Designing around preconceptions in earth science

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Abstract: *This paper describes the evolution of an informant-based design workshop for the teaching and learning of Earth Sciences in a Singaporean Secondary 1 school. Data collected from three earlier workshops were analyzed to uncover students' preconceptions about earth science and to elicit their suggestions, which guided the design of a fourth workshop that addressed these preconceptions. Informed by a distributed cognition perspective where knowledge is shared across people and artifacts, the workshop was designed to engage the informants in an authentic learning experience which involved them in activities such as fossil excavation, rock analysis and plate tectonics simulation. Ideas from these workshops were analyzed and synthesized for the development of a 3D computer game called Voyage to the Age of Dinosaurs.*

Introduction

Students come to the classroom with a set of preconceptions on how the world works, some of which are inaccurate. Studies have shown that through the observations of everyday phenomena, such as the rising and setting of the sun and moon, students can form preconceptions that may later cause difficulty in acquiring new knowledge. When learning complex topics such as plate tectonics, scientific data is often reduced to critical events, thus causing more misconceptions among students during the learning process. Within the Singaporean school context, teachers have reported that, due to syllabus and time constraints, many topics within the syllabus could not be covered in depth: a situation which compounds the opportunities for misconceptions to occur.

To address learner misconceptions, several instructional strategies have proven helpful. One strategy, called "bridging"(Brown, 1989), attempts to bridge students' correct beliefs to their misconceptions, by helping students construct a coherent view of the problem through probing their beliefs, and guiding them to resolve any conflicting views. Another effective strategy is interactive lecture demonstrations, in which students are asked predict the outcome of an experiment. The experiment is then conducted, followed by a class discussion about the predictions and in particular focusing on the misconceptions that surfaced in the predictions. Through discussion and hands-on demonstration, students acquire a better understanding of the subject (Sokoloff & Thornton, 1997).

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While traditional approaches to learning frequently emphasize memorization of facts, contemporary researchers are looking into empowering students to take control of the learning and make it more meaningful. Meaningful learning occurs when the students can comprehend and find relationships among the various clusters of knowledge that they have acquired; it's a constructivist approach to learning, which advocates that learners themselves have the ability to create knowledge. Teachers provide guidance to the students when necessary to encourage further inquiry (Packer & Goicoechea, 2000).

You can view students as taking on an apprenticeship role to learn from an expert, and in many cases teachers play this "expert" role. The goal is to teach the apprentice complex tasks with an emphasis on solving real-world problems. This gives the apprentice opportunities to pick up skills within the context of the real world. But in order for this to happen, the learning environment has to change from the traditional classroom approach to one that can help the student-apprentices observe, enact and practice the skills. The situated learning perspective suggests that learning environments need to be designed to give students chances to solve real world problems (Lave & Wenger, 1991).

However, it is often not possible to provide the learners with a situation that adequately simulates the context of the subject to be learnt. For example, the geological concept of plate tectonics is difficult to visualize solely through text and images presented in a textbook, and the problem is further compounded by students' own varied preconceptions of how the earth system works. Fortunately, scientific visualization is now possible with the use of personal computers; through the use of immersive multi-user virtual learning environments, students can collaboratively explore different scenarios, simulating environments that would otherwise be impossible to re-create in real life, or in a traditional classroom environment (Barab, et al., 2007). Our project has been to try to reap the advantages of two approaches: to combine the world of the computer game with low-tech real world learning activities.

Designing the workshops: A Voyage to the Age of Dinosaurs

We used an informant-based approach to design a series of workshops that elicited the students' preconceptions on specific topics in Earth Sciences, and then involved students to help design a multi-user computer game that we hope will engage them in learning Earth systems science through the popular theme of dinosaurs. For this study, we are working with Singapore's Secondary 1 (equivalent to US Grade 7) level geography curriculum, although the contents of the game are not limited to the contents of the syllabus. Previous research has drawn attention to the difficulties young learners experience in building a concept of the Earth as a complex system. Understanding the earth as a constantly-changing, dynamic and complex system is difficult because of the human scale of our immediate, day-to-day experiences of Earth's phenomena, which is one of the critical barriers to understanding in earth science (Gobert, 2000).

In the computer game, Voyage to the Age of Dinosaurs (VAD), we use dinosaurs as a main conceptual anchor as we believe it provides a motivating context for students in learning geography concepts. The activity of finding fossils can convey the concept of weathering, and the location of fossil finds conveys facts about plate tectonics. Among fossils, dinosaur bones are the most compelling to bring to our consciousness the massive scale of geologic time and the Earth's processes. Therefore, this project approaches the topics of Earth's processes with a focus on fossils and fossilization, which has the potential to provide learners with alternative ways of experiencing Earth processes as part of a complex whole.

One key innovation of our study is how we involve our student-informants as active participants in the design and development of a 3D multi-user virtual environment. Our aim was both to provide an alternative environment for the learning of Earth Sciences and to change the role of students, from passive recipients of knowledge to learners who actively contribute to the design and development of knowledge. The creation of VAD involves a series of workshops designed to engage the learners as active participants in the game development process. To date, we have conducted 5 workshops with 20 participating Secondary 1 students from two schools.

Workshop 1: Learners' Earth Science Concepts

In the first workshop we sought to uncover and analyze student preconceptions about earth science. We conducted interviews in small groups of three to four students, with one facilitator. First, we presented the group with a picture of a dinosaur fossil (Mesosaurus), and asked the informants to describe the possible life, death and fossilization of the creature and to explain how it could be found in two different continents. They were also asked to draw, write and describe what would happen if the Earth were sliced in half, and describe what they understood about volcanoes, including geological processes and plate tectonics.

The students associated the formation of fossils with catastrophic death, such as being killed in a natural disasters or being attacked by predators. The students were unclear about the structure of the earth and related processes, such as plate tectonics and continental drift. Terms were often used interchangeably and occasionally in the wrong context within the discussion. Students also described volcanoes as mountains with lava inside, and had the common perception that volcanoes are all conical in shape.

Not surprisingly, we found that teachers, parents and the media were the main sources of information for our students. We also observed that some students in this workshop were careful to give only answers that they thought were factually correct, citing teachers and textbooks as their sources.

Workshop 2: Learners' Stories and Voices

The second workshop was held over two days. On the first day, students were brought to the Singapore Science Center, which had an ongoing dinosaur exhibit and a dinosaur-themed movie in the immersive large-screen Omni Theatre. The Centre exhibited mechanized life-sized dinosaurs, which situated the students in a simulation of a period when dinosaurs still roamed the Earth. Students were then asked to create a scenario that could be incorporated into a computer game. Student stories focused on themes of dinosaur death and fossilization, spectacular earth processes such as earthquakes and volcanic eruptions, and fights between specific dinosaurs.

On the second day of the workshop, the students were brought to the Evolution Garden at the Singapore Botanical Gardens where they had the opportunity to explore earth's history of early plant life through a walkabout exhibit. The students were then brought back to the National Institute of Education (NIE) so they could enact and film a movie based on the story they created the previous day. They were free to use any materials they wanted; we provided them with movie cameras and props, such as miniature dinosaurs and backdrops.

Our purpose was to bring the students out of the classroom so that they could express themselves more freely. Although they were uncomfortable initially, they later became more expressive. The workshop foregrounded their playfulness with ideas and representations, as they used resources beyond the language and geography terminology of the classroom. This was demonstrated especially by a group of 4 students who called themselves T-Rex. While they were quite reserved on the first day of the workshop, T-Rex became very creative in their movie production, in which they shook the camera to represent an earthquake and used a red raincoat to simulate lava flow during a volcanic eruption.

Workshop 3: Prototype game play

The purpose of the third workshop was to solicit feedback from the informants on the prototype of Voyage to the Age of Dinosaurs, version 1.0. We collected the students at one of the participating schools and invited them to test our prototype of the game, as well as two other dinosaur-themed games. The students were asked to evaluate the two pre-existing games, and to design their idea of "the hottest game in town." Then we asked them to discuss VAD v1.0 and to raise any issues or features they would like to be modified. The students' suggestions reflected current trends in computer gaming such as missions, genres, characters, props, rules and reward systems for the game. We tried to incorporate student suggestions in subsequent versions of VAD in generative and educative ways.

Workshop 4: Embodiment of computer game elements

Workshop 4 was focused on 3 areas that linked earth science and dinosaurs: (i) rock types and rock formation, (ii) plate tectonics and landforms such as mountains and volcanoes, and (iii) paleontological fossil excavation. In this workshop, students in their small groups were rotated through 5 stations in ways that roughly mimicked the game play of VAD v.2.0. We wanted to find out how these activities could be useful for students' learning in their own right, and apply these designs to day-to-day teaching and learning in classrooms.

Workshop 4 took place at NIE, once again removing students from their classrooms. This was partly to free them from the subordinate role of students, and partly for our own convenience in setting up all the equipment involved. They began by using compasses to navigate to a forested area, which contained traces of dinosaurs - their eggs. Students collected the eggs and when they opened them found directions to the fossil-digging station, which was manned by a real-life paleontologist. There they used small picks and chisels to excavate small plastic dinosaur skeletons from a plaster matrix. Once they had assembled the bones they were directed to a laboratory where they examined rock specimens under dissecting lenses, with the assistance of a facilitator who helped them learn about the types of rocks, their characteristics and the rock cycle. Students then went to the Plate Tectonics and Volcano site where they pieced together 2D maps of the Earth, which had been sliced into its tectonic plates. Students modeled the mechanics of plate tectonics by manipulating different colored slabs of Jello towards each other in a tray over a candle flame, which melted the lowest layers of Jello into a liquid "magma." They squashed the Jello layers together to force the magma to erupt through the upper layers like a volcano. Finally, they went to the computer laboratory where the students played VAD v.2.0. After all students had completed the rotation, we kept them in small groups and debriefed them on their experiences during the day. We also solicited their ideas for improving the computer game in its next iteration.

Our design of Workshop 4 stemmed from our desire to make the virtual world of the computer game more physically real to the students, and also from our realization that further development of the computer game would take much longer than we had hoped. But we also designed Workshop 4 as a physical embodiment of the game because we learned in previous workshops that students liked more hands-on, interactive, experiential learning episodes, and that these could embody geological concepts better than a 3D immersive computer game. Our hope was that students' physical connection to these elements of geology and paleontology would compel their intellectual and emotional involvement in learning.

How exactly did Workshop 4 address the student preconceptions we had discovered in previous workshops? The navigation and dinosaur-egg collection activity echoed the students' stories that they filmed about dinosaur fights. Finding their way through the forested ecosystem in which dinosaurs thrived was the focus of this activity, and allowed them to enact the role of hunter.

In the fossil digging activity students could enact the role of paleontologists in a situated learning environment involving the tools and dirt of a real dig. The presence of a real paleontologist lent authenticity to the activity and helped to position the students as apprentices, learning how actual excavation of dinosaur fossils is a delicate process. Students took this opportunity to ask the paleontologist questions about the dinosaurs and fossils that they encountered.

The concept of plate tectonics is difficult to convey to students both because of the scale of events and because, while students understand the notion of the tectonic plates as a jigsaw puzzle, their grasp of what causes the puzzle pieces to move over the outer mantle of the earth is very weak. For instance, the students' primary conception of a volcano is that of a 'mountain', and a 'container' metaphor, in which magma/lava is the liquid that fills the 'container,' and volcanic eruption is an outcome of exceeding the capacity of the container - an 'overflow.' To convey the difficult concept that rocks actually melt and become liquid under conditions of intense heat and pressure, we modeled tectonic plates in Jello, and had students push them together over a heat source; the bottom layers of the Jello melted; the upper layers folded, deformed, and mimicked subduction and mountain formation processes; when students continued to provide pressure, the Jello "magma" forced its way up and out of vents through the solid layers above. The hands-on approach helped students appreciate the different states rock can achieve. The different colors of the Jello "plates" showed which layers were melting and deforming, and allowed the students enacting mountain formation to appreciate better the forces at work in plate tectonics and rock formation.

We have found that students' understanding of rocks and the rock-cycle, along with their relationships to the Earth's processes, remain thin. They made minimal conceptual links between fossils and rocks. In Workshop 4, we sought to present the study of rocks as science, allowing the students to exercise scientific thinking by hypothesizing and categorizing the rocks they were presented with. So we provided microscopes not only to enable magnified examination of rocks, but also to signal to the students that the study of rocks was a scientific endeavour, instead of facts to be remembered from the textbook. We presented students with the task of classifying rocks as either fossil-bearing (sedimentary) or non-fossil-bearing (metamorphic and igneous) rocks, based on their observations of different rock samples. The facilitator of the activity played the role of the mentor in 'uncovering' the names, categories, characteristics and formation processes of the different rocks, and also the possible ways in which fossils could have been preserved in some rocks. Thus, we designed to allow students to 'enact' geological and paleontological work as apprentice geologists. Later we received positive feedback from the teachers about high levels of student interest and engagement at this station, compared to ‘normal’ classroom lessons.

Conclusion

Our approach in designing Workshop 4 was to address student preconceptions in Earth science by incorporating as many student suggestions as possible into the computer game, Voyage to the Age of Dinosaurs, and then embodying the different sequences of that game in ways that allowed students to act as either experts or apprentices in the physical world. Students reacted positively to being part of the scientific process and to their guidance through selected types of scientific discovery. They gave us plenty of suggestions for future development of the computer game in VAD 3. Interestingly, no student suggested that more quizzes be added to the game, or that overt tests of knowledge play any role in it; instead, they advocated adding a shop and trading system, as well as more specialized avatars. It seems that our process of eliciting student preconceptions and listening to student voices has made our students eager to take more control of their destinies, at least as far as the computer game is involved. We hope that this extends to their learning in general, and that our workshop design process helps in the process of making students more engaged in their own educations.

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