Utilizing Geo-referenced Mobile Game Technology for Universally Accessible Virtual Geology Field Trips

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Abstract

Declining interest and low persistence is well documented among undergraduate students in Science, Technology, Engineering, and Math in the United States. For geoscience, field trips are important attractors to students, however with high enrollment courses and increasing costs they are becoming rare. We propose in this concept paper that the contextualized learning and engagement of field trips can be simulated by virtual field trips for smart mobile devices. Our focus is on utilizing the geo-referencing capabilities of smart devices within spatially scaled educational games. This technology is increasingly ubiquitous amongst undergraduate students, and consequently is an untapped pedagogical resource. The objective of our games is to give students real-world experience in selected fundamental principles of geology. Set in Grand Canyon, each module features images of exceptional geologic sites illustrating these principles. Students navigate "downstream" using their devices' GPS and complete at least one interactive activity per location to progress to the next point. Student response to a pilot game suggests that this indeed is a viable method for making geoscience instruction engaging and enjoyable, and hopefully will result in greater motivation to pursue the geosciences.

Key words: Virtual field trip, Geoscience, Smart mobile device, GPS, STEM education, Educational technology.

Introduction

There is a well-documented and nationally reported trend of declining interest, low persistence, poor preparedness, and lack of diversity among U.S. students pursuing Science, Technology, Engineering, and Math (STEM) disciplines (e.g. Ashby, 2006; Fairweather, 2010; Seymour, 2001). In the case of geosciences, we suggest that a primary contributing factor is that introductory courses simply fail to inspire most students. Our experience as well as previous studies lead us to believe that field trips are often the most impactful component of lower division geoscience classes, and it is frequently hands-on field experiences that draw students into a geoscience major (Fuller, 2006; Kastens et al., 2009; McGreen & Sanchez, 2005; Orion & Hofstein, 1994; Tal, 2001).

Lower division introductory geoscience courses are typically taught in the form of a lecture and a complementary lab, not necessarily required to be taken concurrently, and commonly in large enrollment sections. Under such conditions, the ratio of students to instructors is high, which decreases the possibility of one-on-one interaction for each student and decreases the likelihood of a class field trip. High enrollment also increases the sense of student anonymity, consequently decreasing the students' desire to take ownership of their learning, and reduces the potential for inspiring students to pursue the subject. These large enrollment undergraduate classes that cannot manage field trips fail to provide students with the opportunity to experience planet earth "in the wild" and the practices of geologists as they work to understand it. In addition, students often are excluded from field trips because of their physical limitations.

The contextualized *physical learning* of field trips, of *being there*, has the potential to be simulated with everyday technology. Recent research suggests that virtual field trips can be conducted through the use of smartphones and tablet computers (McGreen & Sanchez, 2005), already existing in most students' hands. In this

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concept paper we propose that new applications (apps) for mobile devices be developed for virtual field-trips that will enhance undergraduate student learning in the geosciences, will be accessible to students of diverse backgrounds and physical abilities, and will be easily incorporated into higher education programs and curricula at institutions globally. With a draft game we present as an example, student responses after experiencing it suggest this approach will be helpful for attracting and retaining the next generation of geoscience students.

Background

Benefit of Field Experiences

Field trips have long been a part of students' educational experiences, particularly in Art, History, and Earth and Biological Science curricula. However, they are becoming increasingly more difficult to conduct at higher education institutions (McGreen & Sanchez, 2005). This difficulty is due to a combination of logistics and liability of travel, the high-enrollments of introductory courses, and decreasing financial and administrative support at government-sponsored colleges. Field excursions offer students opportunities to develop and practice the ability to distinguish features amid visual complexity and make scientific observations, identified as critical skills by Kastens et al. (2009). Field trips also provide primary experimental (hypothesis testing) experiences (Fuller, 2006; Orion & Hofstein 1994; Tal, 2001), analogous to the role of lab activities in physics and chemistry. This type of education has been called "contextualized learning" (McGreen & Sanchez, 2005), meaning that it occurs in rich physical environments filled with real-world connections and concepts.

The argument is that students retain more from a field trip than a classroom lab, and more in a lab than from a lecture for specific types of geoscience material. The teacher-student ratio and size of a lecture (often 100+ students) consistently outnumbers both a lab and a field trip (typically 10-25 students). Retention of material learned on field trips and in lab activities is possibly greater because these practical experiences fulfill the requisite components of contextualized learning introduced above (Kastens et al., 2009; McGreen & Sanchez, 2005). Research also supports the benefits in learning provided by models, visuals, and spatial-orienting activities, especially when these tools engage the learner and bring their attention to features they may have missed by simply reading text (Gobert, 2005). Spatial-orienting and illustrating tasks lead to deeper processing by structuring students' knowledge acquisition and result in greater long-term retention compared to summarizing (Gobert, 2005; Gobert & Clement, 1999). Together these findings indicate that a visual interface requiring spatial-orienting tasks provides improved learning and retention over traditional text-based pedagogical approaches and static lab exercises.

Utilizing Smartphones Instead of Banning Them-Gaming in Undergraduate Education

Advancements in communication technology have outpaced implementation strategies within higher education teaching methodology. This communication technology gap is steadily increasing between incoming freshmen and educators (e.g. National Higher Education ICT Initiative 2007; Perlmutter, 2011; PIALP, 2013). Closing the gap can only lead to more engaging and meaningful educational experiences as undergraduate students and the general public are more and more attached to mobile devices (Dahlstrom et al., 2011; Johnson & Johnston, 2013; PIALP, 2013).

Smartphones are visually engaging, portable, WiFi and GPS-enabled, and ever-increasingly ubiquitous. They have become valuable learning tools for the general public in informal settings, for young children, and individuals with disabilities. Smart devices are also used in community and classroom data-collection exercises through basic apps that leverage the use of their various built-in sensors. Examples include the iSeismometer that makes use of the iPhone's GPS and accelerometer to illustrate how seismic data is collected and the Theodolite app that makes use of the internal compass, inclinometer and GPS tools (Johnson & Johnston, 2013).

The use of smart mobile devices to simulate contextualized learning, drawing on technology already familiar to students, has been investigated. The results show that these tools allow students to concentrate on learning the material rather than how to use the equipment (Roschelle, 2003; McGreen & Sanchez, 2005; Clough et al., 2008). Geo-referenced, mobile-learning games (MLGs) can enhance student interest in introductory geoscience courses by providing the physical learning experience of field trips without added costs, accessibility and liability issues.

Our interest is focused on utilizing geo-referencing capabilities in a spatially scaled educational game analogous to the following examples. Benford et al. (2005) created a virtual game to teach young children about African

ecology called "Savannah". The researchers used GPS to gain positional information on players, the children, roaming around an open field that was spatially scaled down to represent a virtual African savannah. This geo-referenced activity enabled the children to role-play as lions while exploring the space looking for resources (game and water) to help them survive. Instead of being told about life in the plains of Africa, the children (lions) fought to stay alive (virtually) in the Savannah by successfully hunting prey. The authors believe their game was an engaging learning experience for the children, and also enjoyable in its physicality. Another example of geo-referenced gaming is in the work of Shelton et al. (2012) who recently examined the use of mobile devices for an educational math game (GeePerS Math) that targets deaf and hard-of-hearing K-12 children. The game is introduced as a superhero training program and the children are faced with word problems that are signed to them by an avatar in the game.

Players must solve the simple addition or subtraction problem in order to proceed to the next location and complete their mission. For example, "You saw six trees at the entrance, and took the path with four trees. How many trees did you pass in the forest?" The concept of exploring a virtual world to learn math was based on previous work that showed that virtual reality technology games improved the ability of deaf children to think flexibly and critically. Similar to Savannah, GeePerS Math generated positive feedback from teachers about the physical experience of the game, e.g.: "I really like that we have them up out of their seats moving" (Shelton et al. 2012).

Although games and/or mobile devices have been examined and used extensively for K-12, there is little known research addressing the cognitive elements of geo-spatial learning when applied as educational tools in undergraduate science courses. According to Squire and colleagues (2007), games and mobile games in particular are tools that enhance learning when designed and implemented effectively with curriculum and instruction. With the prevalence on college campuses of handheld devices such as smartphones, tablets and notebook computers (Dahlstrom et al., 2011; Johnson & Johnston, 2013), there is untapped potential for their use to explore virtual worlds in real geo-referenced outdoor spaces. Only a few years ago the majority of undergraduate students owned smartphones and tablets: today they are mostly ubiquitous (Clough et al., 2008; Dahlstrom et al., 2011; Johnson & Johnston, 2013; McGreen & Sanchez, 2005). Consequently, mobile devices have been attracting the attention of researchers and educators for their potential as learning tools for K-12 and in informal settings.

This technology provides new genres for learning, and mobile devices bring unlimited access to communication and technology. The accessibility allows a transition from occasional usage of a computer lab by a class to the frequent and integral use of portable technology in any setting. Educational games give students the opportunity to participate in "other worlds"; and evidence suggests that simulations increase motivation as well as teach problem solving strategies (Klopfer et al., 2003).

Game Design and Assessment Methods

Game Design

The MLG modules we are testing use geo-referenced mobile technology on both Android and iOS platforms to teach geologic concepts in the context of real world examples. Our goal is to enhance undergraduate student learning, engagement and retention in the geosciences through the design, creation, and implementation of a series of geo-referenced MLGs. Student engagement is targeted with the MLG modules through the use of real world examples and imagery, instant feedback on content, and hands-on interactive activities. In terms of content, the focus is on the "Big Ideas" of Geology and commonly held misconceptions about them (ESLI, 2009). The games are designed to be used as supplementary introductory laboratory exercises for Physical Geology, Earth System Science, and Historical Geology courses.

Each module was structured around a broad construct of introductory geology curriculum (Table 1), from which suitable locations within Grand Canyon were selected as virtual field trip stops. The questions and interactive touch-screen activities for these locations were written and refined by the authors as well as collaborating faculty from the MLG testing institutions. For each module a location map of all field trip stops and a storyboard of images, questions and activities was assembled for the development of the applications.

The geo-referenced MLG concept can specifically address the difficulty experienced by many students with spatial reasoning and spatial orienting tasks (Kastens et al., 2009), two critical skills in the geosciences. The MLG modules were created to virtually navigate downstream along a scaled-down Colorado River through

Grand Canyon – physically moving around in whatever real location the student is in using their smart phone or tablet (Figure 1). The program aims to assist students in learning spatial reasoning and orientation by becoming familiar with the use of a compass and map to locate themselves and actually move to each new location on foot or in a wheelchair.

Figure 1. Two students orient themselves. Inset A: screenshot of a question with playable video. Inset B: screenshot of a Grand Canyon location. Inset C: screenshot of basemap showing complete (orange) and incomplete (green) locations.

Curriculum Constructs

The Earth Science Literacy Initiative (ESLI) defined nine "Big Ideas" of Earth science that all citizens should know (2009). Following this publication, the Michigan Teacher Excellence Program (MiTEP) identified several commonly held misconceptions for each of these "Big Ideas" (Engelmann and Huntoon 2011). Based upon these "Big Ideas" and misconceptions, the pilot MLG module we present results of here considers Big Idea #2: "Earth is 4.6 billion years old" and the misconceptions that "geologic time can be described using hundreds of years" and that "rock layers are always flat" as the bases for creating a module addressing geologic time. A crucial objective of this module is to include the standard curriculum themes of relative age, the geologic column, and numerical age. Within this curriculum, the main focus is on relative age, which includes the subjects of stratigraphic principles, gaps in the rock record and fossils and correlation.

ESLI uses Grand Canyon as the real world example for this "Big Idea" because it is a famous geologic landscape that provides excellent learning opportunities and since it is frequently used as the example of stratigraphy and unconformities (gaps in the rock record) in introductory geology textbooks, it is an ideal game setting to teach these concepts. Following suit, the Geologic Structures and Surface Water Processes MLG modules under development are connected to ESLI's Big Idea #4: "Earth is continuously changing" and Big Idea #5: "Earth is a water planet" (Table 1).

The number of locations throughout Grand Canyon along the Colorado River are designed to fit the game module into a 30-minute time frame. In the game modules, at least one question per location must be answered in order to navigate down Grand Canyon. Correctly answering questions allows the player to progress down the Colorado River to the next location and exercise. Similar to rafting down a real river, this progression is a one-directional system and a player cannot "move upstream".

Table 1. Example Mobile-Learning Games

	Mobile-Learning Game Modules		
	Geologic Time *(pilot results presented here)*	**Geologic Structures** *(under development)*	**Surface Water Processes** *(under development)*
Constructs	Stratigraphic principles • Original horizontality • Superposition • Lateral continuity • Cross cutting relations Unconformities • Disconformity • Nonconformity • Angular unconformity Relative dating Numeric dating Human vs geologic time	Stress and strain (deformation) Folds • Anticline • Syncline Faults • Normal • Reverse • Strike-slip Measuring structures • Strike and dip Plate tectonics (as related to faults and folds)	Hydrologic cycle/hillslopes • Paths of precipitation • Overland flow Fluvial hydrology • Channel types • Hydraulic geometry Sediment transport • Entrainment • Types of load • Transport capacity Groundwater Human influence

Answering questions incorrectly triggers a pop-up explanation of the answer the student selected and the player is then returned to the question and remaining answers. Each time a question is answered incorrectly, the number of points that can be earned for selecting the correct answer is reduced, thus reducing the total score that can be achieved upon completion of the game. This feature provides instant feedback on content comprehension to the player and provides the opportunity to beat a previous score by replaying the game and answering the questions again (correctly) with fewer attempts. A second type of question in the game platform requires the students to examine a photograph and identify a specific geologic feature by tapping or swiping the feature on the touchscreen. This interactive element requires observation and critical thinking skill about the content and its application in the real world example of Grand Canyon.

Assessment Design

Assessment will be addressed through a pre- and post-intervention research design that leverages the validity of disseminating across several different institutions, instructors, and student populations. In addition to content evaluation, three instruments encompassing motivation, interest, and attitude (MIA) will be used. All three measures will be used at the beginning of the semester and after all the interventions are complete. Reliability in the form of Cronbach's alpha and confirmatory factor analyses will be conducted for all instruments with the data we collect.

We are also gathering data of tracked responses to activity questions during game play at collaborating institutions. These embedded items are checks of student understanding immediately after exposure to the content of the MLGs. Finally, demographics about students (ethnicity, gender, socio-economic status, etc.) and the institutions (4-year land grant, 2-year community college, private, etc.) will be gathered for use in a Hierarchical Linear Modeling (HLM) analysis.

Student Feedback on Pilot Game

Before finalization and formal testing of the three games described above, we received initial feedback from students using the prototype game on Geologic Time. These initial responses are shared here to provide insight into the strengths and weaknesses of the MLGs. Historical Geology and Physical Geology students (n=146) at Utah State University volunteered to play the prototype game module in the summer and fall of 2012 and spring of 2013. Students were briefed in the classroom with game-play instructions, and then proceeded to the campus quad outside to play "Grand Canyon Expedition: Geologic Time" in pairs. After game play students were asked to complete anonymous surveys and comment forms to provide feedback on the MLG module. The positive comments from the students' feedback forms are summarized in Table 2.

Table 2. Summary feedback from students on pilot MLG

Strengths
Outside

- Not in classroom
- Orienteering/exploring
- Walking/not stationary

Photographs

- Real world examples
- Not cartoons/drawings
- Like "actually" studying Grand Canyon

Interactive

- Working in partners
- Touchscreen
- Photos appear only once location is reached
- Feedback on wrong answers

Not writing

Positive commentary from the students was encouraging especially considering the objectives of increasing undergraduate student engagement and retention in the geosciences. The first of the positive feedback comments was simply the experience of being outdoors, for example:

"I like being able to walk around and orient myself with a map. It is great to leave the classroom."
In addition to several comments about "feeling like an explorer", it was clear that the use of cardinal directions and even the understanding of a GPS system for orienteering was embarking on unfamiliar territory for some students, for example: "I liked how the directions in the game were the same as the directions are here in Logan."

The second item, the use of real photographs to represent concepts in geology, also received positive feedback:
"I liked how it put what we were learning into real examples that had us out in the field as we would be if we were studying the canyon"
"I liked that it had real pictures and a game-like premise rather than drawing in a lecture-style class. It's always more fun to get up and move while learning"

The third positive aspect, the interactivity of the MLG, ranged from student to student for what interactive part they enjoyed, however a standout point is that some recognized the instant feedback component and felt its importance:
"I liked answering the questions and if you were wrong it would explain why."

Pilot survey results also indicated that students across the board (77%) gained greater confidence in their comprehension of the content covered in the game, on average having ranked themselves around 3 ("neutral") for initial familiarity and around 4 ("agree") for subsequent familiarity of the concepts (Figures 2 and 3). Broader challenges that we face include difficulties with screen visibility in full sunlight, playability in rainy and winter weather, cloudiness impacting GPS sensitivity, and varying GPS sensitivity across devices.
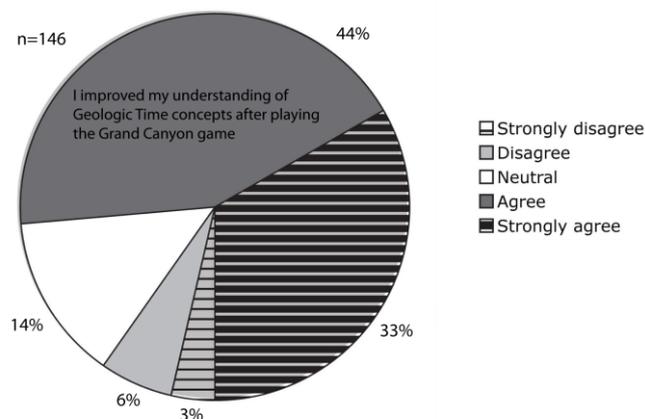

Figure 2. Results of students' (n=146) opinion survey for content comprehension post game play

Rank how familiar you are with the following concepts of geologic time. Mark each statement with your level of agreement (1 = strongly disagree, 2 = disagree, 3 = neutral, 4 = agree, 5 = strongly agree)	1	2	3	4	5
I am familiar with and can define "angular unconformity"			● → ●		
I am familiar with and can define "nonconformity"			● → ●		
I am familiar with and can define "disconformity"			● → ●		
I am familiar with and can define "index fossils"		● → ●			
I am familiar with and can explain "numerical age vs relative age"			● → ●		
I am familiar with and can define "principle of superposition"			● → ●		
I am familiar with and can define "principle of original horizontality"			● → ●		
I am familiar with and can define "principle of lateral continuity"		● ——→ ●			
I am familiar with and can define "principle of cross cutting relationships"			● → ●		

Figure 3. Results of the students' self-assessment survey of geoscience concepts showing average of responses before game-play in grey to after game-play in black (n=146).

Discussion and Conclusion

Field trips have been well established as a successful method for engaging students, but they are increasingly becoming prohibitive. As geoscience educators look for solutions to the declining enrollment at institutions of higher education, mobile games have the potential to be engaging and instructional when combined into virtual fieldtrips. Early feedback from our prototype testing suggests that this approach of virtual field trips using mobile smart devices does enhance student engagement within large enrollment classes. This project presents geo-referenced MLGs set in Grand Canyon as a relatively affordable and highly accessible means for geoscience educators to leverage the smartphone technology already in use by students in a way that aligns with existing curriculum.

We have refined all the MLGs with collaborating instructors from a range of higher education institutions across the country and are testing the modules in classes at the collaborating institutions spanning a diversity of student backgrounds from community colleges to private universities. These MLG modules will all be evaluated with pre and post content and MIA assessment. The large datasets arising from this study will be subject to statistical (HLM) analysis that will include an examination of the correlation between students' demographics and their learning gains.

The results of our early assessments are positive and encouraging for increasing student engagement, especially considering the overall enjoyment of learning with mobile technology despite the buggy operability of the pilot module. Most students found the experience enjoyable and felt it helped them improve their comprehension and understanding of the curriculum, suggesting that this tool allows students to concentrate on the content of the game instead of using cognitive effort to deal with how to play it. Thus educators can take advantage of learning with technology rather than from technology by integrating mobile devices into their teaching (Campbell et al. 2010). This finding is very encouraging for our pilot in that it indicates we have a viable method for enjoyable and engaging undergraduate geoscience education that has the potential to increase engagement and retention by merging students' highly digital and mobile world with their college education. In essence, it helps by closing the existing communication technology gap described earlier. It is an initial step in developing innovative pedagogy that utilizes powerful tools students are already intimate with in order to make first-year STEM courses more engaging and interactive and to make world-class field trips accessible to all.

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