The Importance of Time and Sequence on Learning in Mobile Augmented Reality

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Problem

Place-based education has the potential to facilitate environmental science learning by focusing on contextualized, relevant knowledge that does not rely on the teacher as the sole source of knowledge (Smith, 2007). By situating learning in the real world, many of the challenges of transferring classroom knowledge to real-world contexts can be avoided (Grotzer et al., 2015). Visiting local ecosystems with an entire class of students, however, poses significant logistical and financial challenges for schools and teachers. In addition to the cost of transportation and the pain of scheduling, the real world can be overwhelming for students as it places them in a novel, stimulus-rich environment (Falk, Martin, & Balling, 1978). Mobile augmented reality (AR) activities such as EcoMOBILE have been shown to scaffold environmental science students' exploration of local ecosystems by providing just-in-time instruction and helping them navigate their novel surroundings (Kamarainen et al., 2013).

While analysis of learning gains and qualitative studies have been conducted on EcoMOBILE data, the logged record of student actions in the world has thus far been largely ignored. All students began the activity by collecting water quality data in a highly structured series of steps, but the second half of the field trip was more open-ended and allowed students to peruse a variety of content at hotspots in whatever order they chose. By calculating how much time students spend exploring and what field trip content they see, designers can pinpoint the most impactful content in their experiences and consider how to adjust their activities to maximize learning gains in the amount of time allotted to the field trip. This paper explores data collected during a 2015 implementation of EcoMOBILE with middle school students in a suburban New England public school. Time spent exploring had a large impact on learning gains, completing certain "learning quests" had disproportionately large effects on what students learned, and the order in which content was viewed was impacted by the physical arrangement of the field trip which resulted in differential learning gains for different groups. These findings will be relevant to anyone designing mobile AR field trips for educational use.

Theoretical Framework

In broad terms, AR systems enhance physical spaces and objects by overlaying digital information on top of them, resulting in a combination of real and virtual objects that interact in real-time (Azuma et al., 2001). While many AR applications require the use of heads-up displays expensive headsets, all a device needs to be capable of AR is a front-facing camera and a rear-facing screen (Peddie, 2017). This allows a wide range of mobile broadband devices (MBDs) such as tablets and smartphones to deliver AR content at an affordable price for educational uses. In general, AR experiences are either location-based (using positional data from GPS to trigger content at specific locations), vision-based (using QR codes to trigger the appearance of specific information), or a combination of the two (Cheng & Tsai, 2013). While vision-based activities are location agnostic and can be replicated easily in different locations and settings, location-based AR experiences can be tailored to a specific area and foster more personal connections to content (Kamarainen et al., 2015).

This technology can enhance learning experiences by situating learning in authentic contexts and providing appropriate scaffolding for complex tasks while facilitating communication and social construction of knowledge (Dunleavy & Dede, 2014; Reilly & Dede, 2018). Many of these experiences have been done indoors with vision-based AR, instead of location-based and hybrid activities that take place outdoors (Kamarainen et al., 2018). Situating AR learning outdoors in real-world settings allows users to conduct authentic inquiry activities such as testing water quality or studying the importance of a historical landmark. Situating learning in the real world also turns transfer “inside-out” by grounding learning in the real world which can then inform new material in the classroom versus the more traditional direction transfer usually occurs (Grotzer et al., 2015). Dunleavy and Dede offer a good summary of recent K-20 uses of AR (2014) with a focus on mobile AR.

Beyond the affordances that AR activities provide for users, designers of such activities can collect right log file records of what content students interacted with and how it shaped their learning. These logged events can be used to explore how the order of content viewed or how students moved through the activity might correlate with learning gains. Even when not directed to, groups typically perform AR activities in one of several classifiable ways which can typically lead to better or worse learning outcomes (Klopfer & Squire, 2008). Classifying behavior patterns and clustering like groups together allows designers to know what changes might need to be made and can inform the design of scaffolding to avoid commonly seen issues. In a recent literature review by Akçayır & Akçayır (2017), however, few studies on mobile AR even mention the capability of collecting backend data, let alone describe analyzing it.

This study explores the log file data from an implementation of an EcoMOBILE activity titled “Water Quality Measurements” carried out in 2015 in a suburban New England public middle school. After using the EcoMUVE virtual curriculum in science class to explore how different factors in a virtual ecosystem relate by collecting simulated data (Metcalf et al., 2013), students took a field trip to a local pond to collect actual water quality measurements in their own watershed (Kamarainen et al., 2013). This allowed students to compare and contrast the virtual and real ecosystems and could potentially facilitate transfer of skills learned in EcoMUVE by grounding them in authentic practice. The field trip first involved a more heavily scripted and scaffolded data collection task, then students were free to explore the watershed and look for more information about these measurements at their own pace. Refined over several years of working with local teachers via a design-based implementation research framework (Fishman et al., 2013), modifications were made based on teacher feedback, student opinions, and learning gains. Until now, however, student log file data has not been deeply explored.

Research Questions

The research questions for this study are:

1. How much does the time spent in the open exploration part of EcoMOBILE vary between groups, and how does this correlate with learning gains?

2. Which learning quests are associated with the largest learning gains?
3. Does the order of content viewed impact student success?

Design and Procedure

A survey was administered to students prior to any intervention (“pre”), upon completion of the two-week EcoMUVE virtual ecosystem-based curriculum (“mid”), and after the EcoMOBILE AR field trip to a real pond (“post”). In this paper, only gains between “mid” and “post” are considered. The survey instrument consisted of 24 open-ended explanations and 15 multiple choice items designed to assess student outcomes related to 4 sub-measures: describing data, understanding variability, explaining reasoning, and understanding ecological mechanisms. Survey data from 57 students from four classes of one science teacher are analyzed here. Additional details regarding the survey validation and other student-level covariates can be found in Reilly et al. (2017).

Students worked in small groups of 2-3, and time-stamped log file data from 20 different groups are analyzed. The field trip activity was designed in Augmented Reality and Interactive Storytelling (ARIS), a free open-source editor from the University of Wisconsin.[1] Running on iPad Minis, the ARIS activity guided students through the different content and procedures they needed to carry out at the pond and also acted as a virtual notebook for students to store their data and catalog reflections. The backend log files track each group’s physical movements via latitude and longitude, when certain progress triggers were met, what content was viewed by the groups scanning QR codes at specific hotspots, and when notes were recorded by the group. These data were obtained from the secure ARIS servers after the completion of the activity.

Results

Time Spent Exploring

The amount of time students spent exploring the world after the scripted data collection activity varied widely. Two groups were unable to progress past the first activity during the 45-minute field trip, while others spent between 7 and 33 minutes investigating additional evidence for why data may vary at different parts of the pond. Groups who finished the entire activity spent a mean of 22 minutes exploring this evidence compared to the 9:35 mean of groups who were unable to finish ($t = -4.62$, $p < 0.001$). Groups who finished had an average gain of 7.7 percentage points on the “explaining reasoning” construct while groups who were unable to finish averaged a 5 percentage point decrease in scores ($t = -2.76$, $p < 0.05$). Implementation-related technical bugs have been noted by teachers using EcoMOBILE in the past (Kamarainen et al., 2013) and the effect of these must be closely examined due to the large role time plays in students’ ability to use evidence to explain their reasoning in scientific investigations.

Completion of Certain Learning Quests

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[1] https://fielddaylab.org/make/aris/

For the “understanding variability” construct, a linear mixed-effects model (with students grouped by teams) was built to determine what learning quests are associated with the largest learning gains. Completing the "What's Nearby?" quest is associated with a 26.1 percentage point gain on the post survey when controlling for reading level, gender, performance on the mid-survey, and completion of all other quests ($t = 2.43$, $p < 0.05$). When designing the activity, it was assumed that different content viewed during the exploratory portion of the field trip would give groups different evidence upon which to draw conclusions, but for one learning quests to have such an outsized effect on a construct’s learning gains was not intentional. The full specifications of the models discussed here are included as Appendix A.

No significant differences based on quest completion were seen on the other constructs, but analysis of the “Ecological Mechanisms” construct revealed a significant relationship between reading ability and survey gains. On average, students below grade reading level gained 30 fewer points than their above grade reading level peers ($t = -3.03$, $p < 0.05$), while students on grade reading level gained 23 fewer points than their above grade reading level peers ($t = -3.25$, $p < 0.05$). Differences like this were not noted in pilot implementations of the activity, but this highlights an important design decision made by the EcoMOBILE team. Most content was presented to students via text to read rather than video or audio due to bandwidth limitations in the field. This decision may have inadvertently hurt students’ ability to process the information we presented to them, especially with the more terminology-heavy mechanism content.

Order of Content Viewed

Sequential pattern mining revealed four distinct patterns of quest activity students undertook during the exploratory period, and one sequence of quests correlated strongly with gains on “explaining reasoning” ($r = 0.64$, $p = 0.006$), “describing data” ($r = 0.57$, $p = 0.02$), and overall score ($r = 0.67$, $p = 0.003$). 33% of groups followed this path (Path A), completing four optional quests beyond the structured data collection. The only other common path that completed four optional quests (Path B) did not see similar associations with learning gains. Two of the quests were the same between the two paths, so the difference likely lies in the two quests that differ between the paths as well as the order that content was viewed.

The most obvious difference is that groups in Path B completed a quest that asked them to repeat the data collection procedure they had previously done at the beginning of the lesson but with a different variable to measure (i.e., collect dissolved oxygen measurements this time instead of turbidity readings). Groups who took Path A, however, saw more new content as none of their quests involved repeating the sometimes lengthy and laborious step of collecting data via probeware.

Discussion

One of the main goals in work like this is to identify why certain features had outsized or unintended effects and modify them for future work. Completion of the “What’s nearby?” quest that was associated with higher “understanding variability” learning gains is one such discrepancy. This quest asked students to look around them and consider what factors around the pond might influence their readings and/or contribute to a fish kill like they saw in EcoMUVE.

Students are also directly asked to recall what was in the vicinity of the pond in EcoMUVE and how it may have impacted the pond. This type of linking to past learning is not present in the other quests and it may have aided transfer sufficiently to forge stronger links between material in the two different activities. Students who chose not to complete this quest may have missed a valuable opportunity that wasn't present elsewhere.

One of the major affordances of AR's overlay of virtual information is that you can often "show" students information visually rather than "tell" them via text. In our current design, however, some content was gated behind too much text for average and low readers to process efficiently during the field trip. While this was done for practical reasons due to bandwidth issues mentioned above, this design decision hurt student learning. Future implementations of similar activities could use more pre-loaded video and audio content to rely less on textual information.

Groups that followed Path A completed the following four quests in this order: "Same or Different Challenge", "What's Under the Water?", "Let's Compare", and "WHY?". This order allowed groups to examine the variability of the data their class collected, showed them less salient features beneath the pond's surface that affect water quality, linked their current learning to prior knowledge from EcoMUVE, then had them reflect on the sources of the variability of their class' data. Path B, on the other hand, completed the following four quests in this order: "Same or Different Challenge", "What's Nearby?", "Collect Other Measurements", and "WHY?". In this sequence, learners learned about distant features in the watershed that may impact water quality before returning to do more data collection prior to reflecting. This flow aligned less well with our learning goals for the activity and was mainly the result of how different QR codes were set up around the pond to try and avoid muddy areas. Future field trips will consider the likely physical paths students will take when placing QR codes at the pond, ensuring all paths are equally likely to hit valuable content that can result in learning gains.

Conclusion

This paper will be of interest to designers of mobile augmented reality activities as well as science educators hoping to utilize similar activities on field trips. Designers must do their utmost to eliminate any factors that act as roadblocks for students exploring their activity to ensure all groups have enough time and accommodations to digest the content at their own pace. Additionally, content must be carefully evaluated to make sure that learners taking certain paths through the world will not miss critical information that allows them to achieve the activity's stated learning goals.

Acknowledgements

This material is based upon work supported by the National Science Foundation under Grant No. 1118530. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the author(s) and do not necessarily reflect the views of the National Science Foundation.

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Appendix A

Results of Multilevel Models

	Dependent variable:	
	Variation Gain	Mechanisms Gain
	(1)	(2)
Variation mid score	-0.383*	
	(0.213)	
Mechanisms mid score		-1.226***
		(0.173)
Completed What's Nearby Quest	26.061**	0.733
	(10.708)	(9.328)
Below grade reading level	-0.187	-30.357***
	(11.401)	(10.028)
On grade reading level	-2.091	-23.208***
	(7.822)	(7.149)
User Completed "Collect Data" Quest	-19.640	45.811*
	(27.316)	(26.285)
User Completed "Collect Other Measurements" Quest	-25.378*	-0.061
	(13.781)	(14.406)
User Completed "Let's Compare" Quest	-0.034	-0.122
	(8.810)	(8.173)
User Completed "Map and Graph It" Quest	7.018	-29.942
	(21.173)	(19.314)
Number of notes created	0.589	-0.804
	(2.263)	(2.266)
Male	-6.176	2.611
	(7.001)	(6.386)
Constant	38.790**	83.769***
	(18.129)	(15.118)
Observations	36	36
Log Likelihood	-120.882	-118.655
Akaike Inf. Crit.	267.764	263.310
Bayesian Inf. Crit.	288.350	283.896
Note:		*p**p***p<0.01