mobile wireless devices with FreshAiR™, an augmented reality application, to navigate the pond environment and to observe virtual media and information overlaid on the physical pond. This AR experience was combined with probeware, in that students collected water quality measurements at designated AR hotspots during the experience. We studied the characteristics of learning and instruction using measures of student attitudes, content learning gains, and opinions teachers provided via written and verbal feedback. We observed gains in student affective measures and content understanding following the intervention. Teachers reported that the combined technologies promoted student interaction with the pond and with classmates in a format that was student-centered rather than teacher-directed. Teachers also reported that students demonstrated deeper understanding of the principles of water quality measurement than was typical on prior field trips without these technologies and that students had expanded opportunities to engage in activities that resemble scientific practice. Overall, results of the students' surveys and teacher feedback suggest that there are multiple benefits to using this suite of technologies for teaching and for learning.

1. Introduction

The framework for the next generation of science education standards focuses on the integration of knowledge with authentic scientific practice, which takes place in contexts and communities that are meaningful to students and provides connections to their own experiences (National Research Council, 2011). These ideas are supported by situated learning theory, in which cognition is seen as situated within both a physical and a psychosocial context and as distributed between a person and the tools that person is using (Greeno, 1998; Sternberg & Pretz, 2005). Knowing, doing and context are seen as intertwined and interdependent (Dede, 2008); the learner's environment is essential to the process, since the context can alter, enhance, and support certain types of performances, approaches to problems, or learning activities (Squire & Jan, 2007). In this article, we explore the utility of augmented reality paired with handheld environmental probes to deliver enhanced situated learning experiences to students during a middle school ecosystem science field trip. The EcoMOBILE (Ecosystems Mobile Outdoor Blended Immersive Learning Environment) project (http://ecomobile.gse.harvard.edu) is funded by the National Science Foundation and by Qualcomm, Inc. and supported with resources from Texas Instruments, Inc.

The ability to understand ecosystems is richly enhanced by experiences in real environments. Field trips, both real and virtual, support gains in science knowledge (Bitgood, 1989; Garner & Gallo, 2005; Gottfried, 1980; Knapp & Barrie, 2001); and outdoor experiences can affect student attitudes about nature (Ballantyne & Packer, 2002; Manzanal, Rodriguez Barreiro, & Casal Jimenez, 1999; Bogner, 1998). Yet, the real world can be a challenging learning environment; students may be distracted by the novelty of the social and physical context of the experience and find it difficult to focus on relevant learning tasks (Falk, 1983; Orion & Hofstein, 1994). Students may be overwhelmed by a flood of information and may find it difficult to know where to devote their attention. As a result of these and other logistical factors, field trips tend to be one-time experiences with limited connection to what students experience in the classroom curriculum or in their everyday lives.

Using handheld devices and probes in science has been shown to promote various aspects of teaching and learning in the classroom and in the field. Using probes in a lab setting coupled with computer-mediated presentation of the results promotes critical evaluation of graphs and data (Nachmias & Linn, 1987; Zucker, Tinker, Staudt, Mansfield & Metcalf, 2008; Metcalf & Tinker 2004; Nicolaou, Nicolaidou, Zacharia & Constantinou, 2007), supports student learning of science concepts (Metcalf & Tinker, 2004), and supports inquiry-based science learning (Vonderwell, Sparrow & Zachariah, 2005; Rogers & Price, 2008). Through use of real-time probeware, connections are built between abstract representations and concrete experiences with the data and related concepts (Vonderwell et al., 2005).

We posit that combining probes and handheld devices through the use of augmented reality (AR) can further support this learning by situating the data collection activities in a larger, meaningful context that connects to students' activities in the real world (Squire & Klopfer, 2007). AR is an "immersive" interface (Dede, 2009) utilizing mobile, context-aware technologies (e.g., smartphones, tablets), and software that enables participants to interact with digital information embedded within the physical environment (Dunleavy & Dede, in press). Our research is exploring the unique affordances of AR that can support this kind of situated learning in environmental science education.

Combining AR and the use of environmental probes can provide multiple affordances in support of situated learning during field trip experiences. AR interfaces can enable contextualized, just-in-time instruction; self-directed collection of real-world data and images; and feedback on student actions and responses. AR's have also been shown to support social interactivity; respond to shifts in context; facilitate cognition distributed among people, tools, and contexts; and provide individualized scaffolding (Klopfer & Squire, 2008; Klopfer, 2008; Dunleavy & Dede, in press). We hypothesize that a combination of both AR and environmental probes may enhance the field trip experience in ways that neither technology could accomplish on its own.

Through smartphones enabled with augmented reality technology, and environmental probes comparable to those used by environmental scientists (Texas Instruments NSpire™s (TI NSpire™s) with Vernier probes), we are conducting pilot implementations of a curriculum that scaffolds authentic participation in scientific practices by middle school students. For our pilot studies, this article describes the extent to which using this combination of technologies aided students' learning of ecosystem science concepts and their attitudes toward ecosystem science.

2. Research Design

2.1 Research Questions

We aimed to address the following research questions:
What do students' learning and motivation, and teachers' experiences look like following a combined AR+TI NSpire™s with environmental probes experience, based on the following measures?:

1. Content learning gains related to our specified learning goals: water quality characteristics, relationships between biotic and abiotic factors, data collection and interpretation skills, and the functional roles (producer, consumer, decomposer) of organisms in an ecosystem. .
2. Student attitudes related to self-efficacy and opinions about the field trip experience (as measured by affective surveys and post opinion surveys).
3. Teachers' judgements of usability and value of technologies related to field trip instruction.

Students were given a survey before and after this EcoMOBILE pilot curriculum that included questions on affective measures and content understanding. The survey questions used are a subset of a larger survey developed and tested in an earlier project (see Metcalf, Kamarainen, Tutwiler, Grotzer & Dede, 2011). The affective survey used a subset of the earlier survey items that focus on self-efficacy. Details on assessment of the validity of these items for assessing self-efficacy can be found in Kamarainen, Metcalf, Tutwiler, Grotzer & Dede, (2012). The items used in the content survey came from multiple sources 1.) items derived from previously-validated standardized tests from the Massachusetts Comprehensive Assessment System (MCAS) and North Carolina Testing Program (Q11, Q12, Q13) and 2.) items developed by our research team to address specific learning goals related to water quality and graph interpretation (Q8, Q9, Q10, Q14). The survey was reviewed by three experts in the field (an ecosystem scientist, cognitive psychologist, and middle school science teacher) prior to use. Further results related to the validity and reliability of the full survey from the earlier work are forthcoming. Students were also given an opinion post-survey on how much they liked different aspects of the field trip experience. Additionally, we collected feedback from teacher participants including a group post-interview with the teachers and ecology center program director and individual teacher post-surveys. Details are included below.

2.2 Participants

Sixth grade students (n = 71) in the classes of three teachers in a school district in the northeast participated in the study in the Fall of 2011. Two of the teachers taught two science classes each; the third taught one class, for a total of 5 classes. Teachers were selected for participation by the district science coordinator (3 teachers selected out of a total of 9 dedicated 6th grade science teachers in the district), and selection was based on logistical considerations rather than teacher interest, teaching experience, or propensity for use of technology. The number of students in the classes ranged from 16 to 22 with 74% of those students returning their permission slips for a total study participation of 71.

2.3 Intervention

2.3.1 Technology

In our pilot studies, the technology components included an AR experience running on wireless-enabled mobile devices, as well as water measurement tools using graphing calculators with environmental probes:

- 2.3.1.1 Augmented Reality experience: The augmented reality experience was created using the FreshAiR™ augmented reality development platform (playfreshair.com) designed by MoGo Mobile, Inc. The FreshAiR™ platform allows an author to create augmented reality games and experiences with no programming experience required. These games and experiences can then be accessed anywhere from an iPhone or Android mobile device with wireless connectivity, camera, and GPS capabilities. "Hotspots" are placed on a map of the physical setting, and these hotspots become accessible to students at the real location in the field. At a hotspot the student can experience augmented reality visualizations overlaid on the real environment, as well as interactive media including text, images, audio, video, 3D models and animations (supported by Qualcomm Vuforia technology), and multiple-choice or open-ended questions enabling immersive, collaborative and situated mobile learning experiences.
- 2.3.1.2 Water measurement tools: Students collected water measurements using Texas Instruments (TI) NSpire™ handheld devices with Vernier environmental probes. The TI NSpire™ provides graphing calculator capabilities along with a Data Quest data collection mode that allows display of multiple probe readings on a single interface. Probes were provided to measure four variables; dissolved oxygen concentrations, turbidity, pH and water temperature.

2.3.2 Duration and Learning Goals

The EcoMOBILE curriculum included one class period before the field trip, the field trip itself, and one class period after the field trip. The learning goals of the field and classroom activities focused on understanding of the relationship between biotic and abiotic factors, data collection and interpretation skills, and the functional roles (producer, consumer, decomposer) of organisms in an ecosystem.

2.3.3 Pre-Field Trip

Prior to the field trip, the students also had access to "learning quests", which are online modules providing a 5-10 minute activity that introduces the students to the ideas behind dissolved oxygen, turbidity, and pH. These provide a definition of the water quality variable, the range of values that students might expect to see, and information about why the value might change. Two of the teachers used these learning quests during class two days before the field trip, while the 3rd teacher used them as one of the "stations" during the activities on the day prior to the field trip.

During the school day before the field trip, teachers conducted a pre-field trip classroom lesson in which students practiced using the probes to measure temperature, dissolved oxygen, turbidity, and pH. The classroom had 5 stations – one for each of the 4 measurements – plus a final station where students measured all four characteristics for a classroom aquarium. At each station, students measured both a control of plain water and a source that would provide an extreme reading for the measurement being tested. For example, in order to test pH, the students took measurements for both tap water and vinegar. Students worked in teams to visit each station for about 5 minutes. Afterward, the groups gathered to review their results and discuss the range of readings for each measurement type.

2.3.4 Field Trip

Each class went on a single field trip to the same local pond, adjacent to a district-managed Ecology Center staffed by a program director who leads all school field trips. Therefore, instruction during the field trip experience was consistent across all classes. The field trips lasted approximately 3.5 hours. The activities during the field trip included the following:

- The program director presented an orientation about the pond (20 minutes)
- A research team member provided an introduction to the FreshAiR™ program using the smartphones and reminded students how to use the probes in conjunction with the smartphones (15 minutes)
- Students participated in the EcoMOBILE experience at the pond, described in detail below (1 hour)
- While at the pond, students also helped the program director collect macro- and micro-organisms from the pond using nets (10 minutes).
- Break for lunch (20 minutes)
- The teacher led a discussion about the data they had collected (20 minutes)
- Students observed pond organisms under a microscope and made sketches of the organisms they saw (1 hour)

For the EcoMOBILE experience, students were assigned to pairs; and each pair collected data on two water quality variables, either temperature and dissolved oxygen or pH and turbidity. Within each pair, one student was given the smartphone to carry, the other the TI NSpire™ and probes (Figure 1). Students were told to switch roles halfway through the experience so that each had a turn with each technology.

The EcoMOBILE experience included the following AR-facilitated activities:

- Upon arriving at a hotspot near the pond, students working in pairs were prompted to make observations about the organisms around the pond and classify (producer, consumer, decomposer) an organism they observed. Students answered questions about their observations, and received constructive feedback based on their answers.

- At the next hotspot, students were prompted to collect water measurements using the TI NSpire™ and environmental probes. The AR delivered additional information that helped them make sense of the measurements they had collected. Student recorded their data on a worksheet.
- Students were then prompted to collect water measurements at a second location that they could choose. Students once again recorded their data and were prompted to compare the two measurements.
- At a later hotspot, students were prompted to sketch on paper an organism they had observed near the pond.
- Two more hotspots provided visual overlays, 3D models, videos, and additional information related to consumers and decomposers, as well as posed questions related to the role of these organisms in the ecosystem.
- As the final activity in the field, students met with another pair of students who had collected the other two water quality variables, and the two pairs compared their measurements before returning to the classroom.

The augmented reality program specifically supported students' use of the probes by helping them navigate to a location to collect a sample, providing introductory information just-in-time for student use (Figure 2), delivering step-by-step instructions for use of the probes (Figure 3), entering the reading in response to a multiple-choice question (Figure 4), and delivering immediate feedback related to the student-collected measurement (Figure 5 and 6).

2.3.5 Post-Field Trip

On the next school day after the field trip, back in the classroom, students compiled all of the measurements of temperature, dissolved oxygen, pH, and turbidity that had been taken during the field trip. They looked at the range, mean, and variations in the measurements and discussed the implications for whether the pond was healthy for fish and other organisms. They talked about potential reasons why variation may have occurred, how these measurements may have been affected by environmental conditions, and how to explain outliers in the data.

In summary, the EcoMOBILE activity was designed to provide opportunities for both real-world observation and interaction separate from use of the technology (e.g., time for un-mediated observation and sketching on paper), as well as interactions with technology-centered objects including videos and 3D visualizations. In order to reinforce our learning goals, we aimed to take advantage of the affordances of both real and virtual elements available to the students.

3. Data Analysis and Results

3.1 Affective Data Analysis

We assessed students' self-efficacy related to ecosystem science knowledge and skills and their valuation of environmental monitoring. Students indicated, on a Likert scale, their degree of agreement with statements related to ecosystem science skills and attitudes. The Likert scale used was: "strongly disagree", "disagree", "neutral", "agree", "strongly agree". We analyzed the data with a factor analysis to assess aggregation of these items around proposed latent traits, and found that we could use a single factor to represent the information in the affective assessment items. Therefore, the seven Likert-scale questions were aggregated to a single mean affective score for each student, and pre-post gains were assessed using a paired t-test on these aggregate scores.

Based on the debate around use of parametric versus non-parametric tests on Likert data (Norman 2010), we analyzed the item specific results using both approaches. Upon witnessing a significant overall effect on the pre-post mean per student, we analyzed each item independently using a paired Wilcoxon signed-rank test and paired t-test to detect a change in the distribution of student responses to each item. Also, a Kruskal-Wallis test along with ordinary least squares linear regression were used to determine whether teacher or the pre-intervention content survey scores were significant predictors of gains in affective scores, according to the hypothesized population model below:

$$GAIN\_A_i = \beta_0 + \beta_1 PRE_i + \beta_2 TEACHER_i + \varepsilon_i$$

where $GAIN\_A_i$ is the mean gain in affective score (post-pre) for student (i), PRE_i is the mean score on the pre-intervention content survey for student (i), $TEACHER_i$ is a categorical variable designating teacher for student (i), ε_i is the residual, β_0 is the intercept, and β_n designates the regression coefficients for each predictor. To test for OLS assumptions of linearity, we plotted pre-content scores against gains and visually verified a linear relationship between them. We inspected plots of residuals against predicted values of gains, as well as normal probability plots, to verify assumptions of residual homoscedasticity and normality in the sample.

During one field trip, a film crew from a major telecommunication company attended the field trip to capture footage of students using wireless handheld devices during field trips. We found that this particular class showed strong gains on the affective survey for all items, despite chilly and rainy weather during the trip. We inferred that student attitudes may have been confounded by the importance and excitement they felt in association with the filming. We therefore eliminated this particular group from our analysis of the affective data, but included these students in the analysis of content gains, given no apparent difference between this class and others on the content survey results.

3.2 Affective Results

Overall, student responses to affective items showed a positive shift in their attitudes about their ability to understand focal topics and do science related skills. The mean affective score increased by 0.26 points (pre_mean = 3.88 ± 0.5, post_mean = 4.14 ± 0.58), with a moderate effect size of 0.48, meaning that the average increase in student scores was about one half of a standard deviation. Teacher and pre-intervention content scores were not significant predictors of the mean gain in affective measures.

The item-specific analysis showed that the most significant gains were observed on prompts related to understanding what scientists do (Table 1, Item 3), followed by moderate gains in figuring out why things happen/what causes changes (Items 1 and 6), self-efficacy in using graphs and tables (Item 2), and importance of taking measurements (Item 7). There were no differences in statistical outcomes of the parametric and non-parametric tests, therefore we present the results of parametric paired t-tests in Table 1. Post-hoc comparisons indicated that teacher and scores on the pre-intervention content survey were not significant predictors of the gains in student affective measures on these items (Table 2, $F_{(3,48)} = 0.82$, $R^2 = -0.01$, p-value = 0.49). In addition to assessing the influence of our intervention on student affect, we analyzed changes in student content understanding.

3.3 Content Understanding Analysis

Student responses to content assessment items were scored right or wrong, and student scores on the pre and post surveys were aggregated to a total score per student (total score was the total number of questions a student answered correctly out of 9). A paired t-test was used to determine whether changes in pre-post scores were significant. Given significant gains in the overall student scores, we fit a multiple regression model to assess whether gains could be predicted by teacher based on the hypothesized population model below:

$$GAIN_i = \beta_0 + \beta_1 TEACHER_i + \varepsilon_i$$

where *i* designates the student of interest, *GAIN* is the student gain on the post-intervention survey (post-intervention score – pre-intervention score), *TEACHER* is a categorical variable that designates the teacher for student (i), ε is the residual, β_0 is the intercept, and β_n designates the regression coefficients for each predictor. We inspected plots of residuals against predicted values of gains, as well as normal probability plots, to verify assumptions of residual homoscedasticity and normality in the sample.

Performance on individual items was assessed using McNemar's test to determine whether significant numbers of students transitioned from a wrong to a right answer on each item. Finally, we used ANOVA to assess whether there were significant differences in the pre-survey scores among teachers or among class periods, in order to determine whether there were pre-existing differences among the teachers or class periods that could have affected interpretation of the results.

3.4 Content Understanding Results

We witnessed significant learning gains on the content survey ($T_{(70,1)} = -8.53$, based on paired t-test). Students' scores went up by an average of 19% from the pre to post survey (Mean_pre = 4.3 ±. 1.8, Mean_post = 5.9 ± 1.9, based on 9 total points) The effect size associated with these gains was substantial (1.0), indicating that student gains were equivalent to one standard deviation around the mean of the data. Teacher was not a significant predictor of the student gains in content understanding ($F_{(2, 68)} = 1.83$, R^2 =

0.02, p-value = 0.17). The mean scores on the post surveys for each teacher were teacher1 = 6.6, teacher2 = 5.2, teacher3 = 5.6, thus teacher2 had a significantly lower post-intervention survey score compared to the other teachers (F(2,68) = 3.76, p-value = 0.03). Also, pre-survey scores were significantly lower ($F_{(2,68)} = 4.12$, p-value = 0.02) for one of the teachers participating (teacher1 = 4.9, teacher2 = 4.3, teacher3 = 3.6). Therefore, there were differences between teachers in the pre- and post-intervention content scores, but these differences did not manifest as significant differences among teacher in overall gains in content scores.

Analysis of the item-specific results indicates that student gains were significant on topics related to the water quality variables that were measured with the environmental probes. Gains were significant on questions 8, 9 and 10 (Table 1). On questions related to food webs, abiotic/biotic resources and graphing (Questions 11-14), students generally demonstrated a high level of understanding of these concepts on the pre-survey (greater than 64% of students got these questions correct). Again, on the post survey, greater than 72% of students answered these assessment items correctly.

3.5 Student Opinion Post-Survey

In addition to understanding how student affect and content understanding changed during the intervention, we also asked students to offer their opinions about the field trip using a one-time field trip opinion post-survey. On this survey, students were asked "On a scale of 1-7, how much did you like the EcoMOBILE field trip? Circle your answer. (1 = dislike very much, 7 = liked very much)." The average answer was 5.4, indicating that students generally enjoyed the field trip (Q1, Figure 7). Subsequent questions asked about different features of the activity; students average rating of each activity was 4.6 or above. Technology-rich activities tended to receive the highest ratings, e.g., 6.0 for the 3D visualization triggered by image recognition (using Qualcomm Vuforia technology) (Q7), 5.7 for answering embedded questions (Q5), and 5.6 for earning virtual badges (Q8). Less technology-focused activities tended to receive lower ratings, e.g., 4.6 for making a sketch on paper (Q6), or 4.9 for learning about decomposers through reading on-line instructions (Q4).

Students were also given open-ended questions asking what they liked and didn't like about the experience, what they thought the activity had helped them to learn, and if they had any suggestions for improvement. The following summarizes a sample of student responses from two classes:

> *What did you think was fun about the EcoMOBILE game?* Common student answers included "finding hotspots," or "everything." Other answers mentioned using a smartphone, finding the 3D duck, and taking measurements. One student described liking "that we got to have equipment and be scientists."
>
> *Was there anything you didn't like?* Students most often mentioned technical glitches, or simply answered "no." Individual students also mentioned having to

draw a sketch, answer questions, having to take turns using the phone, or carrying the equipment.

What did the game help you learn about ecosystems? Students most often mentioned one or more of measurements or organisms that they had learned about. Another common response described learning the importance of taking measurements, and understanding the impact on the environment, e.g., "it helped me learn what pH, turbidity, and dissolved oxygen were, and if it was good or bad for an ecosystem."

How could the game help you learn more? Some students left this blank; others provided a wide range of suggestions, including making the game longer, adding levels, covering a larger area, getting to use all four probes, asking more difficult questions, or adding more activities, "not just something to read."

3.6 Teacher Reactions: Interviews and Post-Surveys

Findings related to student outcomes were contextualized by gathering reactions from teachers about the EcoMOBILE experience. Looking across the teacher surveys and transcripts of the teacher roundtable discussion following the EcoMOBILE activities, a number of responses were common. Teachers discussed that technology facilitated interactions among students and with the pond environment that resemble scientific practice, a finding that aligns with student survey responses indicating they better understood what scientists do. Teachers spoke about the benefits of the AR platform for managing a productive field trip, and also identified directions to move in the future.

3.6.1 Interactions among students and the pond

Prior to the field trip, two of the teachers had expressed concern that the smartphones might be too engaging; leading students to ignore the real environment in favor of the media and capabilities provided by the smartphones. Post-field trip comments indicated the contrary was true – teachers noted that the smartphones promoted interaction with the pond and classmates.

> *It felt like 90% of the time they were at the pond environment, they were working on interacting with the pond and their partner, whereas previous times it felt like it was maybe 60 or 50% of their time they were independently interacting. ~ Teacher1*

Two of the four teachers mentioned that one of the most productive aspects of the experience were hotspots where the AR platform and environmental probes were used to show something that could not be seen in the real world (e.g. measuring abiotic variables like dissolved oxygen and pH, seeing a starch molecule in a ducks stomach). One teacher described how the environmental probes helped students understand photosynthesis and cellular respiration at a molecular level saying:

…the idea that there are molecules like oxygen in places, they're sort of putting that piece together, like they're just beginning to understand the world in a more multi-dimensional way, do you know what I mean?... and I think the probes did help them see some of that. ~Teacher1

Another use of AR that teachers believed was successful was in leading the students to do something active in the real world, for example using the smartphones to navigate to a hotspot where they were then instructed to collect a sample using the environmental probes. Teachers noted that using the smartphones and environmental probes helped the students become familiar with interpreting the water quality measurements, and noted that students were able to apply these ideas in other situations.

"They do seem pretty conversant with turbidity, pH, dissolved oxygen and I would say more conversant with those things than [students from previous classes]…

The teacher went on to explain a different part of her curriculum in which they were reading about acid rain, and she said,

…they were all like "whoa!" when it said that acid rain had a pH of 1.5 - 5.5, they KNEW - fish can't live in that. You know, like, they had that sense… ~Teacher1

Finally, other observations of the teachers indicated that allowing the students a window into the unseen parts of the environment also helped students to identify with scientific practices and motivated students in a new way,

My students were psyched about like molecules, too… all that world unseen, all that new stuff is making them feel much more like this is real science or adult science. A bunch of my students are hooking into science in a way that they report that they never have before. I can't help but think that the high-powered technology helps… Teacher1

Another teacher reiterated this idea in relation to how this project reached students who were from underserved communities, saying,

…the exposure to the technology, that this is what [scientists] are using, that's pretty important Teacher2

Thus, teachers indicated important ways in which the probes and AR supported student adoption of modes of interacting with their classmates and the environment that closely resemble scientific practices.

3.6.2 Managing a productive field trip

Teachers commented that the smartphones helped to structure students' movement through space and guided their interaction with the pond and with classmates. The students were able to work independently, at their own pace, with the teacher acting as a facilitator. Teachers reported that the activities were more student-driven and less teacher-directed. The teachers thought this was beneficial in that it provided students with a different sense of ownership over the experience.

> *It helped structure their movement through space…so rather than having a whole group of kids clustered in one muddy, wobbly spot at the edge of the pond, they were all at sort of different spots going through it at their different paces and because they were moving independently through the different parts, I felt like it gave them a different ownership over the experience than if there had been just one teacher voice and a crowd of kids. ~ Teacher1*

Another feature of the activity was the opportunity for collaborative communication and problem-solving among students that arose from the augmented reality experience.

> *It invited much more student on student dialog because they had to engage together to sort of figure out things that were coming through to them on the smartphone. So it, in some ways, I thought that their dialog probably deepened their understanding. ~ Ecology Center Program Director*

One teacher observed that the students seemed to rush through some of the information presented on the smartphones, while the Ecology Center Program Director, who guides the field trips for all the students in the school district, lent perspective saying:

> *having done a lot of ponding with the kids without smartphones and seeing how they often rush through things anyway… if anything, I was struck that the kids were sort of ... paced through the activities more than usual ~ Ecology Center Program Director*

Written feedback from the teachers indicated that AR was particularly useful in engaging students. Two teachers were neutral (rating of 3) in their self-reported assessment of the contribution that the smartphones and FreshAiR™ made toward student learning, while one teacher gave a rating of 5 (assessed using a Likert scale, where 1 = very little and 5 = very much). In comparison, all teachers rated the TI NSpires™ and environmental probes as a 4 or a 5 for their contribution toward student learning. These results are based on the teachers' self-reported impression of students learning gains, rather than empirical data. The results of our student opinion and content surveys support the idea that the smartphones supported high levels of student engagement, while the student learning gains were most apparent on items related to the combination of AR and probeware.

3.6.3 Issues to Resolve in Future Implementations

Teachers spoke of managing the tension between positive aspects of student engagement and students' desire, negative in its effects on learning, to speed through an activity without fully reading or comprehending the activity in order to see what is next. As noted above, one teacher found this tension common to any field trip with or without technology, yet it remains a challenge to design experiences that meaningfully engage students in the tasks at hand so that the take home message is meaningful, not just novel. In future research, we plan to design interventions that allow students to use these technologies during multiple field trip experiences in order to examine whether novelty attenuates and engagement is sustained. We hypothesize that situating these learning experiences in local environments and equipping students to use technologies that allow them to collect data and observations that are meaningful outside of a classroom context should lead to sustained engagement beyond that offered by the novelty of the technologies themselves.

The teachers also expressed concern about the ability to manage the technology and devices when orchestrating the field trip on their own. During the experience, our research team was on hand to guide students and address any technological problems. This means that on each field trip, there were at least four adults involved: the teacher, field trip coordinator, and two members of our research team. Additionally, the research team charged, transported, set-up, and calibrated the smartphones and TI NSpire™ probes. In the field, student pairs managed a smartphone and TI NSpire™ with relative ease, yet the teacher felt they may not have sufficient resources to prepare the devices ahead of time for the field experience if working alone.

4. Discussion

Recent literature highlights research on augmented reality and indicates its positive effects on students' motivation and engagement (Dunleavy, Dede & Mitchell 2009; O'Shea, Dede & Cherian, 2009; Dunleavy & Dede, in press). The results of our research support this characterization, as the teachers reported high levels of student engagement with the technology, and also with science. Students' engagement with the technology was also evident in their responses to the opinion post-survey, in which technology-rich activities were rated higher than those without technology.

Feedback from the teachers suggested that the type of engagement observed was in using the devices as "ready-to-hand" (Soloway, Norris, Blumenfeld & Fishman, 2001), which is a concept initially conceived by Heidegger (1927/1973) and described by Pea and Maldonado (2006) as "a condition of interacting with the world as mediated through the use of objects when we care about them, objects whose design allows us to remain engaged in the tasks to be accomplished, rather than to focus on the devices themselves." Other researchers argue that handheld technologies (like smartphones or tablets) are uniquely positioned to achieve this immediate relevance and utility, as students may use tools and media that are not dictated by the curriculum (Klopfer & Squire, 2008), and the activities can draw on tools and techniques that may be available to them outside of the classroom and can be used during future informal learning opportunities (Klopfer, 2008, p. 58). Equipping handheld technologies with augmented reality applications can scaffold student use of scientifically relevant tools and modes of communication (Squire & Klopfer, 2007) and could support subsequent participation in meaningful scientific communities of practice.

Positive effects on student engagement observed by teachers were mirrored in the positive gains we saw on student responses to the affective survey. We observed gains in a number of affective items and saw particular gains in student self-efficacy and their understanding of what scientists do. These findings echo other research that has shown that technology integrated with field trip experiences can engage students in inquiry-based activities and help students identify with scientists and scientific practices (Bodzin, 2008; Zucker et al., 2008). Students offered their own thoughts on the impact of the augmented reality experience on their learning as one student said,

> *It's much better than learning from a textbook because it's more interactive… because you're in… you're in it, you can see everything instead of just reading, and the questions are related to what you can physically do, instead of what you just know from your knowledge. ~ 6th grade student using EcoMOBILE during a field trip.*

Using augmented reality on the field trip allowed teachers to use pedagogical approaches that may otherwise be difficult in an outdoor learning environment. The technology supported independence, as students navigated to the AR hotspots to explore and learn at their own pace. This freed the teacher to act as facilitator, an affordance of AR that has been hypothesized by other researchers (Roschelle & Pea, 2002). The teachers also highlighted this as one of the greatest benefits to teaching with the mobile devices. The program director shared her thoughts saying

> *I was able to work a little more one-on-one and with small groups, I sort of just traveled around and checked in with kids, I wasn't directing things, that felt really different to me and I really liked it….It felt more like, you know, what I like to think of teaching as being - not just directing top-down. ~ Ecology Center Program Director*

Such feedback suggests that AR can provide a powerful pedagogical tool that supports student-centered learning. Given the positive effects of student-centered approaches on higher-order skills such as critical thinking and problem solving (McCombs & Whisler, 1997), these technologies may support the use of sophisticated pedagogical approaches of great benefit to student learning. They can encourage active processing thus helping students to develop deeper understanding, discover gaps in their understanding, and realize the potential for transfer in similar contexts (Perkins, 1992). Since student strengths and preferences for learning are very diverse, these technologies provide ways of individualizing instruction in a group setting, fostering increased motivation and learning (Dede, 2008; Dede & Richards, 2012). Thus, AR may provide an extension of technologies that have already been identified as supporting student-centered learning in the classroom (Hannafin & Land, 1997).

The teachers indicated that the technology promoted more interaction with the pond environment and with classmates compared to field trips in past years. The teachers stated that they began this project with skepticism about whether the technology would overwhelm the experience, holding the students' attention at the expense of their noticing the real environment. However, teachers and investigators found the opposite to be true. Students were captivated when a squirrel dropped a seed from a tree near the path and nearly hit a classmate; they called out excitedly when they observed a frog near the shore. Meanwhile, the AR offered students a view of bacteria and molecules – parts of the ecosystem that students would not otherwise have been able to witness in the field.

Such affordances of AR support student recognition of non-obvious or unseen factors as significant actors in ecosystem dynamics. This addresses a long-standing challenge in helping students to recognize the existence of microscopic and/or non-obvious causes (e.g. Brinkman & Boschhuizen, 1989; Leach, Driver, Scott, & Wood-Robinson, 1992). The tendency to miss non-obvious causes is especially prevalent in student thinking when there is a salient, obvious candidate cause. The affordances of AR enable non-obvious causes to compete with more obvious ones for students' attention.

Following directions embedded within the FreshAiR™ program, students were guided through collection of meaningful water quality measurements and were immediately prompted to reflect on the measurements and make sense of the data followed by feedback that clarified or reinforced relationships among variables. This adds a dimension to use of probeware and enhances its affordances by decreasing cognitive load associated with data collection and interpretation, and increasing collaboration among students (Roschelle, 2003; Tatar, Roschelle, Vahey & Penuel, 2003; Rogers & Price, 2008; Zhang, Looi, Seow, Chia, Wong, Chen et al., 2010). The combination of AR and probeware helped to situate the measurements in a meaningful context, and "act becomes artifact" as students were able to carry the data they had collected back into the classroom (Roschelle & Pea, 2002). The results of our pre-post surveys support the conclusion that the activities which integrated probeware resulted in significant learning gains related to student understanding of water quality variables. Teachers also reported examples in which students were able to apply what they had learned to a new situation in interpreting the effects of acid rain on aquatic organisms.

The gains found in student comprehension of water quality metrics and application of these ideas in the classroom context show real promise. Given the relatively brief exposure to the technologies in the field in comparison to the typical length of a unit of study, many questions remain to be answered. These include questions about the persistence of the gains here, about the relative impact of the technology versus the classroom curriculum used to support field activities, and also about the possibilities afforded by longer interventions. Future studies that offer insights into the effects of different dosage levels as well as assessment of the persistence of the student gains are needed. These would guide efforts to assess the appropriate level of use both in the field and classroom. Given the salience and contextualization of the experience for students, we expect that the gains would persist beyond those of typical instruction; however, these are empirical questions yet to be addressed.

Teachers reported high levels of student engagement with the smartphones, but written survey results from the teachers indicated mixed opinions about the specific impact of the smartphones on student learning. Teachers' surveys indicated a strong feeling about the effectiveness of the probeware for supporting student learning, while the AR was rated more neutrally on this same question. Through analysis of observations, survey responses, and interviews we concluded that, in this use case, AR was most effective as a mode of engagement and as a way of structuring and enhancing the probeware-based activities of the field trip. This speaks to the importance of design objectives during the development of AR activities, as our primary goal here was to use the AR to support integration of probeware into the field trip experience. The overall EcoMOBILE experience contributed to significant student learning gains; however, based on our research design, it is not possible to assess the relative impact of different aspects of the experience. Our findings indicate that AR activities can be effectively designed to serve a facilitative or mediating role that supports student-centered pedagogies and integrates real-world activities into a learning experience, which is complementary to AR activities designed for direct instruction. Further insight will be gained as we continue to work closely with teachers to better understand how AR can serve instructional goals and support student learning.

Our findings suggest that combining AR with use of probes inside and outside of the classroom holds potential for helping students to draw connections between what they are learning and new situations. Uncued transfer is enhanced by authenticity (Brown, Collins & Duigid, 1989) where the surface level problem features are closely aligned—signaling to students the possibility that a transfer opportunity exists (Goldstone & Sakamoto, 2003). We think that AR and TI NSpire™ with probeware used together can guide students through a scaffolded, but authentic scientific experience. Situated investigation in the real world may facilitate transfer and may enable "preparation for future learning" (Bransford & Schwartz, 1999) in that students learn skills that may be applicable to learning more generally, for instance, the tendency to consider how to apply school-learned skills in the real world. Considerable effort can be expended in trying to help students transfer their knowledge from the classroom to the real world. Bringing technology enhancements into the real world makes application of the field trip clear. Transfer can then focus on applying knowledge to other real world contexts (Schwartz, Bransford & Sears, 2005).

Overall, results of the students' surveys and teacher feedback suggest that there are multiple benefits to using this suite of technology for teaching and for learning. For teaching, AR can be harnessed to create a learning experience that is student-centered, and provides opportunities for peer-teaching, collaboration, and one-on-one teacher guidance. The scaffolding provided by the AR platform enabled student use of sophisticated measurement devices that would otherwise have been difficult to manage. These benefits to the teacher helped to unlock different learning opportunities for students. We plan to continue exploring the affordances of this combination of technologies for promoting transfer of student learning between classroom and real world environments.

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Figure and Table Captions:

Figure 1. Students working in pairs with a smartphone and TI NSpire™ handheld device.

Figure 2. Introductory information about dissolved oxygen in a pond.

Figure 3. Instructions to student to use the probe at designated hotspot.

Figure 4, Multiple choice question soliciting the students input based on water measurement captured with probeware.

Figure 5. Feedback when student captures a water measurement that is within the appropriate range.
Figure 6. Feedback when a student captures a water measurement that is outside the expected range for the pond. (Image credit: © John Lund/Sam Diephuis)
Figure 7. Mean student responses on the opinion survey following the field trip activity. The items were scored on a 7-point Likert scale, and the mean value on the graph is surrounded by error bars that indicate the standard error around the mean.

Table 1. Summary of results for specific assessment items. Results for questions 1-7 are reported in mean Likert score; questions 8-14 are reported in the percent of students who answered the item correctly. Changes in the affective measures were assessed using paired t-tests, while the content measures were assessed using McNemar's test.
Table 2. Predictors of gains in affective scores between the pre- and post-intervention survey. The model was fit using ordinary least squares regression. Teacher and content pre-survey score were not significant predictors of gains ($F_{(3,48)} = 0.82$, $R^2 = -0.01$, p-value = 0.49)
Table 3. Predictors of the gains in the content survey scores (where gain = post content score – pre content score). The model was fit using ordinary least squares regression. Teacher was not a significant predictor of gains ($F_{(2, 68)} = 1.83$, $R^2 = 0.02$, p-value = 0.17).

Table 1.

Question	Text	Mean_pre	Mean_post	p-value
1	I am able to figure out the reasons why things happen in nature	3.8 ± 0.74	4.2 ± 0.75	0.001
2	It is easy for me to use tables and graphs to figure things out.	4.0 ± 0.78	4.3 ± 0.76	0.01
3	I understand what scientists do to study ecosystems.	3.4 ± 0.9	4.0 ± 0.86	<0.001
4	I can look at data that I collected and see how it fits together	4.0 ± 0.68	4.2 ± 0.85	0.21
5	It is easy for me to connect the things I am learning about in science with what I already know.	4.1 ± 0.78	4.3 ± 0.84	0.26
6	It is easy to figure out what causes changes in an environment	3.8 ± 0.88	4.1 ± 0.81	0.09
7	It is important to take measurements of ecosystems all the time	3.9 ± 0.97	4.1 ± 1.0	0.03
8photosynthesis	There are gases (like oxygen and carbon dioxide) dissolved in the water of lakes, streams and ponds. Describe at least three ways that these gases get into the water.	28.0%	49.0%	0.005
8mixing		31.0%	59.0%	<0.001
8respiration		25.0%	31.0%	0.52
9	When water is cloudy and hard to see through, it has a higher level of	34.0%	93.0%	<0.001

10	Which is the best pH range for water organisms to be healthy?	18.0%	58.0%	<0.001
11	Which of the following events involves a consumer and producer in a food web?	85.0%	83.0%	1
12	How do decomposers obtain their food?	64.0%	72.0%	0.24
13	Which statement best explains the relationships shown?	68.0%	76.0%	0.32
14	Based on the graph above about how many Black-capped Chickadees there are in Cambridge in December?	73.0%	73.0%	1

Table 2.

Predictor	βn (Coefficients)	Standard Error	t-value	p-value
Intercept	0.89	1.13	0.8	0.43
Teacher2	0.95	0.93	1	0.31
Teacher3	1.4	0.96	1.4	0.16
Content Pre-Survey Score	0.8	0.21	0.4	0.71

Table 3.

Predictor	βn (Coefficients)	Standard Error	t-value	p-value
Intercept	1.7	0.3	5.6	<0.001
Teacher2	-0.78	0.56	-1.4	0.17
Teacher3	0.3	0.43	0.7	0.49

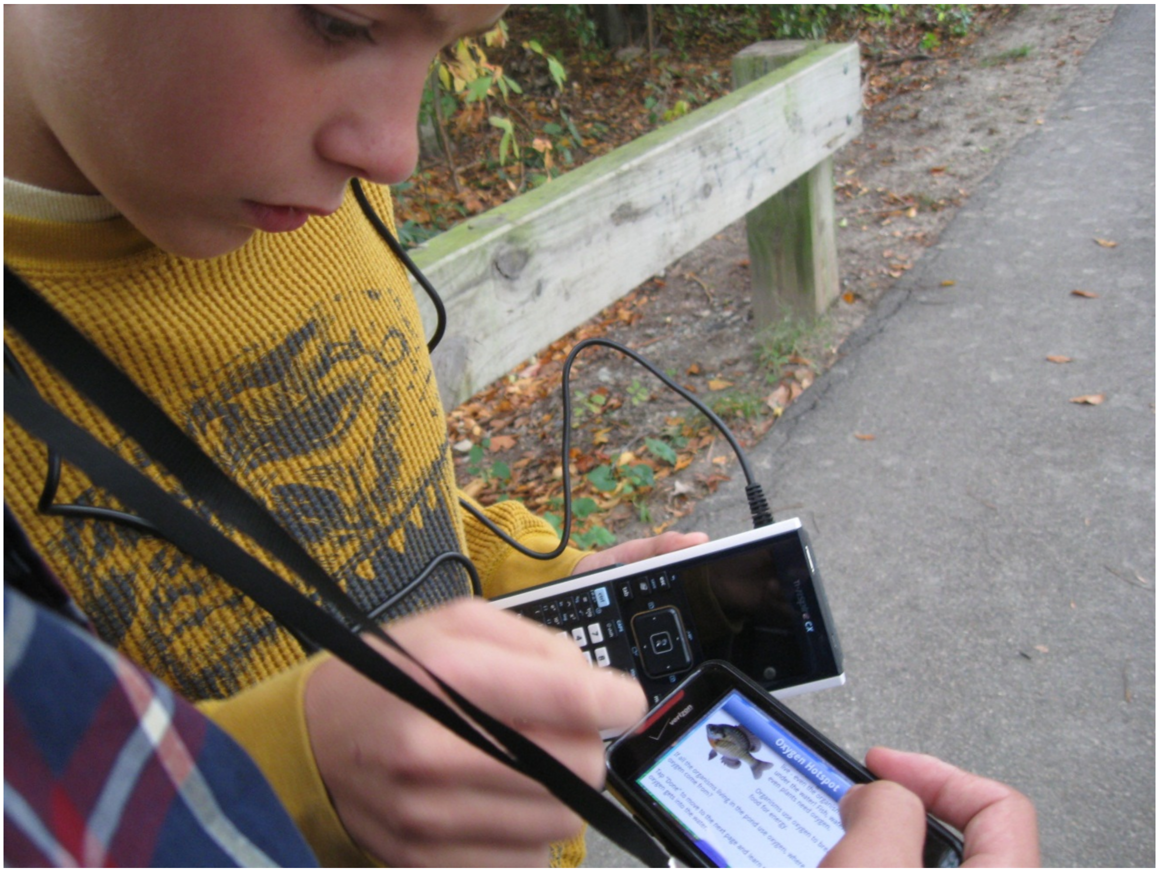
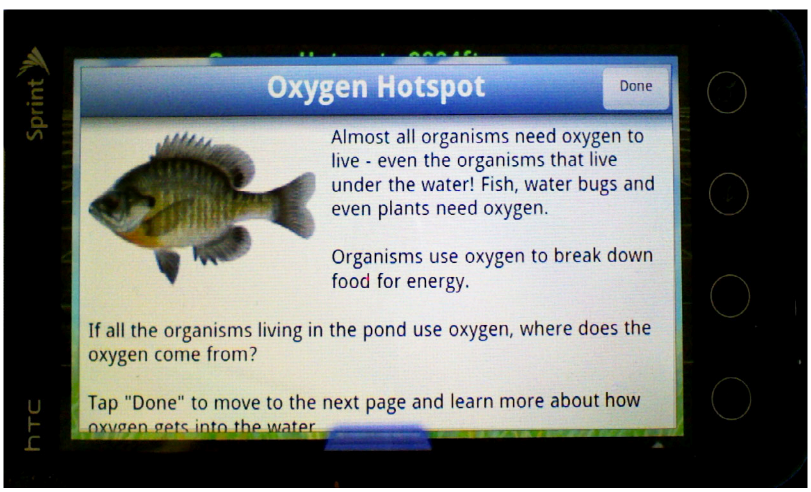


Figure 1.



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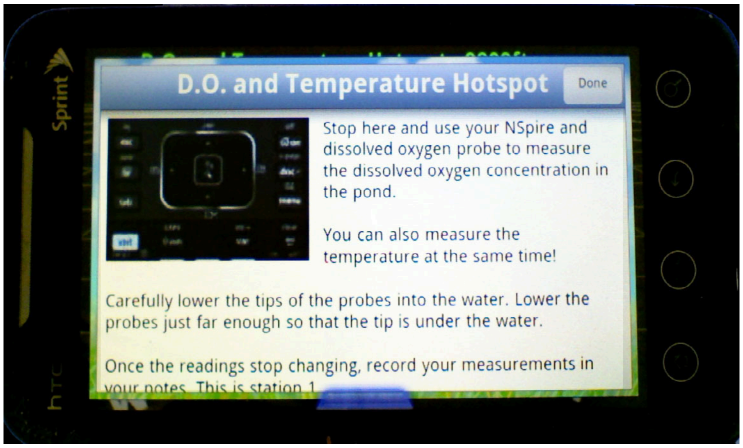

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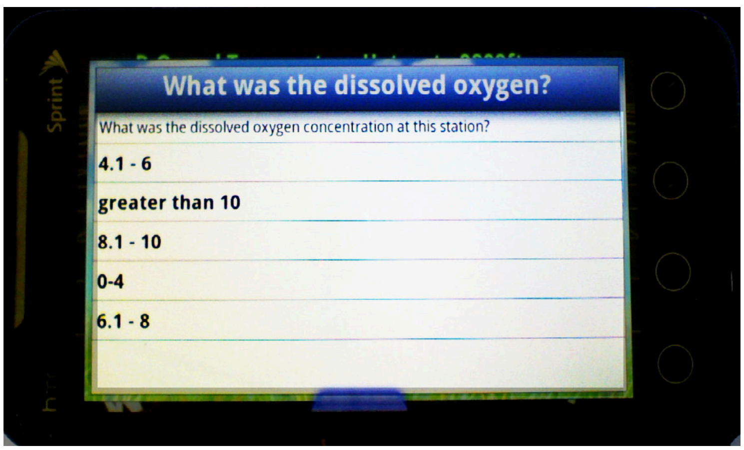

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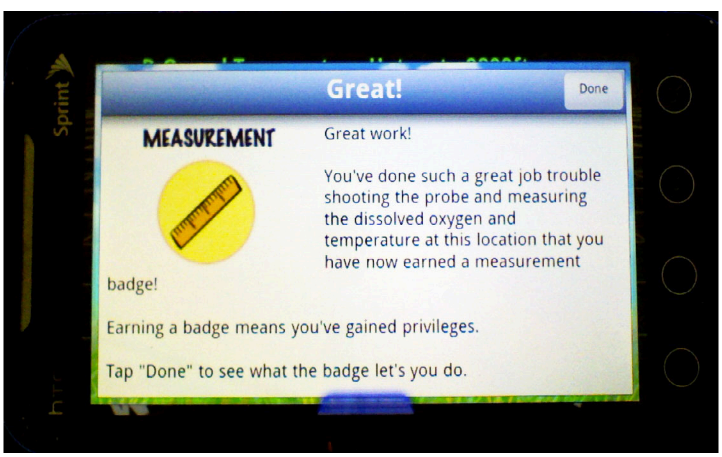

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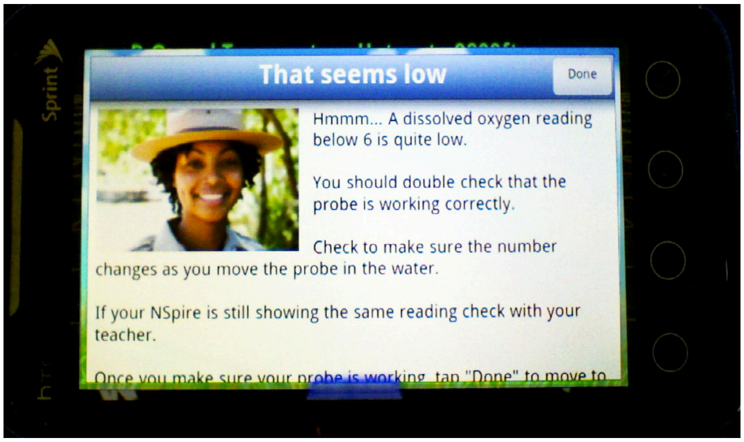

Figure 6.

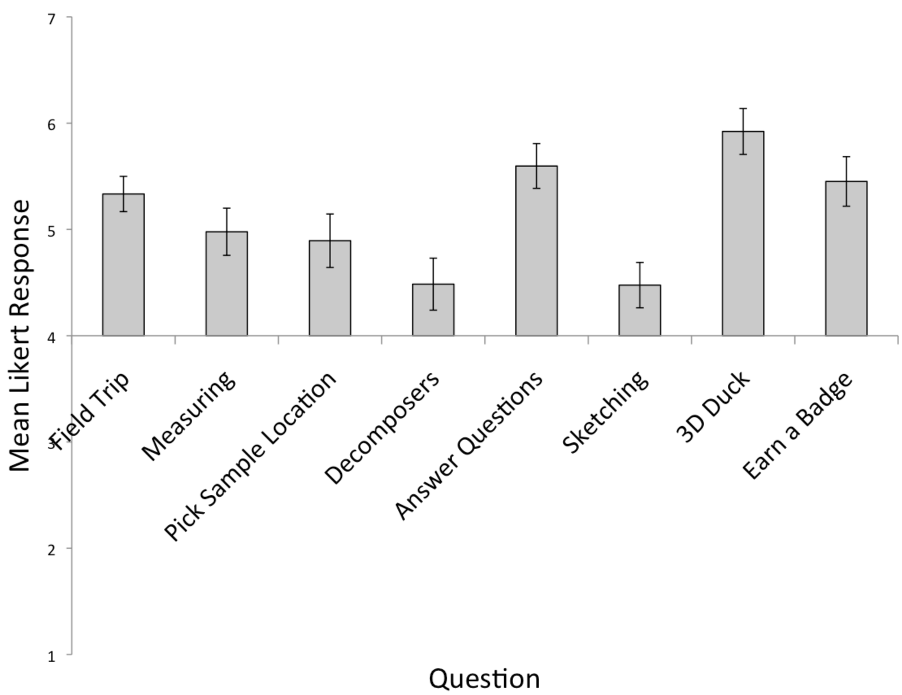

Figure 7.