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ABSTRACT

Information systems can contribute to the success of students in engineering and science. In this study, 3-D visualizations that create a realistic map of rock structures are used to aid students in developing the spatial intuition to understand geological processes. This technology received positive ratings for learning outcomes and within the technology acceptance model. In addition, qualitative data provides additional detail about what features are correlated with the success of direct manipulation visualizations. The qualitative data suggest that the interface design may be a moderator of the relationship between the completeness of the visualization and how much individuals can benefit from the visualization.

Keywords

geospatial information systems, visualization, human-computer interaction

INTRODUCTION

Visualization is a important concept in outcomes in science, technology, engineering, and mathematical (STEM) fields, including undergraduate and graduate major and occupation after graduation (Humphreys, Lubinski, and Yao, 1993) . For this reason visualization skill is encoded in standards for STEM related curricula; see e.g. Yore, Pimm, and Tuan (2007). For example, they can be directed towards interaction between collaborators or as metacognitive tools for the individual (Avouris et al, 2003). Libarkin and Brick (2002) note that visualization should make scientific concepts and structures more accessible, but that visualizations themselves can also prove to be a learning hurdle.

New technologies are providing more possible tools for education, and three-dimensional visualization applications are believed to have great potential pedagogically (Mohler, 2001). Therefore, we would like to know more about this technology's effects and its impact on learning. For example, three-dimensional rendering with movement and/or virtual reality effects can improve both the performance and the subjective ratings by students of how easy it was to visualize a structure (Johnson, Will, and Graunke, 2005). We would also like to know more about how technology affects students' interest in science; this is very important because of the growing need for science and technology training in jobs and modern society.

One example of a three-dimensional computer application is a cyber-mapping system which provides 3D data capture, analysis and visualization (Xu et al., 2000). In this study, we evaluated one such technology, the cybermapping GeoWall, which is a new technology is being introduced in geology to teach structural geology, and assessed the effectiveness of the technology in geology education, evaluated users' acceptance of the technology, and identified design/usability issues of the software.

LITERATURE REVIEW

Information technologies have been adopted in education for multiple reasons, which may include enriching learning, increasing the efficiency of learning, increasing interest in or excitement about education, providing wider access to education, containing the costs of educating, and increasing the efficiency of teaching. All of these reasons suggest why information technologies have been more widely adopted over the last two to three decades. While some technologies may impact all of these motives (e.g. internet access may accommodate richer sets of information, allow students to learn at a distance, and reduce staff and supply costs), others address one or two more specifically. This explains the proliferation of

multiple types of information technologies in educational contexts.

The development in IT has enabled the use of visualization technology in computer-mediated learning software. Visualization is related to various learning outcomes. Prior research has found that animations were especially helpful to high-ability learners (ChanLin, 2000), and that training in spatial visualization skills can improve students' performance in geology (Kali and Orion, 1996) and civil engineering (Alias, Black, and Gray, 2002).

However, students are more likely to pursue knowledge in the STEM fields if they are interested in them and perceive them as leading to enjoyable careers. This is of particular importance at a time when completion of science and engineering degrees lags demand on the job market and when women and minorities are especially underrepresented. For this reason, we included interest in science and enjoyment in science in the research model.

Technology Acceptance Model (TAM) can be applied to evaluate the use of 3-D visualization software in education. Technology Acceptance Model (TAM) is an established theory, which suggests that the antecedents of the attitude towards and intent to use a technology are its perceived usefulness and perceived ease-of-use (Venkatesh and Davis, 2000). TAM (Venkatesh and Davis, 2000) includes four variables: perceived usefulness, perceived ease-of-use, attitude towards the technology, and the intention to use the technology. Perceived ease-of-use (PEOU) is a measure of whether participants believe they will have a difficult time using the technology or not. Perceive usefulness (PU), on the other hand, is a construct that describes whether participants can imagine the technology to be advantageous to them, for example by allowing them to be more productive. Attitude towards the technology is a continuum that describes whether the participants have positive feelings about using the technology. PU affects attitude; PEOU affects attitude both indirectly (through PU) and directly. In turn, attitude correlates with the participants' intention to use the technology: a positive attitude about the technology makes them more likely to plan on or anticipate using the technology in the future.

Learning style is also very relevant in this research. Learning style represents the preference of students on several different variables relating to the modes and environments in which they work. This may also be related to underlying cognitive abilities, including differences between individuals in processing and relating information. For this reason, we propose that learning styles moderate the relationship between perceptions of ease of use and usefulness and the combined attitude towards the technology.

PROJECT BACKGROUND

The project under study is the cybermapping project which is funded by National Science Foundation (NSF). The software developed using the cybermapping technology is called GeoWall.

In this project, precise 3D photo-realistic digital replica of geological outcrops are developed through draping high resolution digital photographs onto surface terrain models captured by terrestrial Light Detection and Ranging (LIDAR) systems. These models are viewed using the 3D visualization system GeoWall through the Open Scene Graph (OSG) software. The GeoWall 3D view is created by two video projectors which are slightly offset from each other. Each projector is sent through a polarizer onto the screen, and the participant wears a pair of polarized glasses. Each projector is polarized in a different direction, and each lens of the glasses is polarized to match one projector. Thus, each eye is seeing the output of one projector. The brain re-interprets these offset images as implying a three-dimensional object.

In this study, the technology was used with an educational purpose: to help teach structural geology. This area of the science of geology requires students to be able to visualize and describe the ways that a three-dimensional solid can become folded and twisted, and to identify these folded structures based on the surface appearance of the structures. This visualization skill is more challenging than simply visualizing the exterior of a solid, and is needed for geological reasoning (Kali and Orion, 1996).
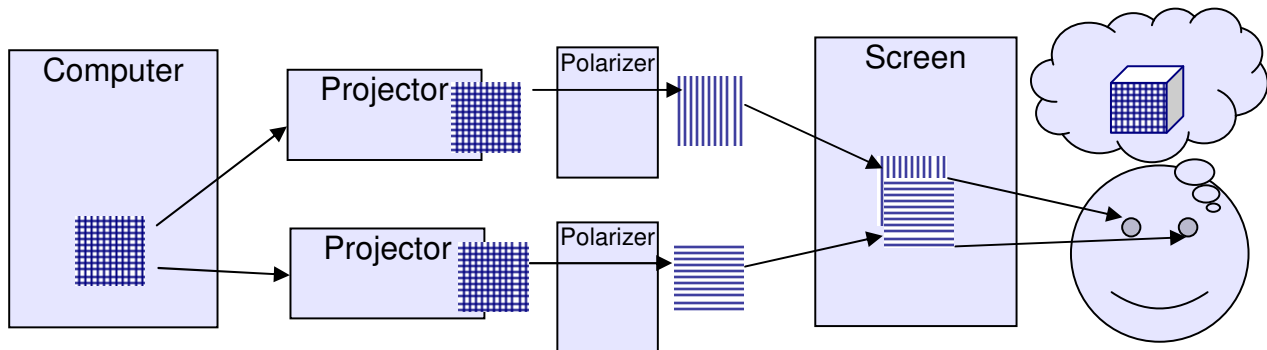
Figure 1: Geowall

RESEARCH MODEL

Figure 2 depicts the research model for this exploratory study. We propose that the design of a visualization software (e..g, cybermapping geowall in this study) affects students' acceptance of the technology, which in turn, influences students' interest in science and enjoyment in science. A positive attitude towards technology will likely increase students' interest and perceived enjoyment in science, as well as their intention to use the technology, which will ultimately have impact on learning outcome. However, students have different learning styles. For example, a visual learner would presumably find it easier to learn a system using effective diagrammatic depictions while an auditory/ verbal learner would find an oral instruction to be more helpful. Therefore, students' learning style is considered as a moderator in this research model.
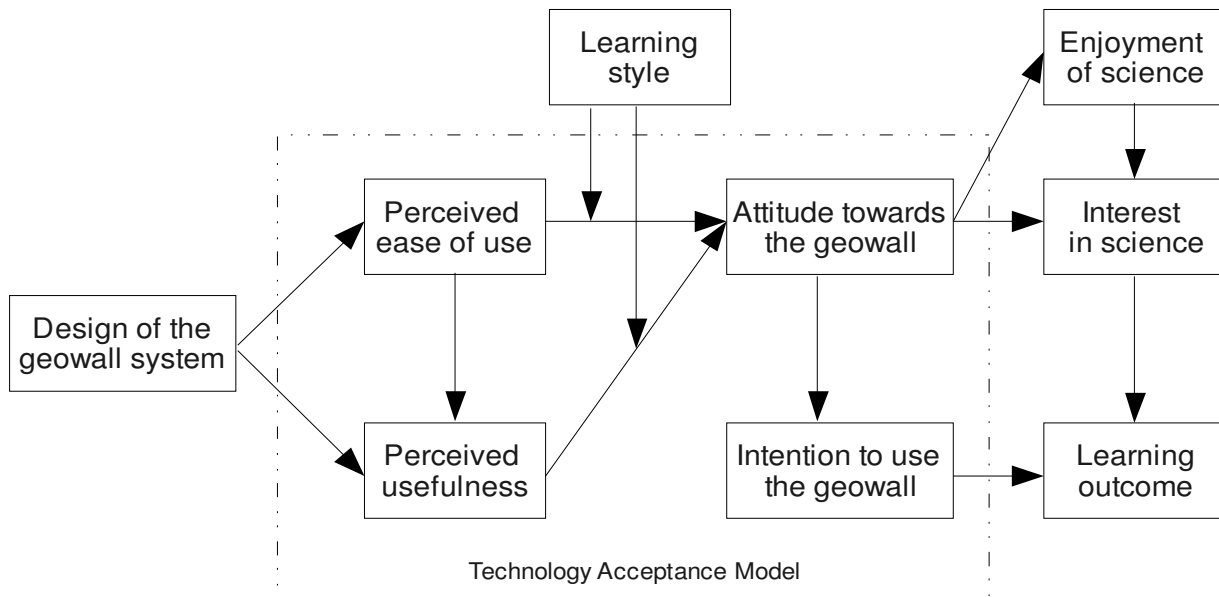

Figure 2: Research model

In this study, the measures used for TAM were adapted from Venkatesh and Davis (2000) to specify the Geowall technology. This measure has been widely adopted and is well confirmed in the literature. We used Fraser (1981) to measure the participants' interest in science before and after class exposure to the cybermapping geowall. This allowed us to make comparisons of the students' interest. This instrument includes three dimensions of science interest: general interest in science, career interest in science, and enjoyment of science. We also used the questions about perceived learning outcomes from Hall, Philpot, and Hubing (2006). These are ratings of how much was learned from and motivated by instructional media including lecture, lab, and textbook.

Felder and Silverman's (1988) Index of Learning Styles tests for four continua that are especially relevant in engineering

education. We have used a shortened version that uses three questions for each continuum in the pre-questionnaire for this project; the reduced question set can be expected to increase the standard deviation but is appropriate for a pilot of this sort and reduces fatigue on the part of participants.

RESEARCH METHOD

Both qualitative and quantitative methods were applied in this study. Quantitative data was collected in a pre-and post-experiment. A questionnaire was administered to the students before and after their exposure to the GeoWall software.

Qualitative methods, such as thinking aloud, observation, and interviews, can increase the in-depth richness of the data set, with the researcher as the observer and interviewer. The strategy of using both quantitative and qualitative information allowed us to test the proposed research model to answer our research question while also gathering additional information that might extend or clarify the research model. It also allows for triangulation to validate the results of the quantitative study.

Think-aloud protocol was used in the usability test, where several participants were observed using the system. The participants were encouraged to verbalize what they were thinking about as they used the system and answered the geology questions. This allowed researchers to know what a user is thinking about while performing tasks. The importance of this information is that it gives researchers insight about what parts of the system allow the participant to experience a streamlined flow of action and what parts face the user with problems.

A semi-structured interview was performed after the usability testing section. Open-ended questions were asked about the strengths and weaknesses of the Geowall system. Participants were asked to describe their understanding of the subject area, how Geowall differed from other methods for learning about the subject area, and their experience with the Geowall system. Notes and recordings were made of all interviews.

Participants and Equipment

The participants for all portions of the study were students enrolled in Geology 51, Physical and Environmental Geology, which is the introductory geology and geoscience course at a technological university. These participants included both beginning geology majors and elective students, so their exposure to these concepts was limited. They were appropriate for this study because it is concerned with the pedagogical impact on the learning of basic geological concepts. All students enrolled in the lab portion of the class were exposed to the Geowall in groups during their regular lab session; these sessions took place in a laboratory space in the geology building.

A questionnaire was administered to the students before and after the session in their regular lecture. Students were also offered the opportunity to participate in the qualitative study in exchange for a small amount of extra credit. These sessions were one-on-one and took place in the same laboratory space.

RESEARCH RESULTS

Quantitative Results

The quantitative results supported the relevance of visualization tools in increasing interest in science. They also supported the Technology Acceptance Model.

The participant pool represented each extreme of the learning style continua. Figure 3 summarizes the participants' learning styles. The four continua in this model are the preference to process information *actively* (physically or through discussion) or *reflectively* (through introspection), the preference to perceive information through *sensory* inputs or *intuitive* (mental) methods, the sensory preference for *visual* or *verbal* input, and the typical progression towards understanding being either *sequential* (incremental, linear, and logical) or *global* (holistic, sudden, and systems-level) (Felder and Brent, 2005). The population of participants in this study was closely divided on active vs. reflective learning styles, with 48% and 52% of the sample respectively. Our sample included 59% intuitive learners, with 41% sensory learners. As is typical of engineering students, a majority (60%) were visual learners, as opposed to the 40% who were verbal learners. Sequential (79%) learners outnumbered global (21%) learners. This group is relatively typical of engineering students, who on average are represented by active learners (64%), sensing learners (63%), visual learners (82%), and sequential learners (60%) (Felder and Brent, 2005).
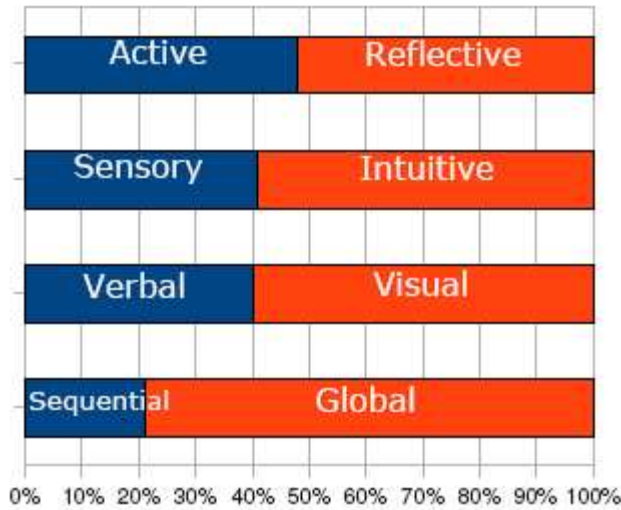
Figure 3: Learning Styles

Science enjoyment and interest also marginally increased, suggesting that further research in this area is warranted (see Figure 4). Science enjoyment increased from an average of 4.95 to 5.1 on a seven-point Likert scale, giving a significance of p=0.08 on a one-tailed t-test. Science interest increased from 4.35 to 4.46 with a significance of p=0.18, and science career interest decreased from 4.76 with a significance of p=0.13. Change in interest in science was not correlated with the student's major. These data, while not significant, suggest that further research with larger participant pools may be warranted.
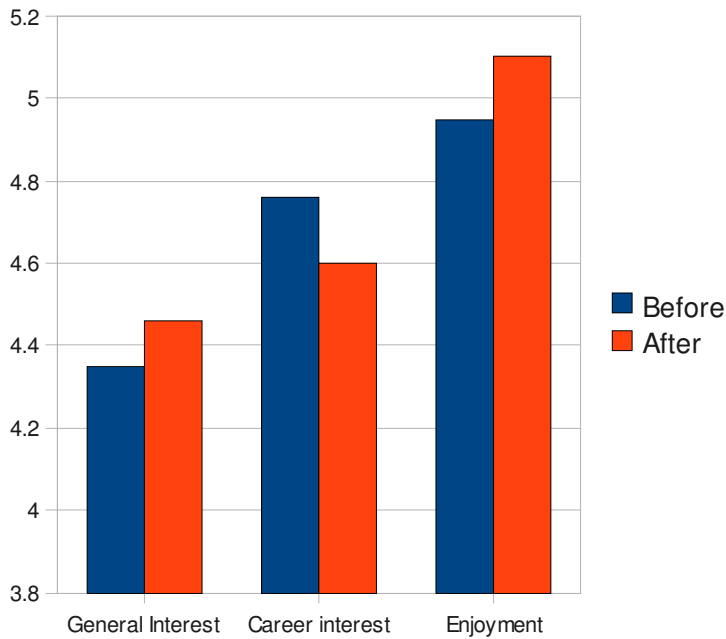

Figure 4: Results on Science interest and enjoyment

The TAM model was supported. Linear regression analysis showed that attitude was strongly connected to perceived usefulness (p=0.000) and perceived ease of use (p=0.001), while intent to use was still correlated with attitude (p=0.002). This technology was perceived positively by the participants. On a seven-point Likert scale, perceived ease of use was 4.51, perceived usefulness 4.98, attitude towards the Geowall technology 5.37, and intent to use technology 4.05. We suspect that the intent to use score was low in part because the technology was perceived as a class-related technology, not one where they could see the applications to their careers easily. This result may change if the technology were framed differently.

Learning outcomes were also seen as favorable. This construct measured whether the students learned a great deal and were motivated by the text, lecture, and lab activities. While the lecture and text both scored highly (4.90 and 4.76), the lab also scored a respectable 4.59 on a seven-point scale. Furthermore, when students ranked their understanding of the topic before and after using the geowall technology, their understanding increased a full rating point (+1.07) on average.

Qualitative Results

Qualitative data was also collected in order to investigate what technological features may impact the perceived ease of use and perceived usefulness of the technology. Six participants participated in the usability testing in which various types of qualitative data was collected. We made videotape recordings of the participants as they completed several tasks that enabled them to work with the cybermapping geowall. We asked them to complete a think-aloud protocol as they worked, and we also observed them and took notes as they worked. After completing these tasks, we performed semi-structured interviews to elicit impressions of their experiences with the cybermapping geowall as well as additional information about its place in their coursework.

Thus, we had three data sources that were combined in the qualitative analysis: the observation notes, the think-aloud recordings, and the interview recordings. These materials were then examined for key themes.

In general, students found the geowall to be useful to consolidate material learned in lecture and to connect small and large scale processes. Participants also noted that they had learned more material to "pour into" the usability testing session than they had at the time of the group lab sessions. They had difficulty with the lack of context and feedback provided in the technology and with the quality of the image. Moreover, the direct manipulation paradigm of the technology was made difficult by the fact that the mouse controls were both unfamiliar and invisible. In interviews, participants likened the use of the geowall to a useful trip to the field. They suggested that the technology would be more helpful to them at this stage if it helped to reinforce the link between concepts and terminology. They noted the importance of feedback to them in their educational activities, and emphasized that rich media examples could be a powerful tool when matched up to lectures or text examples. We also found that a few students had physical complaints after using the technology, and that they came from varied backgrounds. These variations underscore the importance of finding multiple ways to reach students.

Visualization

The students found the geowall technology to be helpful because it helped them to relate concepts to the larger picture. One said, "*I like being able to see at ground level and then turn it to the top.*" Other participants noted that they could see over larger distances, and from various angles, which they found helpful in imagining large-scale processes and visualizing previous stages of development. Therefore, providing contextual cues was extremely important to the participants. They specified a number of ways in which context was lacking or misleading, as well as suggestions for improving context. A map in which the top of the screen was west rather than north in the default position was frustrating to participants; in addition, if they rotated the model, there was no way for them to know what the directions and original position were. No scale was provided with the model, so participants asked how large the area they were viewing was. They also cited the difficulty of orienting oneself as far as the actual angles between the structure and the ground. The view from the side of the formation was also confusing to them because the formation was modeled as a surface, i.e. a hollow shell, so that from the side the verisimilitude of the views from other directions gave way to an artificial "underside" that belied the solid volume of the actual rock. Participants volunteered a number of strategies for combating these problems: labeling landmarks and axes (including making axes of rotation visible), providing compass directions, distances, and scales, and providing a broader area of rock rather than the "strip" shapes they were provided. The participants were also particular to contrast the photographic quality with the artistic renderings from the textbook; the realism of the geowall allowed them to see details that indicated different amounts of erosion, for example. This allowed them to integrate the interactions of several different processes. Because the visual quality was so important to the relevance of the technology, any difficulties with the visualization were particularly frustrating. Precise calibration is required to avoid issues such as blurriness and "double vision"; in this case, details such as the arrangement of the room, control of the lighting, and the movement of the projectors and screen directly impact the usefulness of the technology. In addition, orphaned areas and jagged edges were especially distracting to participants. Manual cropping of these edges may be necessary. Negatives with respect to the technology included physical symptoms such as eyestrain, headache, and nausea that may be improved by correcting the calibration or room setup. One student was also unhappy with wearing the "*goofy glasses*" that felt embarrassing to him. In short, the visualization was a major source of the technology's perceived usefulness, but difficulties with the visual quality and scale may negatively impact perceived ease of use.

Learning experiences

The geowall as a learning tool was frequently compared to other learning experiences that may suggest some ways that visualization is useful to certain students. It was seen as being like a field trip in that it allowed one to see multiple variables, such as erosion and types of rock, and that it could allow more study than a single field trip would allow, despite having a learning curve and not allowing a student to touch the rocks. It also was seen as a useful counterpoint to labs and lectures, in that it could give real-world examples of concepts that were being described. One participant said, "*I can relate this back to the diagrams I've seen in my textbook. If I could have them in conjunction, working together, that would be great.*" Students noted that acquaintances not enrolled in the lab sections struggled more with the lecture portion of the classes, but it was essential that the size of lab groups be small enough that everyone could have enough time to explore the software. Students had widely varying opinions of the relative importance of lab, lecture, text, and field trip, but they also had widely varying experiences, from outdoor activities such as fishing and taking road trips, to working or studying building construction, to a summer field camp or sculpting in multiple media. Thus, the concepts and the processes were much easier for some students to visualize than others. Students also had many different images of the ways the geowall could be extended and used, from having more "exotic" structures available to highlight similarities and differences to allowing virtual tours and access to hard to reach locations, from previewing areas to presenting information to simply knowing something different.

Feedback

Students also felt that their learning process was limited by a lack of feedback. Although they had studied similar structures in coursework, there was a great deal of material at high speed: definitions, shapes, and processes are all part of learning geology, and they interlock with each other. The participants tried to reason about the geological structures, but they expressed uncertainty because of "*not wanting to be wrong.*" This inhibition may limit their ability to take full advantage of educational activities. To overcome this, participants requested additional feedback mechanisms, whether in words or in pictures, using tooltips, overlays, colored layers, animations, or arrows. The lack of feedback was also a major reason why participants felt the technology did not help them in the course as much as it could, which constrained the potential usefulness of the technology.

Direct Manipulation

Direct manipulation allows interface metaphor to have a powerful impact, but it does have its pitfalls. In particular, the methods of manipulation must be learned; learnability may thus be an important component of perceived ease of use. Shifting left and right, rotating, and zooming were the three manipulations allowed by the geowall technology; these were accomplished by holding down the left mouse button, the right mouse button, and both buttons simultaneously while moving the mouse. Participants said the manipulation was frustrating, and that starting and stopping was hard. Even clicking and dragging to move the image was tricky for some who suggested including scroll bars. Rotating also felt confusing; students felt that the motion was backwards from what they expected and took cognitive effort to reverse their expectations. One participant compared it to learning to lean out of curves while riding a motorcycle, and another suggested borrowing interface elements from other software such as Autocad. Zooming was the hardest manipulation, because very few expected to hold down both mouse buttons to zoom. Students tried many different manipulations to zoom, including pulling the mouse in towards themselves to pull the image "closer," using the mouse scroll wheel as in popular games, and clicking on the corners of the screen. Importantly, the participants transferred other conventions to this technology and when they had to learn a new convention, they noted the distraction of the added cognitive load. This may be one reason why the potential interactivity of a technology does not always aid in visualization (Keehner et al, 2008), even though one student who manipulated the model extensively in our session said that "*the more [he] move[s] it around, the more [he] gets... intuition about what [he's] looking at.*"

DISCUSSION

The model used in this study, which adds learning styles, science interest and enjoyment, and learning outcomes to the TAM model, was supported. This suggests a structure to use in future examinations of educational software, which is an important area for application of information technology. In addition, the importance of visualization is confirmed. The specificity of this context may be a limiting factor: this is a specific technology, used with a specific group of students, which may limit its generalizability. However, the need for improved spatial skills and visualization aids is a theme across many areas of science and engineering. We also gathered a great deal of qualitative data, and many of the issues raised by this data also apply to educational and other applications. Learning always has a part to play in the adoption of new technologies and the entrance into communities; thus, it is worth raising the question of how best to remove barriers to entry. Direct manipulation paradigms are common in user interfaces, but this ubiquity must not be allowed to hide the fact that direct manipulations are

still driven by conventions, such as that pressing down a mouse button corresponds to "holding" or "exerting a force on" virtual objects. The frustration engendered by unfamiliar direct manipulation paradigms and a lack of feedback may especially impact lower-ability students (Mohler, 2007), perhaps by increasing their cognitive load. The promise of 3D technologies is mitigated by the need to make sure they are physically and metaphorically appropriate.

CONCLUSION

This study has been included in the NSF grant as a formative evaluation. Future research will include modifications to the design of the geowall software, and a follow-up study to perform a summative evaluation and provide comparative statistics. In addition, we confirm that 3D visualization holds promise as a tool to assist students in learning science and engineering topics. We suggest that further studies be conducted to determine the most relevant aspects of 3D visualization in order to determine how to increase cognitive fit (Suh and Lee, 2005) and task-technology fit. It is plausible that the optimal choice of pedagogical tool may depend on the student's characteristics (such as learning style and spatial skills) as well as the topic and task being investigated.

ACKNOWLEDGMENTS

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