SUPPORTING THE LEARNING PROCESS IN THE CLASSROOM USING 3D COLLABORATION ON MOBILE DEVICES

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ABSTRACT

The current every-day-use of mobile computing devices seems to be restricted to applications such as address books, calendars, task lists, simple web navigation and games. In this particular project we explore the use of a collaborative virtual environment, running on Tablet-PCs and PDAs, in the classroom, as means to support the learning process. We have started deploying the application in a Multivariate Calculus course at our institution in order to test its pedagogical impact. The system allows the interaction between an instructor and a group of students using heterogeneous mobile devices, namely, PDAs and Tablets PCs. The interface allows users to enter equations, visualize their surfaces, add intercepting planes and visualize tangents, both lines and planes. In the stand-alone mode each user can manipulate the surface on his/her local device for his/her better understanding. In the collaboration mode, users can interact by modifying the scene in a collaborative manner. When sharing views, one member of the group has the control of the model while others observe as this user manipulates the surface. Note that this interface works both when users are physically in the same place and distributed over the campus. This paper describes the preliminary results obtained in deploying the application in a session of a Multivariate calculus class. From a technical point of view, the paper describes the design of the system, the techniques used to accommodate heterogeneous devices and collaboration protocol.

KEYWORDS

Computer networks, Mobile communication, Visualization, Collaborative Virtual Reality, Teaching for Understanding.

1. INTRODUCTION AND RELATED WORK

Recent advances in computer technology have fostered profound changes both in the social and personal levels. Education, in particular, is one of the areas that has benefited most from those advances. Technology, for instance, makes it possible to create virtual labs, which allow instructors to present scientific concepts to their students in newly forms, allowing students to acquire a more profound comprehension of the concepts at hand.

Computing power and mobility, found in portable devices such as Tablet-PCs and PDA´s in addition to local wireless networks, are reshaping our ideas on the classroom, interaction between instructor and students and the communication that takes place among students in a class, among others. These changes have introduced changes in the teaching of Mathematics, in particular. Math assistant programs can be considered as truly exploration labs, allowing professors, researchers and students to spend more time on the analysis of results than on repetitive activities.

Teaching for Understanding [Wiske, 1999] is being used at our University in the instructional design of Multi-Variate Calculus courses, allowing students to use mobile technology to explore the 3D surfaces that result when plotting equations of the form $z = f(x, y)$ or $w = f(x, y, z)$. Students are asked to find relationships between those surfaces and objects in their surroundings. In this way, the classroom becomes a lab to comprehend and explore the concepts studied in the subject. A technical team works with a pedagogical team in this project allowing students a better understanding of the concepts studied in Calculus.

Emerging technologies, such as Virtual Reality or Augmented Reality [Billinghurst et. al, 2002] are being used for supporting the teaching/learning process. The application of these visualization techniques in teaching multi-variate calculus is particularly promising, as it aids students in visualizing the surfaces related to equations of the form $z = f(x, y)$ [Alvarez et. al. 2003], [Zimmerman and Cunningham, 1991]. Visualization can be done in a standalone manner, when the student uses the tool by himself or herself in order to deepen his or her understanding of the subject at hand; or it can be used in a collaborative manner [Restrepo and Trefftz, 2005]. The learning process seems to benefit when collaboration is enhanced by technology. Collaborative Augmented Reality is a promising field, as reported in [Orozco et. al., 2006], [Billinghurst and Kato, 2002] and [Schmalstieg et. al, 1996]. The work presented in this paper builds on collaborative visualization, but differs from the above in that emphasis is placed on mobile devices used in the classroom, mainly tabletPCs and PDAs, connected through wireless networks (Wi-Fi).

The rest of this paper is organized as follows: section 2 describes the pedagogical principles of the project, section 3 the development of the tool, section 4 the use of the tool in the classroom, section 5 and 6 present the future work and conclusions and section 7 the acknowledgements.

2. PEDAGOGICAL PRINCIPLES

The education processes, seen as social phenomena, show learning as a result of joint human activity where individuals access development, support and technological materials to construct self-referral connections with their realities. These connections are understood as

concrete intervention circumstances of a determined situation and they also configure the place and the product where the subject's intentions and projects meet.
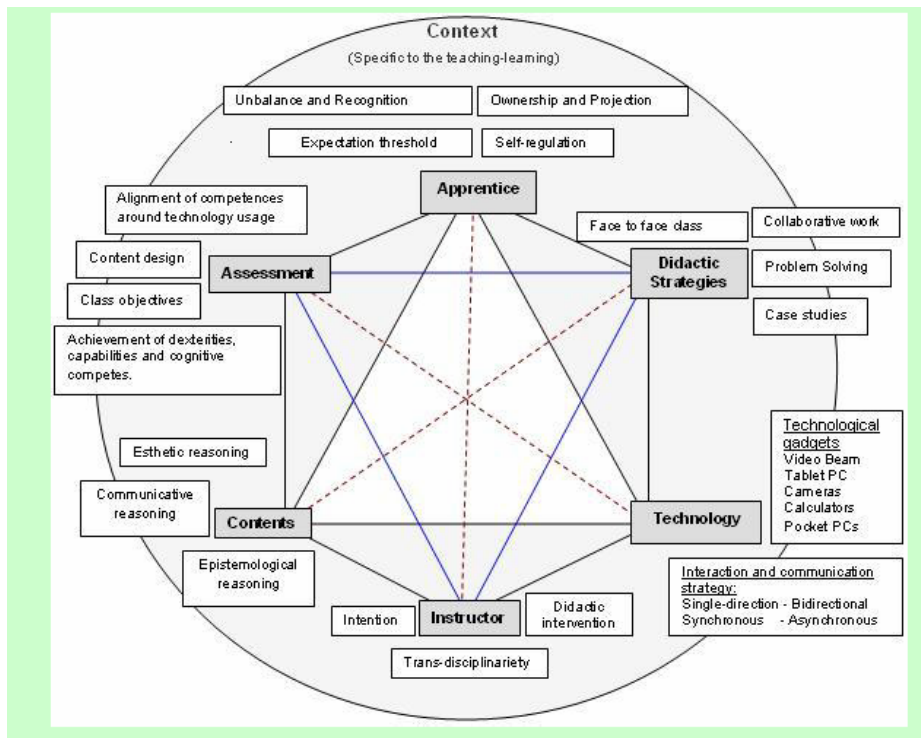

Figure 1. Interactions among the actors and technology involved in the experience.

Figure 1 describes the interaction among the different actors or components involved in the experience. From the cognitive point of view actions where given to develop collective unified and multidisciplinary constructions that revolved around the concepts as well as the formalization of the synthesis and appropriation processes. These actions were managed beginning with the stimulation of concept comprehension in a differentiated way. Like for example the consolidation and interrelation of the studied concepts.

From the procedural point of view this was made explicit by actions to represent, modify parameters, develop specialized searches, argumentation contrast, comparison, analysis and interchange in an autonomous or collaborative-distributed environment. That is, under the responsibility of each of the apprentices with respect to the product that was given by the group. In some experiences evaluation processes of competence acquisition where taken into account.

Situations presented themselves where the error and difficulties were not managed following a norm but were procedural. This allowed a cognitive construction through the auto management and auto control processes in a positive and natural way that was performed by the students, favoring at the same time the interaction with the teacher.

2.1 Pedagogical design of the interaction experiences

The way concepts are presented, has a deep impact on the comprehension achieved by students. A key issue in the design of the experience was the fact that the technological development has to go hand in hand with a pedagogical approach in order to achieve profound and meaningful understanding by the students.

- Learners should recognize the explicit outcomes in a way that the information and process planning, through the activity, target theirs expectation threshold and promote ownerships option and self projection (Talizina, 1975).
- The activities process and the learning material must be presented in such a way that match the different cognitive level and learning styles of the learners in the field of communicative, epistemological and esthetics reasoning on the Vygotsky zone of proximal development (ZPD) (Wertsch, 1985).
- Strategies should provide achievement of dexterities, capabilities and cognitive competences through unbalance and recognition of theoretical and conceptual models, as well as, organizer structures that permit the transformation and construction of their own and others knowledge (Vygotsky, 1996; Piaget, 1971; Ausubel, 1960, Izquierdo and Sanmartí, 2003).
- Learners should be given control of the learning process, working with others learners in collaborative and cooperative real-life situations, allowing them to use their metacognitive skills (Hooper and Hannafin, 1991; Johnson and Johnson, 1996; Palloff and Pratt, 1999; Meyer, 1998; Sternberg, 1998).
- The situations should allowed a cognitive construction not managed following a norm but procedural through the auto management and auto control processes in a positive and natural way that was performed by the students, favoring at the same time the interaction with the teacher/tutor chosen Teaching for Understanding (TFU) support (Wiske, 1999; Stone, 1998).
- Learners must be provided with interventions and feedback that allow taking corrective action if required. Intervention should be presented in different modes to accommodate the targeting of intrinsic and extrinsic motivation, attention, relevance, confidence, satisfaction, and encouraging the use of their self-regulation in an autonomous way (TFU) (Wiske, 1999; Stone, 1998).

One of the fundamental objectives of the portfolio is for students to document their advances in the understanding of Calculus and its application in science. This improves their self-esteem, helping them to increase their confidence on their learning capacities, allowing them to create relations between what they learn and what they observe in their surroundings. The portfolio was divided in three phases:

Preliminary phase: Students search their surroundings in order to explore what objects, constructions, places, daily used elements, among others, are the result of applications of calculus and sciences. Students find relationships between these objects with the formulas covered in the course, take pictures and describe the objects mathematically. Students collect all documents, URLs, pictures and other materials that are collected during the development of the project.

Guided research: Students, aided by the instructors, select a project allowing them to apply the concepts covered in the course. During this phase, students report periodically their

advances in the construction of the project and discuss with an expert their advances and questions.

Final performance: Upon completion of the project, students present their projects and results to their peers. In their presentations show the various phases of the project and the possible solutions found to the problem. An expert performs a qualitative final evaluation of the project.

3   SYSTEM ARCHITECTURE

In order to achieve collaboration in the classroom, two types of interaction take place: 1) collaboration through the tool and 2) face-to-face interaction. The second type takes place since all participants in the session are located in the same room. Figure 2 shows the system architecture.
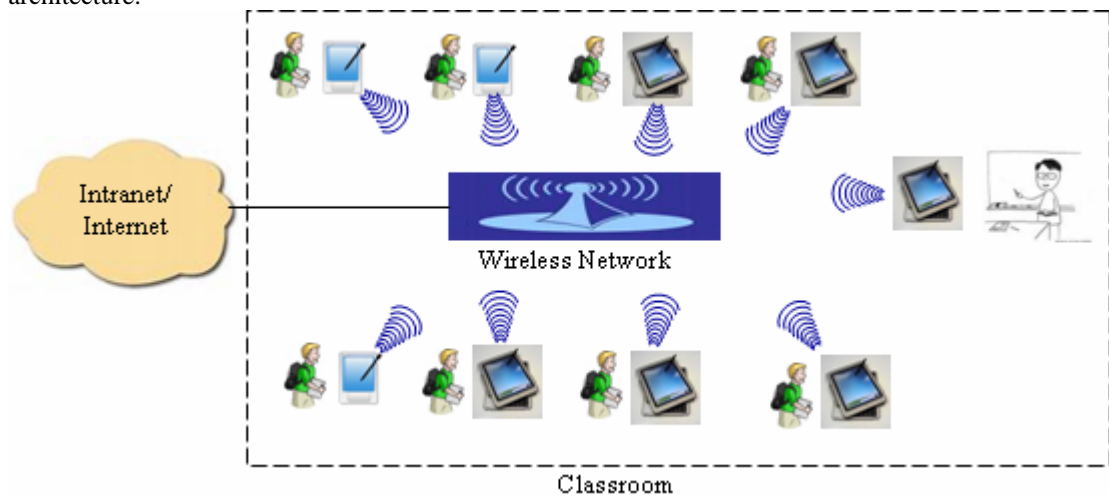

Figure 2. System Architecture

Wireless Network:
Communication takes place through a wireless network. In this case, a Wi-Fi IEEE 802.11b/g network. The network can be configured either as 1) infrastructure or 2) ad-hoc. If there is an access point in the classroom, students share an entry point to the Internet. If an access point is not available, an ad-hoc network can be configured, allowing stations to communicate amongst them.

Communications protocol:
From a user point-of-view (either the instructor's or the students'), the application uses a peer-to-peer protocol. But the application is actually implemented on top of unicast protocols, which make it necessary to have one station act as a server and all the others as clients. In this manner, any interaction between a pair of nodes has to go through the server node. When a session starts, all nodes need to know which station is acting as the interaction and graphics server.

Given that all participants are located in the same place, there was no need to implement any video- or audio-conference tool. Students and instructors communicate using their voices.

Support services:

All participants can use all available educational tools available at the university, given that they have access to the Internet. E-mail, Web pages and e-learning platforms are readily available as support for the learning process. No other local support systems have been developed so far.

4 DEVELOPMENT OF THE TOOL

When developing software to run on Tablet-PCs and PDAs, several technical challenges had to be addressed. It became necessary to create a programming model with the following characteristics:

- Construction of robust and rich interaction techniques allowing students to utilize the tool on mobile devices inside the classroom.
- Memory and computing power are limited on mobile devices. For this reason, the choose of language and platform had to be strongly influenced by performance considerations.

Based on these issues, the following architectural decisions were made:

- C++ was chosen for development. Its efficiency and direct control of the hardware resources had utmost importance on the PDA version.
- MFC (Microsoft Foundation Classes) was chosen as framework to design the graphical user interface. MFC includes a rich set of widgets and runs on TabletPCs and PDA's.
- OpenGL ES was chosen as 3D API, for being an industry standard.

With theses architectures, it is possible to have direct hardware control in order to build portable and efficient software that allows for user interaction with the 3D applications.

4.1 High-level description of the architecture

The final architecture corresponds to the well known layer pattern to decouples different aspects of the functionality, as described in Figure 3. Its main components are:

- Core layer: Expose the basic services needed to support communication on rendering of 3D scenes.
- Toolkit: Offers classes and services to model and manipulate the scenes the user describe using a mathematical language.
- Application: This layer all aspects of interactivity with the user

The use of frameworks were also critical in our project, since it allows us to develop quickly and with great quality result. We used the following frameworks:

- MFC: Having used Microsoft's Visual Studio for development, gave us access to it's rich library of classes know as the Microsoft Foundation Classes.

- STL: The Standard Template Library know comes with every C++ compiler distribution and was quite useful to handle algorithms and data structures.
- XTL: The eXternalization Template Library is an open source library designed to serialize data in an representation independent format. This was necessary to support the use of different technologies in the project (we can use Java on the server and C++ on the clients for example)
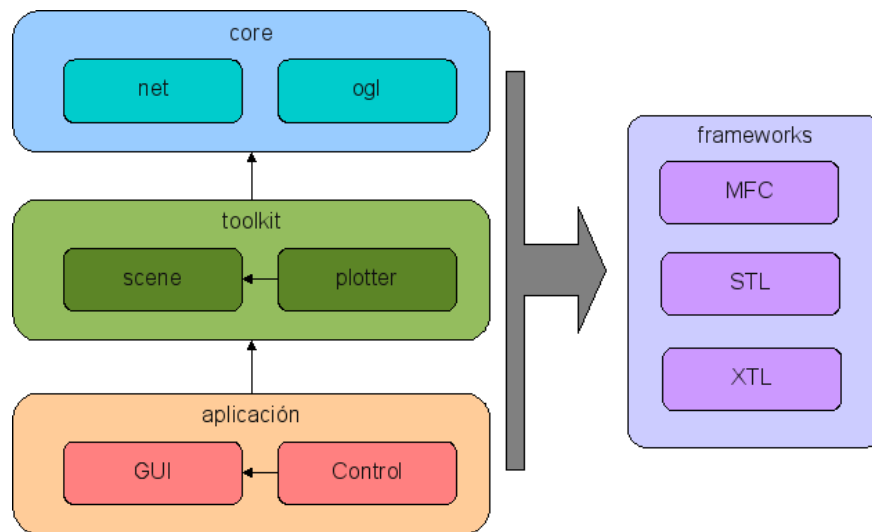
Figure 3: Design components.

4.2 Functionality

The application allows users to:
- Define the surface in terms of an equation of the form $z = f(x,y)$.
- Rotate the surface in any direction.
- Zoom-in and out of the camera in order to observe specific portions of the surface.
- Add intersecting planes along any axis (x, y or z)
- Visualize traces (intersection of a surface with a plane) parallel to the x, y or z axis.
- Intersect planes that are parallel with the axes (x, y or z) with the surfaces, and move the corresponding traces accordingly.

On the TabletPC, the interface is designed as an MDI (Multiple-Document-Interface), that is, users can manipulate multiple windows in the working space, as described in Figure 4.
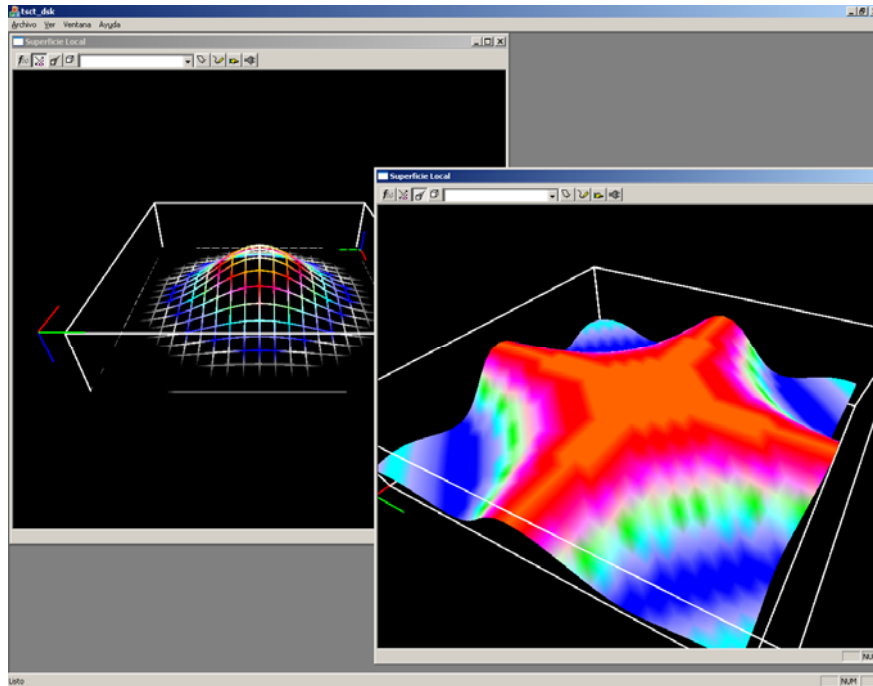
Figure 4. Application Interface

Each sub-window contains a toolbar allowing the users to manipulate the figure as described before, as described in Figure 5:
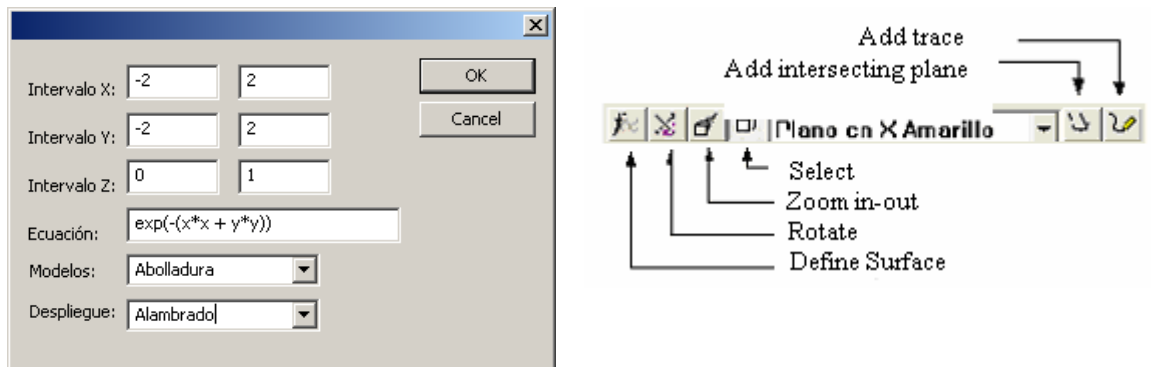

Figure 5. Dialog boxes.

5   PEDAGOGICAL DESIGN OF THE EXPERIENCES IN THE CLASSROOM

The way concepts are presented, has a deep impact on the comprehension achieved by students. A key issue in the design of the experience was the fact that the technological development has to go hand in hand with a pedagogical approach in order to achieve profound and meaningful understanding by the students.

Teaching for Understanding (TFU) was chosen as the pedagogical support to design the classroom experience. This pedagogical framework helps the instructor answering questions such as: What strategies should be used by the instructors in order to achieve true understanding by the students? How to determine what the students have actually understood? How do students manifest their understanding of the topics covered in a unit? How can the instructor support the development of understanding? What types of tasks are more appropriate for students to achieve understanding? These and other questions that in some cases are not taken into account when designing new curricula are the fundamental actions that take place in the education process [Wiske, 1999].

TFU proposes for dimensions of understanding: (1) Contents, which are directly related to the curriculum, (2) Methods, which are the way to build new knowledge, (3) Praxis, the way how the practical aspects are implemented and, (4) Communication forms, related to the area-of-knowledge specific language. With the help of technology, new communication ways are discovered. Also, in order to implement TFU, it is necessary to consider four components: (1) Goals of understanding (What level of understanding will students reach at the end of a learning process?) (2) Generative topics (What motivates students to learn a new concept?) (3) Performances of understanding (What activities are carried-out by the students allowing them to improve and demonstrate their level of understanding?) (4) Continuous evaluation (How to evaluate the advancement of understanding?)[Blythe, 1999].

TFU allows the instructor to integrate new technologies and resources, allowing students to develop new abilities, dexterities and comprehend new concepts, in a way that is not possible in traditional classes. It allows the instructor to determine those topics that are most important in the development of a subject, as well as which concepts can be acquired by the student, in a parallel manner, without wasting time. This pedagogical framework helps each student taking advantage of his/her best-developed intelligence, discovering and developing his/her potential. TFU is a flexible pedagogy, which Math instructors can use in the preparation of courses, allowing them and their students in the preparation of their courses. It allows both instructors and students achieving new insights and profound understanding of the concepts at hand. When applying this pedagogy in the teaching of Math, instructors can define short- medium- or long-term goals. TFU integrates diverse methodological approaches in order to foster understanding of the studied subjects, particularly those that are fundamental for building knowledge in the studied area, thereby creating a link between the interests and need of the students. This pedagogy has not a single way to be applied, and therefore, the way how it is presented to the student and the level of understanding achieved by the instructor himself play a very important role in its implementation. In order to implement TFU, students were asked to create a portfolio to write their experiences with the subject and the relationships they built with other subjects or their surrounding. The portfolio was divided in three phases: (i) preliminary, (ii) guided investigation and (iii) final performance as seem on item 2.1.

One of the fundamental objectives of the portfolio is for students to document their advances in the understanding of Calculus. This improves their self-esteem, helping them to increase their confidence on their learning capacities, allowing them to create relations between what they learn and what they observe in their surroundings. Computational tools help students discover new patterns or processes that would, otherwise, be unnoticed. TabletPCs and PDAs allow students to keep working in a natural way outside of the classrooms, in their natural surroundings.

5.1 Integration between pedagogy and technology

The instructor presents various activities in order to facilitate the recognition of the problem related to the instructional design. Once the problem is recognized, the instructor invites students to discuss about several solutions, thereby motivating students to follow an action plan and the regulation necessary to achieve it (Talizina, 1975). An example of this is the activity to model a real surface (a hill), based on functions of the form $z = f(x,y)$. The relevant characteristics of the surface must be recognized and related to known mathematical functions, thereby integrating reality with the math functions. In this process, students create the conceptual networks proposed by Ausbel (Ausbel, 1960). The solution process motivates the students' participation in multiple ways. In this way, the classroom becomes an interaction space in which the graphical representation of equations is an instrument to debate and contrast multiple points of view, thereby explicating the performances of understanding (Wiske, 1999, Wiske, 1998).

The communication process, both with the peers and the instructor, invites to the knowledge and appropriation of codes that are pertinent to the learning context, in a proximal development zone, as described in (Wertsch, 1985 and Vygostky, 1996). The explanation of the solution, as well as the position taken in relation with it, motivates students to build knowledge in a process based on respect by the peer and on assuming their own responsibilities (Stemberg, 1998).

The design of learning experiences based on the pedagogical approach, and their technology-supported implementation in the classroom, allows for the creation of multiple interaction forms, as described in figure 6. The vertices of the rectangle are:
- The instructor (I)
- The students (A)
- Physical objects (RO)
- Virtual objects, built by the students and visualized through the Internet (VO)

The above interactions allow students to contrast the presented concept in various ways:
- Interacting with the instructor whether face-to-face or technology-mediated.
- Interacting ith his/her peers, sharing the computer graphs and discussing the explicit understanding about the concepts at hand (Talizina, 1975). In this interaction, students can use language, share real or virtual objects, creating new meanings (Wiske, 1999, Wiske, 1998), creating relationships between real and virtual objects and other activities.

- Applying the concepts at hand from the performances of understanding (Teaching for Understanding).
- Modifying their concerns about the topics at hand.
- Creating relationships between the objects and the course contents, thereby creating new relationships and conceptual structures (Ausubel, 1960).
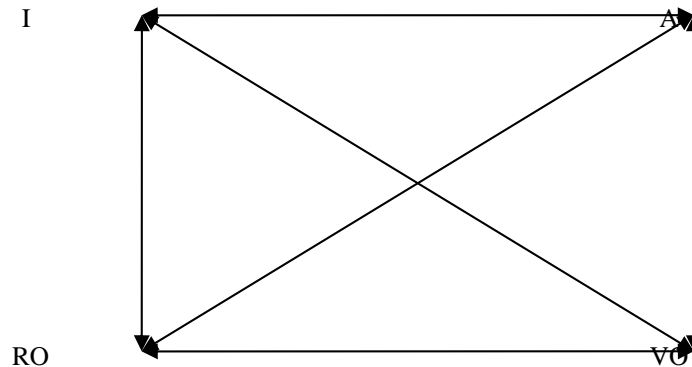

Figure 6. Interactions between people and objects in the classroom

The pedagogical design and its technology-mediated application, allows students to build their knowledge in an incremental manner, starting from the interactions with their peer, instructors and virtual and real objects. These interactions, in turn, help students build their self-esteem and ability to contrast concepts.

5.2 The experience in the classroom

Calculus is, by nature, the math of change. It allows students to understand, in a formal manner, a great variety of phenomena from several areas of knowledge [7], allowing them to find patterns to:
- Represent changes in an understandable way.
- Understand the fundamental types of change.
- Identify particular types of change whenever they happen.
- Apply these techniques in the outside world.
- Control a changing universe.

Learning experiences were designed with these ideas in mind, keeping into account the learning phases described previously. TabletPCs were used initially as exploration tools. TabletPCs were taken into the classroom and Internet was used allowing students to explore web pages covering the studied material. MuPAD [MuPad, 2006] was also used to plot several equations of the form $z = f(x,y)$.

Nevertheless, students had limited interactivity. They could not rotate, mark points on the surface, intercept planes with the surface nor move the surfaces to visualize traces. Mobile technology, on the other hand, fostered group collaboration. Students explored new solutions to the proposed problems, and were eager to show their peers and their instructor their results. Figure 7, describes a working session in the classroom.

Figure 7. Students working either alone or in groups.

The portfolio was developed during the course, were presented in the classroom with the aid of mobile technology. Alternative solutions were considered with the use of TabletPCs.

5.3 Results and evaluation

The experience with the application was undertaken with a group of 35 computer science students at our University. By the end of the experience, students were asked several oral questions and they filled-out a questionnaire. These are some of the questions and the most representative answers to each question:

1. *What use did you find for the program that was used in the classroom?*
   - It allowed me to better understand 3D graphics.
   - 3D graphics are easily observed. The way how the intervals and functions are defined is particularly useful.
   - It allows me to touch and visualize what is done with the equations.

2. *What concepts are better understood with the use of the program?*
   - Understanding of the equations of various solids, as well as concepts such as traces,

maxima, minima and curves, among others.
   - Limits of integration and the concept of volume.
   - Tangent planes, variation and slopes.

3. *Did the use of TabletPCs with this program allow you to understand better the concepts of Multi-Variate Calculus?*
   - Definitely yes. The exercises and the explanation of the instructor are not enough.
   - It allows me to visualize the graphs, and this way the memory of the concepts covered

in the course.
   - It allows us to get closer to reality.

6   FUTURE WORK

This paper shows partial results of the combination of mobile technology (TabletPCs and PDAs), software development and pedagogy, and how this combination can improve the

learning of Math. The future work will continue in two fields: the technological and the pedagogical.

From a technical point of view, we are about to test the new version of the application, which will run both on TabletPCs and PDAs with a campus wireless network connection. This will allow the instructors and students to interact from any place in the university campus. In order to accomplish this, we will have to develop new protocols to support interactions outside of the classroom (probably multicast protocols). In this case, we will need to support audio- and video-conferencing tools, in order to keep a "natural" communication between the participants. With the increase of bandwidth consumption, Quality of Service will become an important issue.

Figure 8 shows a preliminary version of the software running on PDAs.

Figure 8. In future developments, a more mobile solution will be implemented, and PDAs will be used in the classroom.

From the pedagogical point of view, we have found that interaction of pedagogy and technology during the project has benefited students, allowing them to better understand that Calculus is a powerful tool for thought, and that many objects that we use on a daily basis could not have been developed with a profound understanding of the Calculus concepts. In the next experiences we hope to improve the interaction between technology and pedagogy, allowing students to reach more profound understanding of the Calculus concepts.

7   CONCLUSIONS

From a purely technical point of view, the development of the application was quite a challenge. OpenGL as one of the project's requirements limited our options only to C++. OpenGL Support on mobile devices seems either immature (over free/open implementations) or license restrictive (commercial ones). Win32 is supposed to be a uniform platform, but trying to use the same code for Win32 on the desktop and Win32 for PocketPC was really hard. There are too many subtle differences that are difficult to debug. We ended up with 3 applications using 5 sets of code (Java, , C++, OpenGL, Win32 for PC, Win32 for PocketPC).

On the other hand, the development of this project shows that it is possible to create multi-disciplinary teams to formalize learning experiences allowing students to better understand mathematical concepts that will be very useful in their future professional lives. Some conclusions presented by the students are:

- The tool is very good, and one can find relations between Calculus and objects in Nature. Without the use of the application, this would not be possible, since without the application I cannot create all the graphs that I need to accomplish this.
- The application allows us to find a relationship between Calculus and reality.
- Applications like this should be used in all courses. We are surrounded by technology, anyway.

ACKNOWLEDGEMENTS

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