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Experiential Learning in Soil Science: Use of an Augmented Reality Sandbox

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ABSTRACT

Active participation in science, technology, engineering, and math (STEM) courses maximizes learning while novel technologies allow instructors the opportunity to create interactive activities in the classroom. With this in mind, we incorporated the use of an augmented reality (AR) sandbox at the University of Wyoming to facilitate an experiential learning experience in soil science. The AR sandbox was developed by researchers at the University of California-Davis as part of a project on informal science education in freshwater lakes and watershed science. It is a hands-on display that allows users to create topography models by shaping sand that is augmented in real-time by colored elevation maps, topographic contour lines, and simulated water. It uses a 3-dimensional motion sensing camera that detects changes to the distance between the sand surface and the camera sensor. A short-throw projector then displays the elevation model and contour lines in real-time. Undergraduate students enrolled in the Introductory Soil Science course were tasked with creating a virtual landscape and then predicting where particular soils would form on the various landforms. All participants reported a greater comprehension of surface water flow, erosion, and soil formation as a result of this exercise. They also provided suggestions for future activities using the AR sandbox including its incorporation into lessons of watershed hydrology, land management, soil physics, and soil genesis.

Core Ideas

- Greater learning occurs when students are active participants.
- An augmented reality sandbox belongs in the soil science classroom.
- Experiential learning increases student engagement.

Studies show that greater learning takes place in science, technology, engineering, and math (STEM) when students are active participants in their learning (Freeman et al., 2014). Researchers uncovered that a primary reason students leave STEM fields within the first couple of years of higher education is poor teaching (Seymour and Hewitt, 1997). Traditional lectures and readings are not engaging student interest. Studies show, however, that active participation in STEM courses maximizes learning (Freeman et al., 2014). One way in which this learning is enhanced is by engaging in a cycle of practice and feedback (Ambrose et al., 2010). Participating in an activity and observing the outcomes, provides feedback that guides further practice and understanding.

Active learning through the use of multisensory techniques can also help with retention of learning. For example, when a student interacts with information both visually and kinesthetically, information in encoded differently in the brain than through passive listening (Persellin and Daniels, 2014). The acquisition of information through a variety of senses allows the brain to encode information and store memories more deeply (Persellin and Daniels, 2014).

In natural resource and environmental sciences education, this often involves field visits to examine phenomena in the natural setting and explore parameters that influence these features (i.e., climate, geomorphology, geologic material, organisms). Field visits, although ideal, are not always feasible for many reasons including cost, time constraints, inclement weather, and scheduling difficulties, among others. Therefore, alternative interactive activities can help increase student engagement and retention in the classroom and laboratory. Bearing this in mind, we incorporated the use of an augmented reality (AR) sandbox in the Introductory Soil Science course (SOIL 2010) at the University of Wyoming to facilitate an experiential learning experience in soil science. As a relatively new technology, the effectiveness of using AR in a soil science classroom has not yet been examined (Reed et al., 2014).

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Abbreviations: 3D, 3-dimensional; AR, augmented reality; KeckCAVES, W.M. Keck Center for Active Visualization in the Earth Sciences; STEM, science, technology, engineering, and math; Q, question.

Augmented Reality Sandbox

The AR sandbox was developed by the University of California-Davis W.M. Keck Center for Active Visualization in the Earth Sciences (KeckCAVES) as part of a National Science Foundation funded project (Grant DRL 1114663) on informal science education for freshwater lakes and watershed science (Kreylos, 2016a). The AR sandbox is a hands-on display that allows users to create topography models by shaping sand that is augmented in real-time by a colored elevation map, topographic contour lines, and simulated water. It uses a 3-dimensional (3D) motion sensing camera (Microsoft Xbox Kinect) that detects changes to the distance between the sand surface and the camera sensor. A short-throw projector then displays the elevation model and contour lines in real-time. In addition, the developers created a rain feature that is initiated when the user holds an object such as his or her hand at a certain height (Kreylos, 2016b). Water will then flow across the landscape as it would in the natural environment. Features including flood, drain, lava, and snow are also available (Lake Visualization 3D, 2016).

Many AR sandboxes (>150) have been created using the original model developed by LakeViz3D and are in museum settings, while others are incorporated into university-level learning environments (Lake Visualization 3D, 2016; Reed et al., 2016). Students enrolled in physical geology at East Carolina University use the AR sandbox to explore natural water movement on the land surface across drainage basins (Woods et al., 2015). At the University of Redlands, geology and natural disaster courses incorporate the AR sandbox to decrease barriers to spatial learning and help students understand topography (Jenkins et al., 2014).

In soil science education, as in all geosciences education, hands-on experiential learning is critical to enhance student learning and comprehension. The objectives of this study were (1) to incorporate an AR sandbox laboratory module into an introductory soil science course to encourage students to explore and think critically about soil formation across different landscapes and landforms, and (2) to assess the impact of using an AR sandbox on student learning through a qualitative survey.

METHODOLOGY

Augmented Reality Sandbox Construction

An AR sandbox was constructed for use in the Introductory to Soil Science laboratory at the University of Wyoming (Fig. 1) (Kreylos, 2016b; Lake Visualization 3D, 2016). Following available guidelines, a 76 by 102 by 23 cm (30 by 40 by 9 inch) box was built to house the sand and support beams constructed to hold the 3D camera (Microsoft Xbox Kinect) and short-throw digital data projector (Optoma W303ST) (Kreylos, 2016b; Lake Visualization 3D, 2016). A computer running Linux with a Nvidia GeForce graphics card is dedicated to the sandbox. Software to create the visualization was created by KeckCAVES (2016) using open-source virtual reality development toolkit for 3D graphics applications. Features to flood and drain the sandbox were programmed and initiated by using the F and D keys, respectively, on the associated keyboard and were based on the Saint-Venant shallow-water equations (Kurganov and Petrova, 2007; KeckCAVES, 2016).

Student Laboratory Module Development

Undergraduate students enrolled in the Introductory Soil Science course at the University of Wyoming during spring 2016 were asked to voluntarily complete a laboratory module centered around using the AR sandbox (Fig. 2). The goal of the module was to improve understanding of landforms, landscapes, and the soils that form in these diverse locations. Learning objectives for the module include the comprehension of watersheds, topography, erosional and depositional processes, and soil genesis (Table 1). The

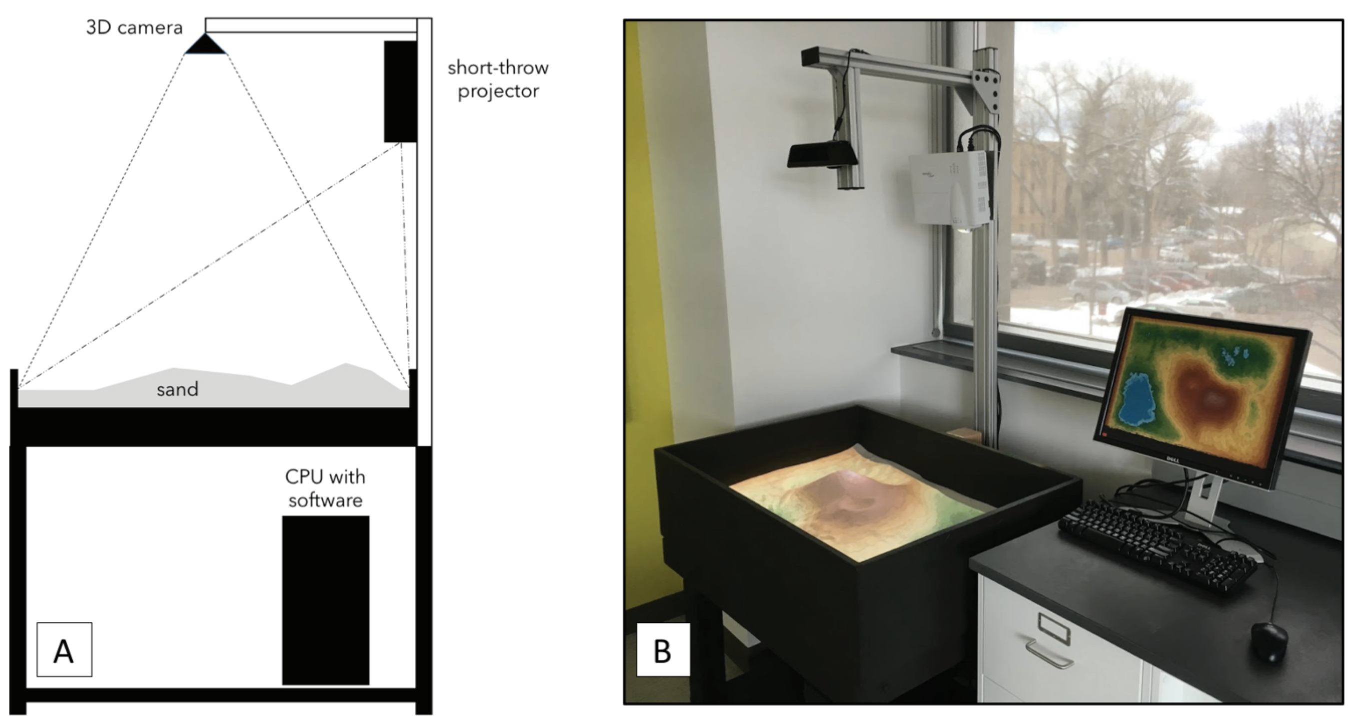

Fig. 1. Diagram of an augmented reality (AR) sandbox (A) and the AR sandbox in the Introductory Soil Science laboratory at the University of Wyoming (B).

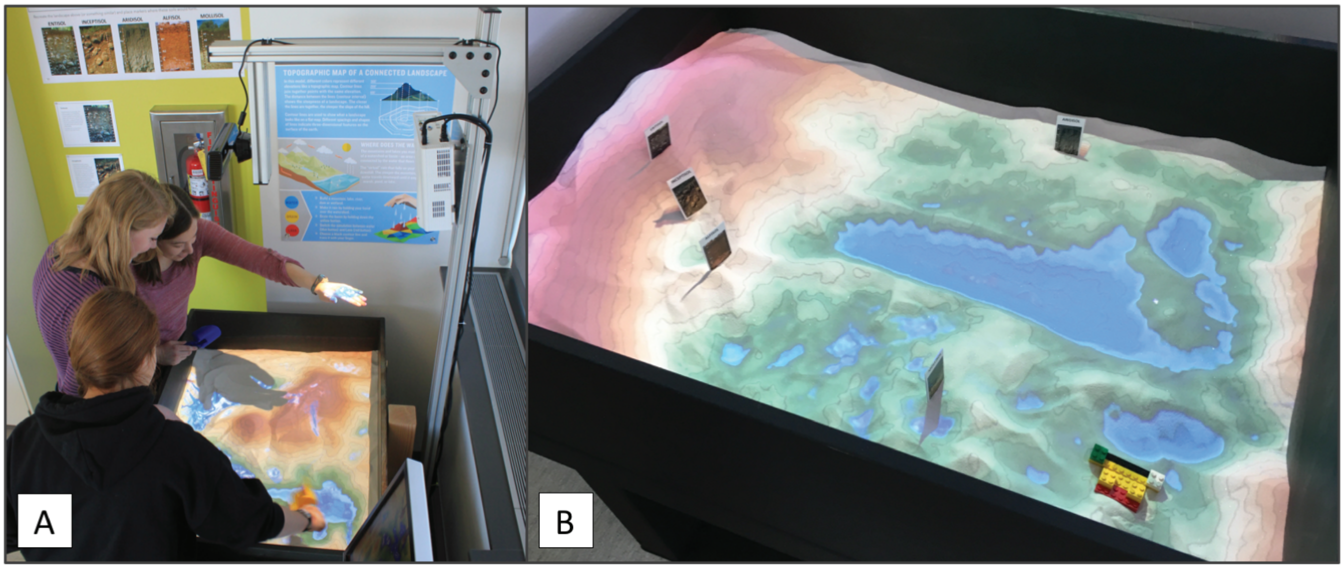

Fig. 2. University of Wyoming undergraduate students participating in the augmented reality sandbox laboratory module (A) and a landscape created by the students with locations of different soil orders shown using markers (B).

module was composed of two parts, with the first allowing time for the students to explore the functionality of the sandbox including the rain, flood, and drain features, as well as the real-time topographic map rendering. The second part involved the students recreating a theoretical model of the landscape between Medicine Bow Peak (3662 m) in the Medicine Bow–Routt National Forest and the town of Laramie, WY (2184 m), and identifying the locations where five soil orders (Entisols, Inceptisols, Aridisols, Alfisols, and Mollisols) would likely form in that landscape. Small, 2.5 by 5 cm (1 by 2 inch) soil profile images labeled by soil order were used as markers the students could insert into the sand surface to indicate where the soil order would form. Students worked in groups of two to four and were encouraged to discuss and work together to develop their best theory of soil formation across the landscape.

After the student groups completed the second part, they described their reasoning behind the placement of the soil order markers to the instructor. Discussion was encouraged to ensure comprehension of the soil-forming factors involved. The students received extra credit for completing this voluntary lab module and therefore were required to answer a series of questions to gauge their comprehension and involvement in the exercise (Table 2).

Assessment of Student Learning

To examine the efficacy of student learning using the AR sandbox, a qualitative survey consisting of the following survey questions were administered to the students after participating in the module (Table 3). Student survey responses were anonymous and voluntary. Data were analyzed for salient themes. This procedure involved reading each transcript multiple times for context, identifying key words and metaphors, developing descriptive codes, listing possible meaning units, and developing thematic descriptions of patterns in the meaning units.

Table 1. Learning objectives for the laboratory module entitled: Incorporation of Experiential Learning in Soil Science Education: Use of an augmented reality sandbox.

	Learning objectives
1.	Understand watersheds, how water flows across the landscape, and how flow relates to land surface elevation and shape.
2.	Understand topographic maps and the use of contour lines to show the earth's surface in 3 dimensions.
3.	Create a 3-dimensional model from a topographic map.
4.	Understand how the earth's surface changes through natural processes including erosion and deposition.
5.	Explore erosional and depositional processes.
6.	Understand about how landform, landscape position, and elevation influence soil genesis.
7.	Be able to predict where soils are located based on landform, landscape position, geomorphology, and elevation.

Table 2. Questions assigned to gauge student comprehension and involvement in the augmented reality sandbox exercise.

	Questions
1.	What did you notice about the flow of water?
2.	What areas on the land surface that you created are more likely to erode? How do you know this?
3.	What types of soil would you expect to form in these easily erodible areas?
4.	Where would this eroded material accumulate?
5.	What types of soils would you expect to form in this zone of accumulation?
6.	Given a set of soil types (use at least 4 of the markers provided), place them in locations where they would likely form. Draw a cross section of your 3D model and label where the soils would form and why.

Table 3. Survey questions administered to students after participating in the augmented reality sandbox module. Instructions provided stated: *Please circle or write in answers to the following questions*.

Survey questions
1. What year are you at UWYO? a. freshman b. sophomore c. junior d. senior
2. What is your major?
3. Have you used an augmented reality sandbox before? a. YES, where? ______________________________ b. NO
4. Have you previously taken a geomorphology course? a. YES b. NO
5. Did interacting with the augmented reality sandbox improve your understanding of where soils form in the landscape? If so, how?
6. Did interacting with the augmented reality sandbox improve your understanding of water flow in the landscape? If so, how?
7. Would you recommend this lab activity to be used in future labs? Why or why not?
8. Do you have any suggestions for how the augmented reality sandbox can be incorporated into the classroom or lab?

RESULTS AND DISCUSSION

The results from the qualitative survey revealed that participants (n = 45) ranged from freshmen-level through senior-level standing at the university (2 freshmen, 14 sophomores, 17 juniors, and 12 seniors). Students from 11 majors participated in the laboratory module with the majority from rangeland ecology and watershed management (27%), agroecology (13%), and agricultural education (13%). Sixty-nine percent of students surveyed had never interacted with an AR sandbox, whereas 31% had used the one on display at the University of Wyoming Geological Museum. Only 4% of respondents had previously taken a geomorphology course.

In response to survey question 5 (Q5), which asked, "Did interacting with the AR sandbox improve your understanding of water flow in the landscape? If so, how?," 75% of respondents answered yes to the above question and provided comments including those listed in the supplemental material. Two major themes were derived from their responses: (1) visual learning and (2) topography.

Visual Learning

Nine of the respondents specifically mentioned appreciating the visual learning that took place. They were able to physically see the movement of the water as they changed the topography. One participant explained, "I was able to physically see the flow of water over the landscape."

Topography

Several participants mentioned that their understanding of slope and elevation was improved by manipulating the landscape. For example, "It really makes you think about how the water flows relative to the elevation and slope." Or, as another participant stated, "The ability to change the topography and make water flow on it in an instant gives a better understanding of different types of slope."

Sixteen percent of respondents stated no to Q5, but commented generally that they already had a good comprehension of water flow from previous courses. Nine percent responded with either somewhat or "a little" but followed with comments including "…it reinforced my knowledge growing up where I did, I dealt with water and hills a lot," and "It showed places that were more susceptible to drought when drained." Statements such as these show a connection to the interactive tool and the ability to comprehend these processes more holistically.

One of the goals of the AR sandbox module was to improve understanding of soils that form in diverse locations. To evaluate the effectiveness of this exercise, Q6 asked respondents, "Did interacting with the AR sandbox improve your understanding of where soils form in the landscape? If so, how"? The overwhelming majority of the respondents (96%) stated yes and provided comments listed in the supplemental material. These comments are predominantly supportive of two themes: (1) visual learning and (2) environment.

Visual Learning

As in Q5, the opportunity to physically see changes by manipulation the sandbox was mentioned as a useful way to further understand concepts. One student summarized by stating, "Watching how moving one thing changed something else was more explicit than just talking about it." Another student mentioned, "It helped me to visualize the differences in environments that each soil forms in and be able to put it all in to memory."

Environment

Several students mentioned that manipulating the sandbox helped them understand the role of environment in soil formation. Altering the elevation, observing erosion, and creating hills or grasslands furthered understanding. One participant stated, "It brings pictures to life and helps me understand how the environment plays into soil formation." Or as another student stated, "It helped me further develop where I could help to find the soils. The hands-on activity really helped."

The notion that the AR sandbox activity was useful in visualizing where and how soils form on the landscape is powerful. Most respondents appreciated the hands-on nature of the activity and the connection to a local environment to predict soil development.

In Q7, participants were asked if they would recommend this lab activity to be used in future labs. All but one student responded emphatically that they recommend using the AR sandbox in future lab activities (see supplemental material). In general, respondents stated the exercise was hands-on, interactive, and entertaining, all while helping them to better grasp the concepts covered in lecture.

To facilitate future learning scenarios, students were asked in Q8 to provide alternative suggestions for how the AR sandbox could be incorporated into the classroom or lab. Several students responded that it should be made into a longer lab activity or one that recurs throughout the semester as learning progresses (see supplemental material). Others provided suggestions for future use including its incorporation into lessons on watershed hydrology, erosion, and soil water. Some respondents suggested adding features including snow, soil permeability, and crop suitability.

CONCLUSIONS

The incorporation of an AR sandbox in entry-level soil science education has proven beneficial in terms of increased student-led learning, enhanced interest in and connection to subject matter, and improved engagement in connecting complex topics. The sandbox allows users to have fun in a 3D environment while learning topics traditionally learned in lecture, textbooks, and the field. Students were enthusiastic about this activity, enjoyed the learning experience, and would recommend its use in future labs. Although this study does not predict future retention, it does show excitement for learning about soil science in an entry-level course that could result in greater retention. A limitation of this study is that it provided self-reported learning only. Further studies measuring test scores with a control group would reflect measurable learning.

Future scenarios will allow us to use the AR sandbox in the laboratory before taking students into the field to learn soil morphology and genesis. We anticipate enhanced learning when students comprehend processes prior to working in real landscapes. The AR sandbox could be incorporated into many different learning environments, such as pre-K-12 education, extension activities, and upper division soil and landscape analyses courses. Another powerful use for the AR sandbox is science communication where scientists can communicate their research to the public, land management agencies, policymakers, and funding agencies. Instructions to build an AR sandbox and forum discussion pages are available online for those interested in building an AR sandbox (Kreylos, 2016b).

SUPPLEMENTAL MATERIAL

Select survey responses to qualitative survey questions that represent common themes throughout the augmented reality sandbox laboratory experience in soil science.

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