A Collaborative Tool for Synchronous Distance Education

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ABSTRACT

In this paper we report results of the use of a telepresence application in a simulated distance education setting. The application combines video-conference with a networked virtual environment in which the instructor and the students can experiment with virtual object in a collaborative manner. The teaching for Understanding (TFU) framework is used as the pedagogical approach. Current preliminary results show that the combination of the telepresence application with TFU, can compensate for the lack of physical presence of the instructor in the classroom

KEY WORDS

Advanced Technology in Education and Training, Collaboration, University, Multimedia, Audio and Video Streaming, Virtual Reality, Evaluation of Learning Technology Systems

1 Introduction

Adverse conditions such as warfare, lack of adequate locations, prohibitive costs and absence of faculty, hinder the creation of schools and colleges in rural areas of developing countries. Additionally, geographic, social and political circumstances prevent people from moving freely from rural areas to cities, therefore limiting their access to academic institutions. Distance education, based on information technologies, is a promising alternative for providing access to good quality education to individuals living in these regions. Technologies supporting asynchronous distance education, in which each student works alone at their own pace, can be considered viable alternatives to overcome the absence of physical classrooms. Traditional printed material can be replaced by web pages that are accessed by the students regardless of their physical location [1] [2] [3]. The use of pre-recorded video classes have become another widely used resource, due to the availability of multimedia devices in low-cost personal computers [4]. But in many cases, synchronous interaction among students or among the instructor and the students is desired, in order to enhance the productivity of collaborative activities [5]. In such case, required equipment is not very different from the one required for asynchronous education.

Remote courses can benefit from teleconferencing to compensate for the instructor's absence. Internet teleconferencing is already possible even for geographically distant regions. Desktop video-conferencing tools, pioneered by Carnegie Mellon University's CU-see-me, have made synchronous sessions available even to PC users connected to the Internet through telephone links [6] [7]. It is also convenient to be able to use slides presentations covering the subjects explained in class. In addition, some of the topics have to be illustrated and observed in detail to augment the understanding. In many cases this involves the use physical objects representing the problem of study. For example, a human body in an anatomy class or a virtual building in an architecture class. Several Virtual Reality applications have been utilized to create educational virtual worlds in which the students and the instructors can share experiences that are related to various educational contents [8] [9] [10] [11]. In these applications, users share a networked virtual world and a set of objects they can interact with, providing the illusion of a shared space in which they can collaborate.

Our aim was to develop a full computer-assisted collaborative work tool to support synchronous distance instruction, bringing education to places with limited access to schools and other adverse conditions. We consider that this tool must:

- Be able to run with commodity hardware (web-cameras, regular microphones, desktop PCs)

- Adapt to several platforms and resource availability as shown in [12].

- Provide different interaction methods, among them: video-conferencing, regular slides and a shared interactive virtual environment.

It could be argued that the use of the above technologies, as means to compensate for distance, may alter the level of understanding the students achieve when compared with a normal face-to-face class. The effects of computer-mediated distance learning need to be measured in order to verify the success of the computer application. In this research we aim at showing how the combination of new technologies (multimedia and virtual reality) and an appropriate pedagogical framework support synchronous distance education sessions. The Teaching for Understanding (TFU) Framework [13], developed by a group of researchers at the Harvard Graduate School of Education, is being used to assess the level of understanding of the students. A panel of experts grades the student's levels of un-

derstanding (naive, novice, apprentice or master). Understanding is also measured along the four dimensions proposed by TFU (knowledge, methods, purposes and forms).

The rest of this paper is organized as follows. Section 2 describes similar existing applications and how the approach presented in this paper differs from them. Section 3 describes the application in detail. The pedagogical framework used to validate the usefulness of the application is described in section 4. Section 5 explains how the experiments where conducted. Results are presented in section 6. And finally, section 7 describes the conclusions and future work.

2 Related Work

The application built for the work reported in this paper aims at combining several forms of communication/interaction: Slide presentations, Video-conferencing (streamed audio and video) and a Shared Virtual Environment (SVE). Several applications involving SVEs and synchronous communication mechanisms have been created for several applications fields. This section describes some of the most representative ones and how our application differs from them.

The NICE project [9] was created as an immersive learning environment for children, implemented using CAVE [14] technologies. In NICE, several children could collaborate with other remotely-located children to construct and cultivate simple virtual ecosystems. Children could communicate via voice, but each participant could only see a 3D avatar of the other, lacking any facial expressions. Our tool adds video to facilitate this.

ISABEL, a Computer Supported Cooperative Work application meets some of the requirements for developing a synchronous remote class, including video-conference and shared applications (e.g., slides presentation) [15]. The shared application model of ISABEL relays upon VNC, what does not extend well for shared virtual environments as all user have the same view of the application window. In our virtual environment an independent user can change freely her view or interact with the virtual world individually.

AVALON [10] was previously created by our group to explore the use of Networked Virtual Environments as means to support distance education. Users moved freely inside virtual worlds that were created to support specific contents of an Environmental Awareness course. Users could communicate with voice, sent over the network. The instructor could project slides in a whiteboard, located in a specific part of the virtual world. Each participant was represented with a 3D avatar, but no video was transmitted. In order to compensate for the lack of video, students could choose among a set of expressions in order to communicate their status to the instructor. These expressions were then displayed on top of the corresponding student's avatar.

Similar in principle to AVALON, MUVEES [11] and Active Worlds [16] provide different education oriented virtual worlds that vary in contents according to subjects being studied. Avatars represent users and there is some support for facial expressions. Video-conference is not part of any of these systems.

We integrate the most basic interaction methods in a single window for a remote class and collaboration. Our system is a self-made tool that can extend according to our needs, for example, it can be re-configured to meet the needs of the available platforms. We use Java to ensure portability and modular development. Additionally, Java includes APIs for 3D environments and multimedia applications. The next section explains how the application described in this paper integrates the different interaction mechanisms.

3 The Collaborative Synchronous Tool

The application described in this paper integrates several forms of interaction, namely: Slides, Video-conferencing and a Shared Virtual Environment. Switching among the forms of interaction is easily accomplished by an easy access toolbar at the top of the main application window. A typical class, using the application, includes some slide presentations and a guided interaction with a virtual content. The interaction is performed both by the instructor and the students collaboratively. Figure 1 shows the students' window during a slide presentation for a physics class. At the right-hand side of the window the local (top) and remote (bottom) video windows are shown. Each slide is converted into an individual graphical file that is sent to the student side when displayed by the instructor. Controls at the bottom of the instructor's window, allow him/her to navigate among the slides. The instructor's mouse pointer position is reflected in the students' window.
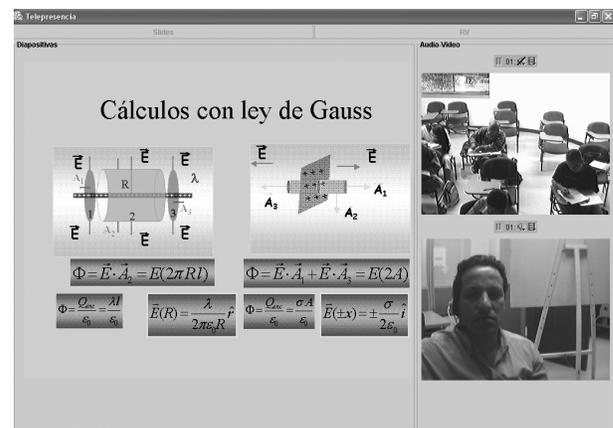

Figure 1. Students' window during a slide presentation

Figure 2 shows the instructor's window during an interaction in a shared virtual world illustrating an electric field. Note that the local and remote video windows remain in place. The instructor can use a telepointer (3D arrow) to point inside the virtual world. The instructor's tele-

pointer is commanded by a Polhemus 3D tracker, allowing for a very natural interface. For the students' application a normal mouse and keyboard can be used for interaction. Both the instructor and the students can move their viewpoints around the shared virtual environment using the arrow keys in the keyboard. The students' point of view is represented by a red telepointer, allowing the instructor to see from where they are observing the environment from.
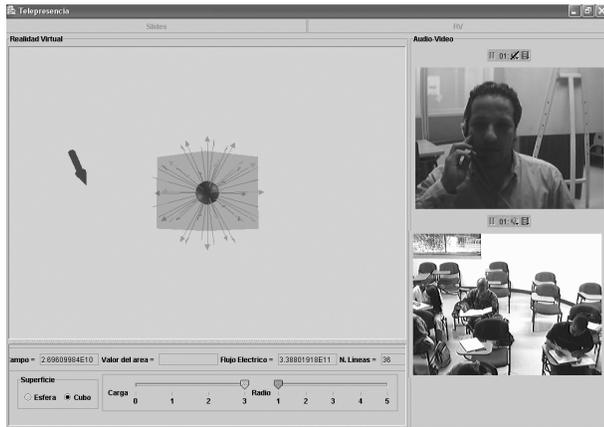

Figure 2. Instructor's window during a collaborative interaction in the shared virtual environment

Several virtual reality contents have been developed for a Computers Graphics and an Electricity and Electromagnetism course. Contents for the Computer Graphics course include, among others, parametric lines, curves and surfaces, objects as polygon meshes, 3D transforms and illumination. Electricity contents include charge transfer, Coulomb's Law, Gauss's Law, magnetic fields, etc. Each of the contents includes a 2D panel with formulas, object attributes and some adjustable parameters. Instructor and students observe the panel and can modify it to study the effects. In a normal lesson, the instructor explains the theory first and then performs a demonstration in the shared virtual environment. Students interact with the virtual objects next, guided by the instructor. Then they can adjust the parameters freely.

Local and remote video windows are shown at all times. Bi-directional voice links are also active among the two points at all times. This allows the instructor and the students to communicate in a very natural and effective manner. We employ Java Media Framework for video and audio transmission. Video format is 320 by 240 pixels at 15 frames per second, it is transmitted over RTP in Motion JPEG format. Audio is also sent over RTP. The current implementation is point-to-point. The instructor application is at one end and the students (all together in a remote location) at the other. At this point, more than two ends have not been necessary. However, we plan to extend the application to provide support for multiple students locations.

4 Pedagogical Validation

In order to understand how the use of the application increases understanding in the students (as per our hypothesis), it is necessary to describe the four dimensions of understanding proposed in TFU: The *Knowledge* dimension is related to the student's ability to transform his/her intuitive beliefs into formal knowledge. *Method* has to do with his/her ability to use those methods, accepted in the field of knowledge, to make/validate new assertions. *Purpose* implies the ability to link theory and praxis. This process gives purpose to the knowledge, because it becomes potentially useful in life. Proficiency in the *Forms* dimension is demonstrated by the appropriate use of the symbol system of the studied field. For example, when users interact with the virtual objects, two windows become particularly important: The manipulation window corresponds to the virtual environment, and is related to the manipulation of objects ("concrete" experience). The corresponding equations (formal knowledge) are displayed in the equations window. In most demonstrations, the user can interact with one window and see the corresponding results in the other. We hypothesize that this ability to move between the concrete and the formal, in both directions, increases understanding in the students.

Based on the current results, we observe that the tool may increase the levels of understanding attained by the students, along the dimensions of understanding proposed by TFU as follows:

- Knowledge: As the students manipulate objects in the manipulation window, the application displays the corresponding formalism in the equation window. This allows students to build the link from the intuition to corresponding formalization.

- Methods: The ability to interact directly with formal elements in the equation window allows students to become familiar with the formal concepts in the field that are used to validate and formalize new knowledge.

- Purpose: The ability to see and interact with the virtual objects facilitates the students' ability to extrapolate the use of the knowledge to other applications or fields of knowledge.

- Form: Students are asked to enter formal descriptions in the equation window and predict the results in the manipulation window. This establishes a link from the formalization to the concrete experience, allowing them to internalize the use of the symbolic language of the field.

5 Experimental Setup

In order to measure the effectiveness of the tool in an actual learning environment two experiments were conducted

during the second semester of 2003 and first semester of 2004. For the first experiment the 3D unit of a Computer Graphics course at Eafit University was chosen. For the second experiment a unit of an Electricity and Electromagnetism course, taught at Eafit University for Engineering students, was selected. In both cases students were randomly assigned to an experimental group or a control group. Students in the control group received the traditional class with overhead projector and whiteboard. Students in the experimental group received a "distance" class using the tool. The unit topics were designed from scratch using the Teaching for Understanding approach. The TFU design of the unit, including the generative topic, through lines, goals of understanding and performances of understanding can be seen at [17].

According to Teaching for Understanding, deep understanding takes place when the individual is capable of extrapolating the acquired knowledge to situations different from those presented in the learning process. For this reason, students in the experimental group, as well as those in the control group, were asked to undertake a small project for local industry. Each group had an industry tutor to assist in the development of the project. At the end, students presented their work to the class and a group of experts, including the industry tutor, who graded their performance.

We will now describe the physical setup. The instructor and the student locations were linked through the campus local area network. Output of the application was projected into a large screen on the students' side. Students were then asked to perform similar actions, allowing them to demonstrate (and at the same time increase) their understanding. In the experimental group, the instructor was in an office in the campus and students were in a remote classroom. The classroom was equipped with a web camera, speakers, a projection surface, a microphone and a desktop computer. The instructor station consisted of a web camera, a headset microphone and a desktop computer. The instructor sat in front of the screen while the students were in normal classroom chairs. The hardware setup is being studied and has been reconfigured trying to achieve the best functionality at lower costs. We are particularly careful with the physical aspects since we consider the lesson development may be affected by the physical absence of the instructor and even more by the use of different technological widgets. The arrangement of the devices plays a vital role. For example we found out that the location of the camera influenced the students' attention to the class. If the camera pointed only at part of the group, the students not in view became easily distracted. We then relocated the camera to cover most of the classroom. Audio feedback was also an issue. Volume settings on the Operating System alleviated the problem. A headset microphone was the best option for the instructor's side.

6 Results

As mentioned in the experimental setup, for both experiments, students presented their work and were graded by a panel of experts according to the four levels of understanding (1 = naive, 2 = novice, 3 = apprentice, 4 = master). The criterion for assigning a level of understanding on each question were described in rubrics matrices, in order to unify the grading process done by the experts. The rubrics matrices can be found at [17].
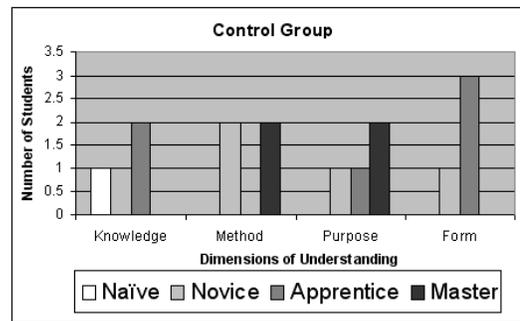
Figure 3. Levels of understanding achieved by subjects in the experimental group of the Graphics course
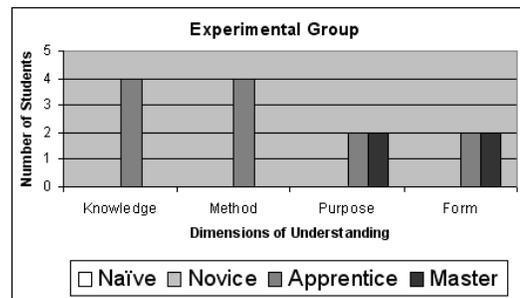
Figure 4. Levels of understanding achieved by subjects in the control group of the Graphics course

For each experiment there were 11 questions. Each question was related to one dimension of understanding (knowledge, method, purpose, form). Averaging over the grades assigned by the experts and the questions for each dimension, each student was assigned a numerical grade in each dimension. Floating point grades were rounded to the nearest integer in order to assign a level of understanding to each student on each dimension of understanding.

Figures 3 and 4 show the results of the experimental and control groups of the Graphics course. Students in the experimental group achieved levels of Apprentice and Master in each dimension of understanding. Students in the control group achieved levels of understanding from naive to master.

Figures 5 and 6 show the results of the experimental and control groups of the Electricity course. Most of
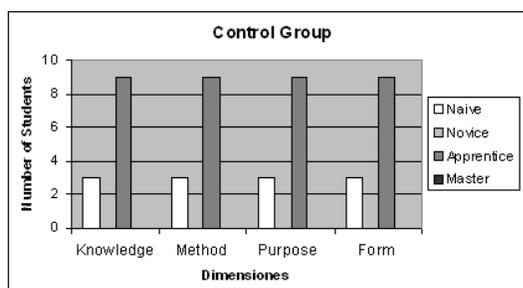
Figure 5. Levels of understanding achieved by subjects in the experimental group of the Electricity course
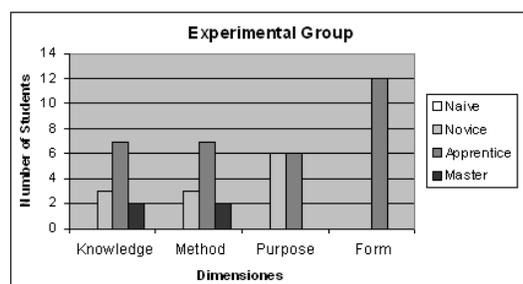

Figure 6. Levels of understanding achieved by subjects in the control group of the Electricity course

students in the experimental group achieved levels of Apprentice in each dimension of understanding. Students in the control group achieved levels of understanding of Naive and Apprentice.

Table 1 shows the numerical grade assigned to each student by averaging the grades assigned by the different experts on all dimensions of understanding for the Graphics course. Subjects E1 through E4 were part of the experimental group. Subjects C1 through C4 were part of the control group. Even though the mean of the grades assigned to the subjects in the experimental group is larger than the one of subjects in the control group, a Mann-Whitney shows that the differences are not statistically significant. Table 2 shows the rankings and R computations for the Mann-Whitney test. The Mann-Whitney test produces a value of 12, the value required for statistical significance of 90% for

Subject	Avg. Grade	Subject	Avg. Grade
E1	3.6818	C1	3.3636
E2	3.6818	C2	3.2803
E3	3.1439	C3	2.5378
E4	3.1969	C4	1.6780
Mean	3.4161	Mean	2.7149
Std. Dev.	0.2960	Std. Dev.	0.7846

Table 1. Mean grades assigned to students in the experimental and control groups in the Graphics course.

Subject		Rank	Subject		Rank
E1		1	C1		3
E2		2	C2		4
E3		6	C3		7
E4		5	C4		8
	R1	14		R2	22
	N1	4		N2	4

Table 2. Ranks used in the Mann-Whitney test for the Graphics Course

Subject	Avg. Grade	Subject	Avg. Grade
E1	2.3646	C1	1.1927
E2	2.3646	C2	1.1927
E3	2.3646	C3	1.1927
E4	2.9896	C4	2.6406
E5	2.9896	C5	2.6406
E6	2.9896	C6	2.6406
E7	2.7344	C7	2.8021
E8	2.7344	C8	2.8021
E9	2.7344	C9	2.8021
E10	3.3125	C10	2.9583
E11	3.3125	C11	2.9583
E12	2.9010	C12	2.9583
Mean	2.8160	Mean	2.3984
Std. Dev.	0.3333	Std. Dev.	0.7365

Table 3. Mean grades assigned to students in the experimental and control groups in the Electricity course.

$N_1 = N_2 = 4$ is 13.

On the Electricity course, the mean of the grades assigned to the subjects in the experimental group is also larger than the one in the control group. A Student's t-Tests (0.047) determined that there was a statistically significant difference with a confidence of 95%. The Mann-Whitney test produced a value of 48 and 96 for U_1 and U for $N_1 = N_2 = 12$, so we cannot reject the null hypothesis. This is due to the fact that the grades of some students in the control group are better than the grades of some students in the experimental group. Table 3 shows the numerical grades. Nevertheless, the results are very encouraging. The statistical data shows that the use of the telepresence tool can compensate for the lack of face-to-face interaction between the instructor and the students as they get similar grades according to TFU.

After the sessions, students in the experimental group filled out questionnaires about the tool and about its impact on their understanding. Several students reported that the tool was an important aid in their process of understanding: "[The tool] allows me to experiment and see the topic at hand". "[The tool] helps me understand the concepts explained by the instructor". Others reported on the interaction among students in the group: "We search for solutions as a group, and this makes understanding easier". Visual-

ization of examples aided in the case of complex concepts: "[The tool] allows me to see the concepts at hand, which are already quite abstract, when I can interact with the Virtual Reality part".

7   Conclusions and Future Work

In summary, results obtained so far are very encouraging. According to the experiment results, the combination of the tool and the use of the TFU approach can compensate for the lack of personal contact between the instructor and the students in the simulated distance environment. Also, several physical limitations have been studied and fixed making the tool more usable. Students have reported that their understanding has been enhanced by the tool, particularly by interaction in the shared virtual environment. We therefore argue that using the tool in a real distance learning environment will prove useful.

From a technical perspective, we will next concentrate on two aspects. First, exploring how the application behaves when running over lower bandwidth links. Currently, the campus network is being used for the experiments. In the next phase of the project, real distance education scenarios will be used. In such a setting, the available bandwidth will probably be less. Better compression algorithms and more careful resource allocation will have to be used in these scenarios. This might imply using Quality-of-Service techniques in order to assign more resources to different modalities (voice, video or virtual reality) at different times, as proposed in [12]. Second, allowing students to be at different places. This will imply moving from a point-to-point architecture into a one multicast or peer-to-peer topology.

8   Acknowledgments

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