



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

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1 **EcoMOBILE: Integrating Augmented Reality and Probeware with Environmental**
2 **Education Field Trips**

3
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20 **Highlights**

- 21 1. We designed an experience integrating augmented reality and environmental
22 probes.
- 23 2. This combination of technologies had benefits for both teachers and for learners.
- 24 3. Gains were revealed on both affective and content dimensions of learning.
- 25 4. These technologies facilitated student-centered instructional practices.
- 26 5. EcoMOBILE promoted science understanding more than previous field trips
27 without AR and probeware.
- 28
29

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30 **Abstract**

31

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

55

56

57 **1. Introduction**

58

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

75

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

88
89 Using handheld devices and probes in science has been shown to promote various aspects
90 of teaching and learning in the classroom and in the field. Using probes in a lab setting
91 coupled with computer-mediated presentation of the results promotes critical evaluation
92 of graphs and data (Nachmias & Linn, 1987; Zucker, Tinker, Staudt, Mansfield &
93 Metcalf, 2008; Metcalf & Tinker 2004; Nicolaou, Nicolaidou, Zacharia & Constantinou,
94 2007), supports student learning of science concepts (Metcalf & Tinker, 2004), and
95 supports inquiry-based science learning (Vonderwell, Sparrow & Zachariah, 2005;
96 Rogers & Price, 2008). Through use of real-time probeware, connections are built
97 between abstract representations and concrete experiences with the data and related
98 concepts (Vonderwell et al., 2005).

99
100 We posit that combining probes and handheld devices through the use of augmented
101 reality (AR) can further support this learning by situating the data collection activities in
102 a larger, meaningful context that connects to students' activities in the real world (Squire
103 & Klopfer, 2007). AR is an "immersive" interface (Dede, 2009) utilizing mobile, context-
104 aware technologies (e.g., smartphones, tablets), and software that enables participants to
105 interact with digital information embedded within the physical environment (Dunleavy &
106 Dede, in press). Our research is exploring the unique affordances of AR that can support
107 this kind of situated learning in environmental science education.

108
109 Combining AR and the use of environmental probes can provide multiple affordances in
110 support of situated learning during field trip experiences. AR interfaces can enable
111 contextualized, just-in-time instruction; self-directed collection of real-world data and
112 images; and feedback on student actions and responses. AR's have also been shown to
113 support social interactivity; respond to shifts in context; facilitate cognition distributed
114 among people, tools, and contexts; and provide individualized scaffolding (Klopfer &
115 Squire, 2008; Klopfer, 2008; Dunleavy & Dede, in press). We hypothesize that a
116 combination of both AR and environmental probes may enhance the field trip experience
117 in ways that neither technology could accomplish on its own.

118
119 Through smartphones enabled with augmented reality technology, and environmental
120 probes comparable to those used by environmental scientists (Texas Instruments
121 NSpire™s (TI NSpire™s) with Vernier probes), we are conducting pilot implementations

122 of a curriculum that scaffolds authentic participation in scientific practices by middle
123 school students. For our pilot studies, this article describes the extent to which using this
124 combination of technologies aided students' learning of ecosystem science concepts and
125 their attitudes toward ecosystem science.

126

127 **2. Research Design**

128

129 2.1 Research Questions

130

131 We aimed to address the following research questions:

132 What do students' learning and motivation, and teachers' experiences look like following
133 a combined AR+TI NSpire™s with environmental probes experience, based on the
134 following measures?:

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

143

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

162

163 2.2 Participants

164

165 Sixth grade students (n = 71) in the classes of three teachers in a school district in the
166 northeast participated in the study in the Fall of 2011. Two of the teachers taught two
167 science classes each; the third taught one class, for a total of 5 classes. Teachers were

168 selected for participation by the district science coordinator (3 teachers selected out of a
169 total of 9 dedicated 6th grade science teachers in the district), and selection was based on
170 logistical considerations rather than teacher interest, teaching experience, or propensity
171 for use of technology. The number of students in the classes ranged from 16 to 22 with
172 74% of those students returning their permission slips for a total study participation of 71.
173

174 2.3 Intervention

175

176 *2.3.1 Technology*

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

180 2.3.1.1 Augmented Reality experience: The augmented reality experience was
181 created using the FreshAiR™ augmented reality development platform
182 (playfreshair.com) designed by MoGo Mobile, Inc. The FreshAiR™ platform
183 allows an author to create augmented reality games and experiences with no
184 programming experience required. These games and experiences can then be
185 accessed anywhere from an iPhone or Android mobile device with wireless
186 connectivity, camera, and GPS capabilities. “Hotspots” are placed on a map of
187 the physical setting, and these hotspots become accessible to students at the
188 real location in the field. At a hotspot the student can experience augmented
189 reality visualizations overlaid on the real environment, as well as interactive
190 media including text, images, audio, video, 3D models and animations
191 (supported by Qualcomm Vuforia technology), and multiple-choice or open-
192 ended questions enabling immersive, collaborative and situated mobile
193 learning experiences.

194 2.3.1.2 Water measurement tools: Students collected water measurements using
195 Texas Instruments (TI) NSpire™ handheld devices with Vernier
196 environmental probes. The TI NSpire™ provides graphing calculator
197 capabilities along with a Data Quest data collection mode that allows display
198 of multiple probe readings on a single interface. Probes were provided to
199 measure four variables; dissolved oxygen concentrations, turbidity, pH and
200 water temperature.

201

202 *2.3.2 Duration and Learning Goals*

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

208

209 *2.3.3 Pre-Field Trip*

210 Prior to the field trip, the students also had access to “learning quests”, which are online
211 modules providing a 5-10 minute activity that introduces the students to the ideas behind
212 dissolved oxygen, turbidity, and pH. These provide a definition of the water quality
213 variable, the range of values that students might expect to see, and information about why

214 the value might change. Two of the teachers used these learning quests during class two
215 days before the field trip, while the 3rd teacher used them as one of the “stations” during
216 the activities on the day prior to the field trip.

217
218 During the school day before the field trip, teachers conducted a pre-field trip classroom
219 lesson in which students practiced using the probes to measure temperature, dissolved
220 oxygen, turbidity, and pH. The classroom had 5 stations – one for each of the 4
221 measurements – plus a final station where students measured all four characteristics for a
222 classroom aquarium. At each station, students measured both a control of plain water and
223 a source that would provide an extreme reading for the measurement being tested. For
224 example, in order to test pH, the students took measurements for both tap water and
225 vinegar. Students worked in teams to visit each station for about 5 minutes. Afterward,
226 the groups gathered to review their results and discuss the range of readings for each
227 measurement type.

228

229 *2.3.4 Field Trip*

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

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

247

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

253

254 The EcoMOBILE experience included the following AR-facilitated activities:

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

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

274

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

281

282 *2.3.5 Post-Field Trip*

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

290

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

297

298

299 **3. Data Analysis and Results**

300

301 3.1 Affective Data Analysis

302

303 We assessed students' self-efficacy related to ecosystem science knowledge and skills
304 and their valuation of environmental monitoring. Students indicated, on a Likert scale,

305 their degree of agreement with statements related to ecosystem science skills and
306 attitudes. The Likert scale used was: “strongly disagree”, “disagree”, “neutral”, “agree”,
307 “strongly agree”. We analyzed the data with a factor analysis to assess aggregation of
308 these items around proposed latent traits, and found that we could use a single factor to
309 represent the information in the affective assessment items. Therefore, the seven Likert-
310 scale questions were aggregated to a single mean affective score for each student, and
311 pre-post gains were assessed using a paired t-test on these aggregate scores.

312

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

321

$$GAIN_A_i = \beta_0 + \beta_1 PRE_i + \beta_2 TEACHER_i + \varepsilon_i$$

322

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

331

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

340

341 3.2 Affective Results

342

343 Overall, student responses to affective items showed a positive shift in their attitudes
344 about their ability to understand focal topics and do science related skills. The mean
345 affective score increased by 0.26 points (pre_mean = 3.88 ± 0.5, post_mean = 4.14 ±
346 0.58), with a moderate effect size of 0.48, meaning that the average increase in student
347 scores was about one half of a standard deviation. Teacher and pre-intervention content
348 scores were not significant predictors of the mean gain in affective measures.

349

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

361

362 3.3 Content Understanding Analysis

363

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

371

$$372 \quad GAIN_i = \beta_0 + \beta_1 TEACHER_i + \varepsilon_i$$

373

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

380

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

387

388 3.4 Content Understanding Results

389

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

396 0.02, p-value = 0.17). The mean scores on the post surveys for each teacher were
397 teacher1 = 6.6, teacher2 = 5.2, teacher3 = 5.6, thus teacher2 had a significantly lower
398 post-intervention survey score compared to the other teachers ($F(2,68) = 3.76$, p-value =
399 0.03). Also, pre-survey scores were significantly lower ($F(2,68) = 4.12$, p-value = 0.02) for
400 one of the teachers participating (teacher1 = 4.9, teacher2 = 4.3, teacher3 = 3.6).
401 Therefore, there were differences between teachers in the pre- and post-intervention
402 content scores, but these differences did not manifest as significant differences among
403 teacher in overall gains in content scores.

404
405 Analysis of the item-specific results indicates that student gains were significant on topics
406 related to the water quality variables that were measured with the environmental probes.
407 Gains were significant on questions 8, 9 and 10 (Table 1). On questions related to food
408 webs, abiotic/biotic resources and graphing (Questions 11-14), students generally
409 demonstrated a high level of understanding of these concepts on the pre-survey (greater
410 than 64% of students got these questions correct). Again, on the post survey, greater than
411 72% of students answered these assessment items correctly.

412 413 3.5 Student Opinion Post-Survey

414
415 In addition to understanding how student affect and content understanding changed
416 during the intervention, we also asked students to offer their opinions about the field trip
417 using a one-time field trip opinion post-survey. On this survey, students were asked “On
418 a scale of 1-7, how much did you like the EcoMOBILE field trip? Circle your answer. (1
419 = dislike very much, 7 = liked very much).” The average answer was 5.4, indicating that
420 students generally enjoyed the field trip (Q1, Figure 7). Subsequent questions asked about
421 different features of the activity; students average rating of each activity was 4.6 or above.
422 Technology-rich activities tended to receive the highest ratings, e.g., 6.0 for the 3D
423 visualization triggered by image recognition (using Qualcomm Vuforia technology) (Q7),
424 5.7 for answering embedded questions (Q5), and 5.6 for earning virtual badges (Q8).
425 Less technology-focused activities tended to receive lower ratings, e.g., 4.6 for making a
426 sketch on paper (Q6), or 4.9 for learning about decomposers through reading on-line
427 instructions (Q4).

428
429 Students were also given open-ended questions asking what they liked and didn’t like
430 about the experience, what they thought the activity had helped them to learn, and if they
431 had any suggestions for improvement. The following summarizes a sample of student
432 responses from two classes:

433
434 *What did you think was fun about the EcoMOBILE game?* Common student
435 answers included “finding hotspots,” or “everything.” Other answers mentioned
436 using a smartphone, finding the 3D duck, and taking measurements. One student
437 described liking “that we got to have equipment and be scientists.”

438
439 *Was there anything you didn’t like?* Students most often mentioned technical
440 glitches, or simply answered “no.” Individual students also mentioned having to

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

443
444 *What did the game help you learn about ecosystems?* Students most often
445 mentioned one or more of measurements or organisms that they had learned about.
446 Another common response described learning the importance of taking
447 measurements, and understanding the impact on the environment, e.g., “it helped
448 me learn what pH, turbidity, and dissolved oxygen were, and if it was good or bad
449 for an ecosystem.”

450
451 *How could the game help you learn more?* Some students left this blank; others
452 provided a wide range of suggestions, including making the game longer, adding
453 levels, covering a larger area, getting to use all four probes, asking more difficult
454 questions, or adding more activities, “not just something to read.”

455 456 3.6 Teacher Reactions: Interviews and Post-Surveys

457
458 Findings related to student outcomes were contextualized by gathering reactions from
459 teachers about the EcoMOBILE experience. Looking across the teacher surveys and
460 transcripts of the teacher roundtable discussion following the EcoMOBILE activities, a
461 number of responses were common. Teachers discussed that technology facilitated
462 interactions among students and with the pond environment that resemble scientific
463 practice, a finding that aligns with student survey responses indicating they better
464 understood what scientists do. Teachers spoke about the benefits of the AR platform for
465 managing a productive field trip, and also identified directions to move in the future.

466 467 *3.6.1 Interactions among students and the pond*

468
469 Prior to the field trip, two of the teachers had expressed concern that the smartphones
470 might be too engaging; leading students to ignore the real environment in favor of the
471 media and capabilities provided by the smartphones. Post-field trip comments indicated
472 the contrary was true – teachers noted that the smartphones promoted interaction with the
473 pond and classmates.

474
475 *It felt like 90% of the time they were at the pond environment, they were working*
476 *on interacting with the pond and their partner, whereas previous times it felt like*
477 *it was maybe 60 or 50% of their time they were independently interacting. ~*
478 *Teacher1*

479
480 Two of the four teachers mentioned that one of the most productive aspects of the
481 experience were hotspots where the AR platform and environmental probes were used to
482 show something that could not be seen in the real world (e.g. measuring abiotic variables
483 like dissolved oxygen and pH, seeing a starch molecule in a ducks stomach). One teacher
484 described how the environmental probes helped students understand photosynthesis and
485 cellular respiration at a molecular level saying:

486

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

491
492 Another use of AR that teachers believed was successful was in leading the students to do
493 something active in the real world, for example using the smartphones to navigate to a
494 hotspot where they were then instructed to collect a sample using the environmental
495 probes. Teachers noted that using the smartphones and environmental probes helped the
496 students become familiar with interpreting the water quality measurements, and noted
497 that students were able to apply these ideas in other situations.

498
499 *"They do seem pretty conversant with turbidity, pH, dissolved oxygen and I would*
500 *say more conversant with those things than [students from previous classes]...*

501
502 The teacher went on to explain a different part of her curriculum in which they were
503 reading about acid rain, and she said,

504
505 *...they were all like "whoa!" when it said that acid rain had a pH of 1.5 - 5.5,*
506 *they KNEW - fish can't live in that. You know, like, they had that sense...*
507 *~Teacher1*

508
509 Finally, other observations of the teachers indicated that allowing the students a window
510 into the unseen parts of the environment also helped students to identify with scientific
511 practices and motivated students in a new way,

512
513 *My students were psyched about like molecules, too... all that world unseen, all*
514 *that new stuff is making them feel much more like this is real science or adult*
515 *science. A bunch of my students are hooking into science in a way that they report*
516 *that they never have before. I can't help but think that the high-powered*
517 *technology helps... Teacher1*

518
519 Another teacher reiterated this idea in relation to how this project reached students who
520 were from underserved communities, saying,

521
522 *...the exposure to the technology, that this is what [scientists] are using, that's*
523 *pretty important Teacher2*

524
525 Thus, teachers indicated important ways in which the probes and AR supported student
526 adoption of modes of interacting with their classmates and the environment that closely
527 resemble scientific practices.

528 529 3.6.2 Managing a productive field trip

530
531 Teachers commented that the smartphones helped to structure students' movement
532 through space and guided their interaction with the pond and with classmates. The

533 students were able to work independently, at their own pace, with the teacher acting as a
534 facilitator. Teachers reported that the activities were more student-driven and less
535 teacher-directed. The teachers thought this was beneficial in that it provided students with
536 a different sense of ownership over the experience.

537
538 *It helped structure their movement through space...so rather than having a whole*
539 *group of kids clustered in one muddy, wobbly spot at the edge of the pond, they*
540 *were all at sort of different spots going through it at their different paces and*
541 *because they were moving independently through the different parts, I felt like it*
542 *gave them a different ownership over the experience than if there had been just*
543 *one teacher voice and a crowd of kids. ~ Teacher1*

544
545 Another feature of the activity was the opportunity for collaborative communication and
546 problem-solving among students that arose from the augmented reality experience.

547
548 *It invited much more student on student dialog because they had to engage*
549 *together to sort of figure out things that were coming through to them on the*
550 *smartphone. So it, in some ways, I thought that their dialog probably deepened*
551 *their understanding. ~ Ecology Center Program Director*

552
553 One teacher observed that the students seemed to rush through some of the information
554 presented on the smartphones, while the Ecology Center Program Director, who guides
555 the field trips for all the students in the school district, lent perspective saying:

556
557 *having done a lot of ponding with the kids without smartphones and seeing how*
558 *they often rush through things anyway... if anything, I was struck that the kids*
559 *were sort of ... paced through the activities more than usual ~ Ecology Center*
560 *Program Director*

561
562
563 Written feedback from the teachers indicated that AR was particularly useful in engaging
564 students. Two teachers were neutral (rating of 3) in their self-reported assessment of the
565 contribution that the smartphones and FreshAiR™ made toward student learning, while
566 one teacher gave a rating of 5 (assessed using a Likert scale, where 1 = very little and 5 =
567 very much). In comparison, all teachers rated the TI NSpires™ and environmental probes
568 as a 4 or a 5 for their contribution toward student learning. These results are based on the
569 teachers' self-reported impression of students learning gains, rather than empirical data.
570 The results of our student opinion and content surveys support the idea that the
571 smartphones supported high levels of student engagement, while the student learning
572 gains were most apparent on items related to the combination of AR and probeware.

573 574 3.6.3 Issues to Resolve in Future Implementations

575
576 Teachers spoke of managing the tension between positive aspects of student engagement
577 and students' desire, negative in its effects on learning, to speed through an activity
578 without fully reading or comprehending the activity in order to see what is next. As noted

579 above, one teacher found this tension common to any field trip with or without
580 technology, yet it remains a challenge to design experiences that meaningfully engage
581 students in the tasks at hand so that the take home message is meaningful, not just novel.
582 In future research, we plan to design interventions that allow students to use these
583 technologies during multiple field trip experiences in order to examine whether novelty
584 attenuates and engagement is sustained. We hypothesize that situating these learning
585 experiences in local environments and equipping students to use technologies that allow
586 them to collect data and observations that are meaningful outside of a classroom context
587 should lead to sustained engagement beyond that offered by the novelty of the
588 technologies themselves.

589
590 The teachers also expressed concern about the ability to manage the technology and
591 devices when orchestrating the field trip on their own. During the experience, our
592 research team was on hand to guide students and address any technological problems.
593 This means that on each field trip, there were at least four adults involved: the teacher,
594 field trip coordinator, and two members of our research team. Additionally, the research
595 team charged, transported, set-up, and calibrated the smartphones and TI NSpire™
596 probes. In the field, student pairs managed a smartphone and TI NSpire™ with relative
597 ease, yet the teacher felt they may not have sufficient resources to prepare the devices
598 ahead of time for the field experience if working alone.

600 **4. Discussion**

601
602 Recent literature highlights research on augmented reality and indicates its positive
603 effects on students' motivation and engagement (Dunleavy, Dede & Mitchell 2009;
604 O'Shea, Dede & Cherian, 2009; Dunleavy & Dede, in press). The results of our research
605 support this characterization, as the teachers reported high levels of student engagement
606 with the technology, and also with science. Students' engagement with the technology
607 was also evident in their responses to the opinion post-survey, in which technology-rich
608 activities were rated higher than those without technology.

609
610 Feedback from the teachers suggested that the type of engagement observed was in using
611 the devices as "ready-to-hand" (Soloway, Norris, Blumenfeld & Fishman, 2001), which
612 is a concept initially conceived by Heidegger (1927/1973) and described by Pea and
613 Maldonado (2006) as "a condition of interacting with the world as mediated through the
614 use of objects when we care about them, objects whose design allows us to remain
615 engaged in the tasks to be accomplished, rather than to focus on the devices themselves."
616 Other researchers argue that handheld technologies (like smartphones or tablets) are
617 uniquely positioned to achieve this immediate relevance and utility, as students may use
618 tools and media that are not dictated by the curriculum (Klopfer & Squire, 2008), and the
619 activities can draw on tools and techniques that may be available to them outside of the
620 classroom and can be used during future informal learning opportunities (Klopfer, 2008,
621 p. 58). Equipping handheld technologies with augmented reality applications can scaffold
622 student use of scientifically relevant tools and modes of communication (Squire &
623 Klopfer, 2007) and could support subsequent participation in meaningful scientific
624 communities of practice.

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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).

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

680
681 Such affordances of AR support student recognition of non-obvious or unseen factors as
682 significant actors in ecosystem dynamics. This addresses a long-standing challenge in
683 helping students to recognize the existence of microscopic and/or non-obvious causes
684 (e.g. Brinkman & Boschhuizen, 1989; Leach, Driver, Scott, & Wood-Robinson, 1992).
685 The tendency to miss non-obvious causes is especially prevalent in student thinking when
686 there is a salient, obvious candidate cause. The affordances of AR enable non-obvious
687 causes to compete with more obvious ones for students' attention.

688
689 Following directions embedded within the FreshAiR™ program, students were guided
690 through collection of meaningful water quality measurements and were immediately
691 prompted to reflect on the measurements and make sense of the data followed by
692 feedback that clarified or reinforced relationships among variables. This adds a
693 dimension to use of probeware and enhances its affordances by decreasing cognitive load
694 associated with data collection and interpretation, and increasing collaboration among
695 students (Roschelle, 2003; Tatar, Roschelle, Vahey & Penuel, 2003; Rogers & Price,
696 2008; Zhang, Looi, Seow, Chia, Wong, Chen et al., 2010). The combination of AR and
697 probeware helped to situate the measurements in a meaningful context, and “act becomes
698 artifact” as students were able to carry the data they had collected back into the classroom
699 (Roschelle & Pea, 2002). The results of our pre-post surveys support the conclusion that
700 the activities which integrated probeware resulted in significant learning gains related to
701 student understanding of water quality variables. Teachers also reported examples in
702 which students were able to apply what they had learned to a new situation in interpreting
703 the effects of acid rain on aquatic organisms.

704
705 The gains found in student comprehension of water quality metrics and application of
706 these ideas in the classroom context show real promise. Given the relatively brief
707 exposure to the technologies in the field in comparison to the typical length of a unit of
708 study, many questions remain to be answered. These include questions about the
709 persistence of the gains here, about the relative impact of the technology versus the
710 classroom curriculum used to support field activities, and also about the possibilities
711 afforded by longer interventions. Future studies that offer insights into the effects of
712 different dosage levels as well as assessment of the persistence of the student gains are
713 needed. These would guide efforts to assess the appropriate level of use both in the field
714 and classroom. Given the salience and contextualization of the experience for students,
715 we expect that the gains would persist beyond those of typical instruction; however, these
716 are empirical questions yet to be addressed.

717
718 Teachers reported high levels of student engagement with the smartphones, but written
719 survey results from the teachers indicated mixed opinions about the specific impact of the
720 smartphones on student learning. Teachers' surveys indicated a strong feeling about the
721 effectiveness of the probeware for supporting student learning, while the AR was rated
722 more neutrally on this same question. Through analysis of observations, survey responses,
723 and interviews we concluded that, in this use case, AR was most effective as a mode of
724 engagement and as a way of structuring and enhancing the probeware-based activities of
725 the field trip. This speaks to the importance of design objectives during the development
726 of AR activities, as our primary goal here was to use the AR to support integration of
727 probeware into the field trip experience. The overall EcoMOBILE experience contributed
728 to significant student learning gains; however, based on our research design, it is not
729 possible to assess the relative impact of different aspects of the experience. Our findings
730 indicate that AR activities can be effectively designed to serve a facilitative or mediating
731 role that supports student-centered pedagogies and integrates real-world activities into a
732 learning experience, which is complementary to AR activities designed for direct
733 instruction. Further insight will be gained as we continue to work closely with teachers to
734 better understand how AR can serve instructional goals and support student learning.

735
736 Our findings suggest that combining AR with use of probes inside and outside of the
737 classroom holds potential for helping students to draw connections between what they are
738 learning and new situations. Uncued transfer is enhanced by authenticity (Brown, Collins
739 & Duigid, 1989) where the surface level problem features are closely aligned—signaling
740 to students the possibility that a transfer opportunity exists (Goldstone & Sakamoto,
741 2003). We think that AR and TI NSpire™ with probeware used together can guide
742 students through a scaffolded, but authentic scientific experience. Situated investigation
743 in the real world may facilitate transfer and may enable “preparation for future learning”
744 (Bransford & Schwartz, 1999) in that students learn skills that may be applicable to
745 learning more generally, for instance, the tendency to consider how to apply school-
746 learned skills in the real world. Considerable effort can be expended in trying to help
747 students transfer their knowledge from the classroom to the real world. Bringing
748 technology enhancements into the real world makes application of the field trip clear.
749 Transfer can then focus on applying knowledge to other real world contexts (Schwartz,
750 Bransford & Sears, 2005).

751
752 Overall, results of the students' surveys and teacher feedback suggest that there are
753 multiple benefits to using this suite of technology for teaching and for learning. For
754 teaching, AR can be harnessed to create a learning experience that is student-centered,
755 and provides opportunities for peer-teaching, collaboration, and one-on-one teacher
756 guidance. The scaffolding provided by the AR platform enabled student use of
757 sophisticated measurement devices that would otherwise have been difficult to manage.
758 These benefits to the teacher helped to unlock different learning opportunities for
759 students. We plan to continue exploring the affordances of this combination of
760 technologies for promoting transfer of student learning between classroom and real world
761 environments.
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924 Figure and Table Captions:

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

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

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

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

930 Figure 5. Feedback when student captures a water measurement that is within the
 931 appropriate range.
 932 Figure 6. Feedback when a student captures a water measurement that is outside the
 933 expected range for the pond. (Image credit: © John Lund/Sam Diephuis)
 934 Figure 7. Mean student responses on the opinion survey following the field trip activity.
 935 The items were scored on a 7-point Likert scale, and the mean value on the graph is
 936 surrounded by error bars that indicate the standard error around the mean.
 937

938 Table 1. Summary of results for specific assessment items. Results for questions 1-7 are
 939 reported in mean Likert score; questions 8-14 are reported in the percent of students who
 940 answered the item correctly. Changes in the affective measures were assessed using
 941 paired t-tests, while the content measures were assessed using McNemar's test.

942 Table 2. Predictors of gains in affective scores between the pre- and post-intervention
 943 survey. The model was fit using ordinary least squares regression. Teacher and content
 944 pre-survey score were not significant predictors of gains ($F_{(3,48)} = 0.82$, $R^2 = -0.01$, p-
 945 value = 0.49)

946 Table 3. Predictors of the gains in the content survey scores (where gain = post content
 947 score – pre content score). The model was fit using ordinary least squares regression.
 948 Teacher was not a significant predictor of gains ($F_{(2,68)} = 1.83$, $R^2 = 0.02$, p-value = 0.17).
 949

950 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.	28.0%	49.0%	0.005
8mixing		31.0%	59.0%	<0.001
8respiration	Describe at least three ways that these gases get into the water.	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

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Table 2.

Predictor	β_n (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

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Table 3.

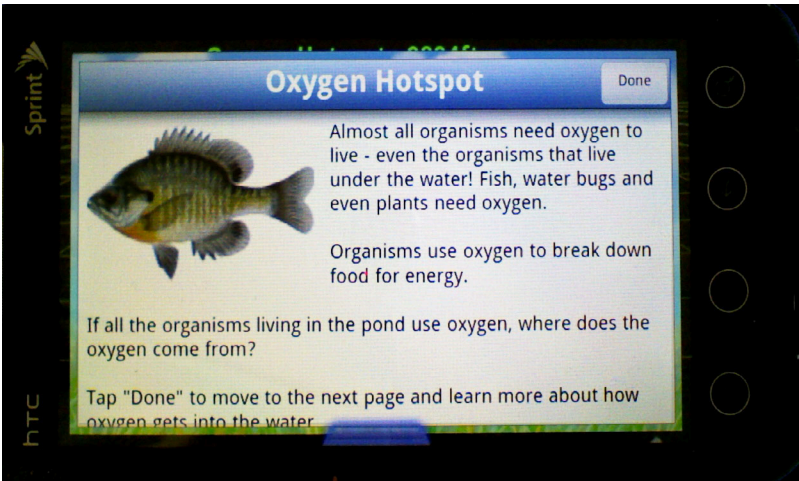
Predictor	β_n (Coefficients)	Standard Error	t-value	p-value
Intercept	1.7	0.3	5.6	<0.001
Teacher2	-0.78	0.56	-1.4	0.17
Teacher3	0.3	0.43	0.7	0.49

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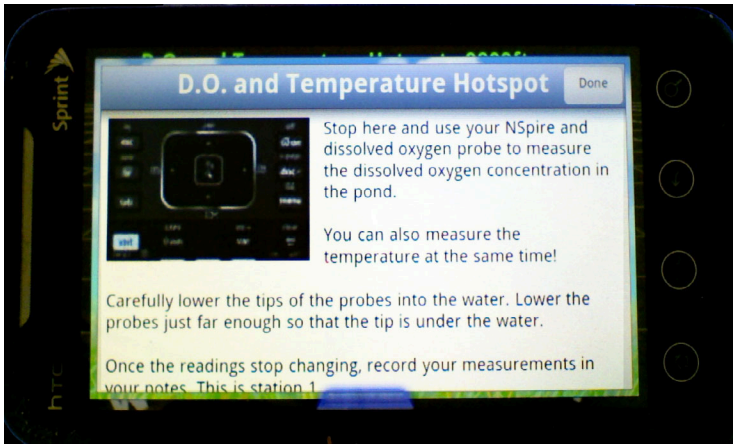
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Figure 1.



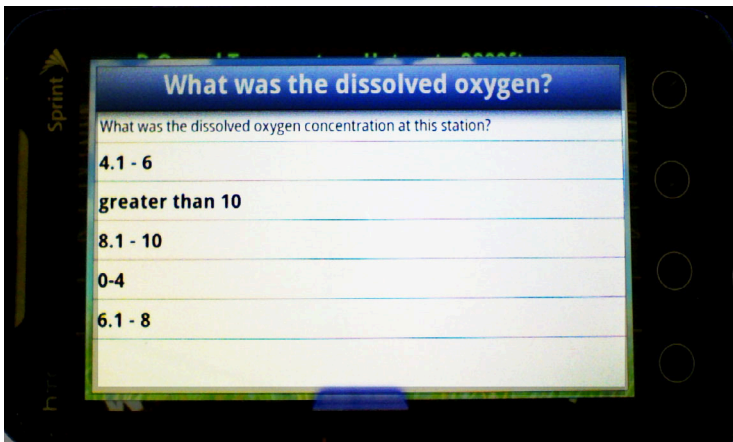
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Figure 2.



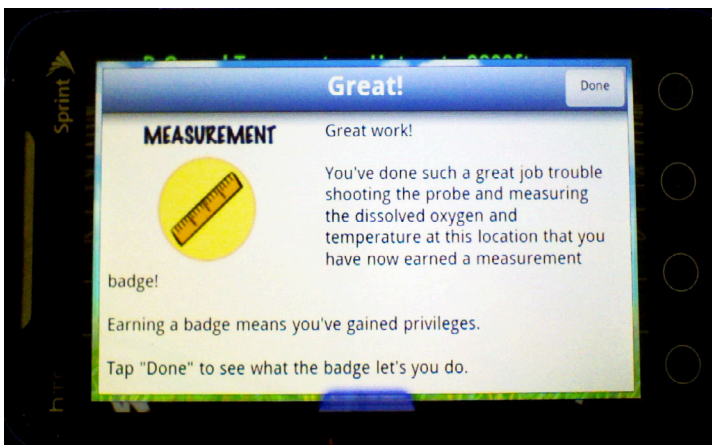
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Figure 3.



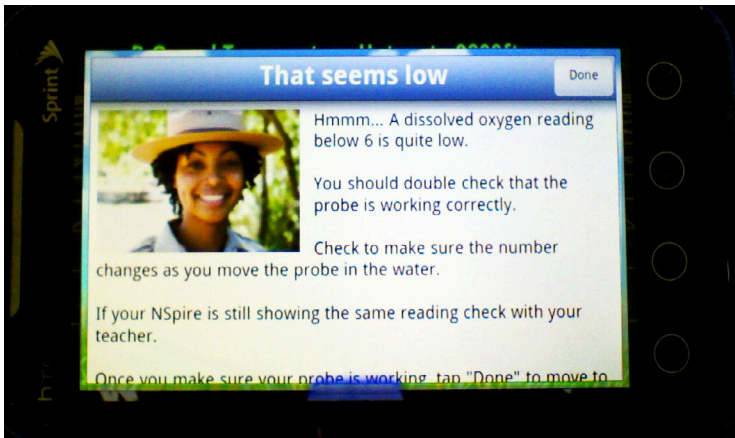
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Figure 4.



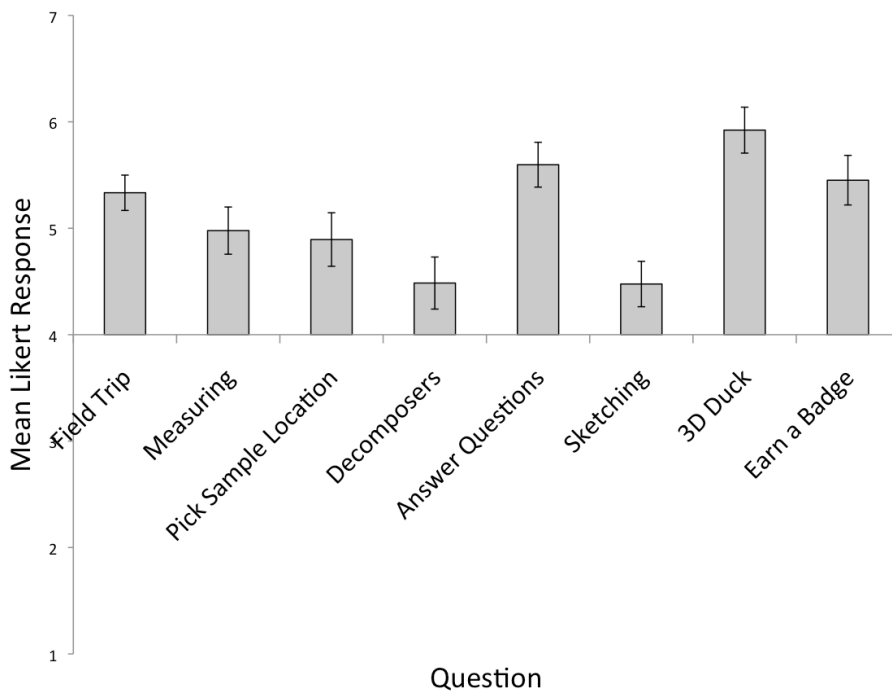
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Figure 5.



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Figure 6.



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Figure 7.