Exploring the Instruction of Fluid Dynamics Concepts in an Immersive Virtual Environment: A Case Study of Pedagogical Strategies

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Abstract

The deployment of immersive, non-restrictive environments for instruction and learning presents a new set of challenges for instructional designers and educators. Adopting the conceptual frameworks of Sherin's (2002) learning while teaching and Vygotsky's (1978) cultural development via the mediation of tools, this paper explores one professor's pedagogical approaches used for instructing fluid dynamics concepts within the Metaverse, a highly innovative, physically immersive visualization display that does not require the use of head-mounted or other restrictive devices.

Introduction

The emergence of virtual realities (VR) in the educational technology landscape in recent years has aroused the enthusiasm of instructional designers and educators, especially among instructors in the discipline of science. Virtual reality technologies enable a new dimension of representing difficult scientific concepts and processes that 2-D desktop graphical representations have not been able to offer (Jimoyiannis & Komis, 2001; Fiolhais & Trindale, 1998). However, integrating these burgeoning technologies into school curriculum and higher education presents a new set of challenges within the realms of learning and instruction (Barajas & Owen, 2000). In the past decade, a plethora of discussions and inquiries in educational technology journals and conference proceedings have placed significant emphasis on various aspects of simulated desktop virtual environments, 2-D multimedia representations and web-based instruction and learning (Davies, 2002; Antonietti & Cantoia, 2000; Maher & Corbit, 2002; Gabrielli, S., Rogers, Y., & Scaife, M. 2000; Gazit, E., & Chen, D., 2003). Moreover, empirical studies on the applications and implementations of immersive, non-desktop virtual reality interfaces in education, especially scalable virtual reality infrastructures are scant (Crosier, Cobb, & Wilson, 2002).

To this end, the Metaverse, a NSF-funded interdisciplinary research project at the University of Kentucky, has marked a milestone in the development of educational technologies. In addition to developing self-configuring, scalable visual displays, the Metaverse makes it possible for learning and instruction in a commodity hardware supported immersive, non-restrictive environment. The objectives are to support meaningful human-computer interaction and to understand the impact these visual environments have on education. For the past three years, the Metaverse team has been translating, designing and implementing prototype instructional materials into immersive displays. One of the preeminent tasks that the educators of the team face is to seek ways of facilitating instruction in this dynamic, non-linear teaching and learning environment. Many initial questions arise. Chief among them, for example, is how can teachers learn to use an immersive environment in which developing their own understanding of the nature of the new computer-generated 3-D environment is of primal concern? As McLellan (2003) pointed out, careful and continual examination of virtual reality technologies, especially within the context of learning and instruction are important for two reasons: 1) virtual reality technologies are still in their nascent stage of development as a category in educational technologies, and 2) rapid technological improvement posts concerns for the issue of outdated technological capabilities.

Thus, the purpose of this exploratory study was to analyze the emerging pedagogical strategies within a non-restrictive, immersive environment. More specifically, this study examined the teaching approaches employed by a professor in the instruction of fluid dynamics concepts using in the Metaverse display. Using Sherin's (2002) concept of "teaching while learning" and Vygotsky's (1978) notion of "cultural development" through the mediation of tools, this paper seeks to understand the instructor's integration of subject matter knowledge and his newly acquired knowledge in deploying the immersive technology. The goals are to: a) shed some light on the development of effective instruction, b) to optimize the full potential that this inherently

“open-ended” learning environment affords, and c) to provide an initial step toward future studies of scalable, immersive, virtual learning environments for educational applications.

Conceptual Framework for the Study

According to Sherin (2002), teachers go through a process of transforming, adapting, and negotiating when faced with changes in instructional curriculum or materials. “These classes of interactions between the teachers’ content knowledge and the implementation of the novel curriculum. . .represent the different ways that teachers apply their content knowledge as they attempt to use new materials” (Sherin, 2002, p. 129). Moreover, Sherin (2002) posits that it is only through the process of negotiating with new instructional materials or situations that teachers truly engage in the active role of learning. In other words, teachers who work with new instructional content often experience a series of changes that prompt them to arrive at an innovative stage of developing new ways of interpreting and presenting their newly acquired content knowledge. However, it is inadequate to address the wide spectrum of pedagogical strategies required to deliver meaningful instruction within an immersive, non-restrictive environment such as the Metaverse display. Specifically, additional concepts are needed to frame the interaction between the instructor and the immediate environment.

Drawing upon Vygotsky’s (1978) concept of “cultural development”, the authors of this study argue that an immersive virtual environment can be viewed as a “culture” in which both the instructors and students alike develop their own tools and verbal and nonverbal signs in the process of becoming familiar and efficient with their navigation within the environment. According to Vygotsky (1978), tools and signs represent different ways of orienting human behavior and are the essence of mediated activities.

> The tools’ function is to serve as the conductor of human influence on the object of activity, it is *externally* oriented; it must lead to changes in objects. It is a means by which human external activity is aimed at mastering, and triumphing over, nature. The sign, on the other hand, changes nothing in the object of a psychological operation. It is a means of *internal* activity aimed at mastering oneself; the sign is internally oriented (Vygotsky, 1978, p. 55).

Within the context of this study, tools, referred to by Vygotsky (1978) as the external object, imply the user’s physical body movement to navigate in the immersive visual display. Analyzing the body movement that revolves around a series of actions, described by Vygotsky (1978) as “true gesture”, the authors attempt to examine the embedded dimensions of teaching that may be unique to immersive environments.

The Environment

This exploratory observational case study is anchored in the Metaverse, a non-restrictive, immersive environment. One of the fundamental concepts behind this infrastructure is its visually immersive and interactive affordances. The 500 square-foot room with its fourteen ceiling-mounted projectors and calibrating systems enable a single user to move around freely without constrain of devices like the head-mounted display, data gloves, or stereo glasses, which are characteristics of typical CAVE-like immersive environments. As the user moves to various locations in the projected two-wall and floor display environment of the Metaverse, a head-tracking device on a fedora hat or being held by the user corrects for changes in the display in real-time. In another words, the viewpoint or perspective changes simultaneously as the user moves within the environment. Further, a user in the display can obtain top, bottom, interior and exterior views of the display or the projected image by strategically positioning him or her in the environment. The problem in using this type of physically immersed environment surfaces when the cues of depth in virtual environments are often different from that of the natural world (Wann & Mon-Williams, 1996). In addition, time lag in displaying the corresponding view as to the user’s body movement also creates challenging usability/context-for-learning issues.

Subject Matter Content

The subject matter content of the inquiry pertained to the behaviors of a laboratory simulated fire whirl. “Fire whirls occur infrequently, usually as the result of . . . large scale wildland or urban fires—the former usually caused by lightning strikes, and the latter often due to earthquakes or some similar disaster” (McDonough & Loh, 2003. p. 1). Studies on the characteristics of fire whirls have been sparse despite the

potential damages that these phenomena can cause and the possible control measures of small pool fire in industrial applications. Selection of this subject matter content also relates to the availability and accessibility of the visual display for the Metaverse environment.

As the technical development of the Metaverse and its contents is an ongoing process, the simulation of the fire whirl in the Metaverse display during this study was a simple cylinder-shape projected image with areas of grey, blue, orange and yellow. The concept of this display is to show the circular moving flow field and the color-coded regions of flame temperature. Walking inside or to other regions can lead to changes in the appearance of the flame and the temperature. One of the objectives in creating this simulation in the Metaverse was to provide visualization of the turbulent flow behaviors of the flame and its various burning regions.

The Participant

Selection of the professor for the study was based upon his involvement with the NSF grant of the Metaverse project, his expertise in the field of fluid dynamics, and his enthusiasm in experimenting with the immersive visualization interfaces. The primary task of the professor was to present and demonstrate the characteristics and turbulent flow behaviors of the simulated fire whirl described earlier. Yin (1994) has noted the acceptability of a case study of one to describe or explore a unique or extreme case. The unique situation criterion is clearly met in this instance.

Data Collection Procedures

To maximize the trustworthiness and reliability of the study, the authors adopted various data collection resources. For instance, the eight-minute presentation of the fire whirl in the Metaverse display was digitally video and audio recorded. The video recording was then transferred to CD-Rom, and the content was transcribed verbatim and member checking by the professor. Moreover, other methods of collecting data included a focused interview with the professor after examining the video-recorded presentation, email communication, and field notes. To compare the behaviors of the professor in the immersive display with his in-class teaching methods, the lead author conducted eight fifty-minute classroom observations for two semesters prior to analyzing the recorded video and transcript.

Analysis

The authors based the analytic techniques of this case study on both the conceptual frameworks of Sherin's (2002) learning while teaching and Vygotsky's (1978) cultural development through the mediation of tools. As such, the researchers examined the interaction categories of transform, adapt, and negotiate, and the mediation of tool (body movement) in two phrases: 1) identified, coded, and analyzed the incidences that negotiation took place in terms of the subject matter content, and 2) identified, coded, and analyzed the incidences of tool (the body) manipulation. These analytic strategies followed the case study tradition of pattern-matching (Yin, 1994), the coding and categorization of evidence (Stakes, 1995), the displaying of events in table and form, and the tabulation of the frequency of incidences (Miles and Huberman, 1984).

Aside from analyzing the video and its transcript, the authors also conducted an ongoing process of triangulating field notes and transcribed interview to search for emerging patterns and themes. Stake (1995) has posited that triangulation increases the validity of the study and thus ensures the accuracy in interpreting the collected data. Moreover, Yin (1994) and Stake (1995) maintain that collecting and analyzing varied evidence sources such as interviews, observation, and documents verifies the authenticity of the phenomena under investigation.

Results and Discussion

Analyzing the transcript and taped video reveal several findings regarding the professor's attempts to cope with delivering his content knowledge in the fire whirl immersive display (new context). Table 1 provides samples of incidences that illustrate the instructor's use of existing content knowledge to implement a new context through the process of transformation. Furthermore, the table shows evidence of the professor's skill in developing new content knowledge and implementing the information into the presentation (process of adaptation), and his approach in developing new content knowledge and modifying the content information as he proceeded with his instruction (process of negotiation). Although each of these three classes of interactions reflects learning through teaching, Sherin (2002) maintains that attention should be placed on negotiation as it signifies the teachers' active role of learning during instruction. By definition, negotiation occurs when

"teachers develop new content knowledge and at the same time make changes in a lesson as it unfolds in the classroom. . . In other words, the teacher not only develops new content knowledge but also uses this knowledge to interpret the lesson in progress and decide how to proceed" (p. 130).

Throughout the presentation, the professor negotiated his fire whirl content and the immersive environment by making comments that centered on his justification of what could have happened if the immersive display was programmed with a complete data set. For instance, in the beginning of the presentation, he remarked, "If we had a complete simulation, we will be able not only to see the temperature in this thing, but we will be able to see the flow field down underneath." In another incidence, the professor developed and integrated his new content knowledge within the context of the environment by pointing out the advantage and disadvantage of having the immersive visual display. "Now, one of the things that's missing from the system that we will eventually have in place is the ability to know just exactly where we are in a given time. As we stand right now, I don't know exactly where I am. But, by walking around in here at the very least we can see how the different regions connect up to the other." These sample incidences illustrate the professor's creativity in generating new content about the flame as he explained its turbulent behaviors in the immersive display. Further, a comparison of the professor's frequent integration of new information during the presentation to the highly structured, non-interactive classroom lectures also suggests the instructor's active negotiation within the immersive environment.

Placing Vygotsky's (1978) concept of "cultural development" through the mediation of tools in the context of this study, the instructor demonstrated his role in creating a culture for the environment and his development in gaining competency in deploying the immersive display. By moving or situating his body (the tool) in various positions and locations, the professor was able to obtain different perspectives or views of the fire whirl visual representation (Figure 1, 2, & 3). Moreover, competencies in obtaining the desired views in the display required skills through repeated actions. For instance, the following statement made by the professor illustrated his lack of confidence in obtaining the desired view of the display and his challenge in mastering his tool (body movement). "If we get in the right place here, we maybe get to a place where I get fire all around me. It's moving a little erratically. Let's try this way. . . there we go." As the instructor gained knowledge with repeated use of the fire whirl immersive display, his accuracy in obtaining the desired view of the display with the least amount of time increased. "The first thing we are going to do is to see if we can look down on top of this to see some evidence of burning. And we can see that here. Over here. . . and it's stabilized. And now we bring the tracker back down and actually get underneath it and look at it from the bottom". This instance, which occurred toward the end of the presentation, exemplified the professor's skills in mastering the nature (the immersive environment) and mastering of behaviors. He became more decisive in manipulating his body movement and in taking the required actions

Interaction Class	**Sample Evidence with number of similar instances**	**Content Knowledge**	**Novel Lesson**
Transform	Discussed the behaviors of flow field by interacting with and showing the visual display (4 incidences)	Unchanged	Changed
Adapt	Invented explanation for the different color regions and heat temperature when asked about the indicators of the changes in time in the immersive display (2 incidences)	Changed	Unchanged
Negotiate	Statement such as "If we had a complete simulation, we'll be able to see the temperature...the flow field down underneath" surfaced throughout the instruction. The professor created new content knowledge (showing the lower part of the flame) caused by the inadequacy of the visual presentation (new content) to fully describe the phenomenon (5 incidences)	Changed	Changed

Table 1. *Illustrations of the three classes of interaction, transformation, adaptation, and negotiation as exhibited by the professor in the 8: 25 minutes of Metaverse fire whirl presentation.*

to obtain the desired views of the simulated fire. In other words, the learning through teaching occurs and can

be described as mediated activities that suggest the fulfillment of the intended goals, which are the requisite pedagogical strategies to support meaningful instruction.

Conclusion

This initial study provides the frameworks to explore the development of pedagogical approaches within the context of the immersive, non-restrictive environment. Although the visual display and the immersive environment are still in an early stage of development, it offers a fertile ground for research in human computer interaction, learning and instruction, and human behaviors that may provide insight in areas of cognitive domain.

Figure 1. Lowering the body (tool-shown in bottom left) to show the underneath view of the flow field

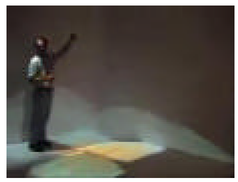

Figure 2. Showing the fire whirl data from the top view by standing (tool) and holding up the tracking device (artifact)

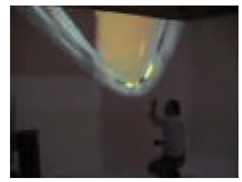

Figure 3. Lowering the body (bottom right) and holding the tracking device with the left hand to manipulate the view of the display

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