

Evaluation of an Augmented Reality Enhanced Tabletop System as a Collaborative Learning Tool: A Case Study on Mathematics at the Primary School

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Abstract

Tabletop systems provide a big multi-touch surface suitable for multiple users to gather around it that can interact with the information collaboratively in a face-to-face manner. This kind of device is well adapted to be exploited in education, combining the advantages of e-learning systems with collaborative learning environments, which are adequate in educational paradigms based on constructivism and knowledge building. This article presents the capabilities of our in house developed tabletop system as a collaborative learning tool, which has been enriched with Augmented Reality capabilities and designed to follow the principles of Ubiquitous Computing and Natural Interfaces. The evaluation of the system was performed in a real educational context. Experience was driven to compare the tabletop learning scenario to other standard learning approaches. The evaluation method was centered on three parameters: efficiency, usability/satisfaction and motivation. Results conclude that tabletops represent a promising technology that can be applied successfully in educational contexts.

Categories and Subject Descriptors (according to ACM CCS): K.3.1 [Computers and Education]: Computer Uses in Education—Computer-assisted instruction (CAI)

1. Introduction

Over time, technological development has undoubtedly improved teaching techniques, allowing for better information communication and improved understanding. Multimedia has played in this sense a key role, allowing contents to be displayed in a much richer and realistic way than they were listed in textbooks and traditional materials.

However, sometimes technology presents a barrier to the student, which requires being an expert in the management of the platform used in the learning tasks. Usually it is necessary to train students in the use of technology to be used later as a learning tool, which results in an interruption in the learning process and consumes a lot of time.

Advances in Natural Interfaces can significantly reduce this negative effect. In these kinds of interfaces, communication effort lies in technology, and the user does their work naturally, without needing to learn how to use elements or techniques created specifically for communication with the computer. Tactile devices respond to this type of interface, where users employ their fingers to interact with the system

by tapping or gesturing. Also a teaching tool must be framed within "Ubiquitous Computing", which tries to hide the most of the complexity of the technology, making their use quite natural.

At present diverse didactic currents propose different educational paradigms that restate the classic method of teaching, like Constructivism and Knowledge Building. Both agree on treating the student as an active member in the learning process, which must somehow construct their own knowledge. They promote collaborative learning, where knowledge lies not with the individual but the entire group.

In this context, tabletop systems are particularly interesting because they are originally designed as a tool for collaborative work, in which multiple users can interact on a common surface, favoring communication in a "face to face" manner.

This paper presents the results of using a tabletop developed at our research institute, to support collaborative learning activities. The software platform that controls the tabletop is able to recognize multiple fingers from different hands

and Augmented Reality (AR) marks. Educational applications have been developed on Adobe Flash, because of its wide distribution and multimedia capabilities. Thus it is possible to easily integrate multidisciplinary development teams composed of programmers, graphic designers and other professionals, maximizing system capabilities and improving productivity in the generation of content. The integration of Adobe Flash and the software platform that controls the tabletop is performed by a middleware layer, based on the TUIO communication protocol [KBBC05] that supports the communication between the tabletop and Actionscript.

Taking advantage of the recognition capabilities of AR marks in our system, we have developed an automatic means for identifying students in real time, allowing historical storage of chronological information of students participation over the interactive surface. This information could be used in real time or in a subsequent analysis.

The case study has been performed about a thematic unit on geometric bodies for fifth year of primary school pupils. This topic was selected by a group of primary school teachers due to the difficulty that its correct understanding presented to students. Two types of content were developed: an application designed primarily to support teachers in their explanation about the features and forms of geometric bodies, and another set of applications designed specifically for the students, in this case, a set of four games, which encourage collaborative learning and maximize the degree of attention.

Results show a significantly improved performance of the group using the tabletop with respect to the group following the regular teaching method. Participant students showed a high interest in the use of the new technology in the classroom. The different sessions of exercises/games showed a high degree of engagement of students, including those with greater attention problems, and a high degree of collaboration in problem resolution tasks.

2. Related work

It is well known and covered in different studies that teamwork is beneficial for learning [Sla80] [Wat91]. When students work sitting around a traditional table, the space between them is used for communication. In that context, look, gestures and nonverbal behaviors are important elements. Participants can see each other and communication is shared with objects and matters under discussion. However, when students work in teams, but in front of a computer, their focus is on the screen, which has been called shoulder-to-shoulder interaction [POMW06], significantly reducing the communication possibilities, leading to a cooperative model of teamwork. Tabletop systems provide a multi-touch surface, which can be large, and suitable for multiple users to gather around it where they can interact with the information collaboratively. Hence the new interfaces based on tabletops

are a good solution as a teaching tool [HRB*09], from the point of view of favoring a truly collaborative environment, and promoting learning based on constructivism.

Another type of work focuses on the advantages of using tangible elements to enhance collaborative work. Resnick et al. [RMB*98] present an excellent work in defending children's learning based on "manipulative interfaces". As they say, the idea that physical objects might play an important role in the learning process is a relatively new idea in the history of education. O'Malley and Stanton [OSF10] discuss how this type of interaction is helpful in learning tasks, providing students tools that encourage collaboration. Pontual and Price [PP09] provide an example with good results, using a tabletop with tangible elements. These authors present a collaborative environment where students can learn the theory of light, thanks to their own experiments, which are created by manipulating tangible elements in a natural form. Other works [FIB95] [IU97] [Ish08] propose the use of tangibles as a tool to improve interaction by making it more natural and closer to interactions that take place in the real world.

Augmented Reality is also used and analyzed in several works as an educational tool. Woods et al. [WBL*04] show the educational benefits arising from virtual and augmented reality, particularly improving the interpretation of spatial, temporal and contextual content. The authors also comment that the use of these technologies improves kinesthetic learning because students interact directly with the educational material, and they associate the content with bodily movements or sensations. This type of learning, though slower, allows improved retention of acquired knowledge.

3. Tabletop system

The tabletop system used in this study (Figure 1) was developed by members of our research group. The system comprises a stereo video projector and two cameras that provide stereoscopic view of the interaction surface. It supports both multi-user and multi-touch interaction. The cameras take images (stereo pairs) of the hands and the objects placed on the surface, recognizing the position of each finger (including the distance to the table).

At the same time, the system is able to recognize AR marks, returning in this case their position and orientation in 3D space. With this functionality, our device is able to combine the advantages of a tabletop with the advantages of projective augmented reality. Thus, simple AR marks, which can be printed on paper with a simple printer and glued to a card, can be used as tangible items to enrich the user interface in an economical way (unlike other systems).

This hardware configuration allows any type of table as the projection and interaction surface. This is a valuable quality for installation in a classroom. The self-calibration capability of the tabletop provides a robust system that can

be moved to any location in the classroom, using several students' tables to create the surface of interaction. When the learning activity with the tabletop is finished, the system can be stored, and the students' tables reorganized.

The system recognizes multiple fingers and hands. This means that several users can interact with the system at the same time allowing cooperative interaction.



Figure 1: *Tabletop system.*

The current version of the system also supports marker-less AR capabilities that basically is used for augmenting the content of regular textbooks.

A specific API, based on the TUIO protocol [KBBC05] has been developed to provide (supporting a distributed computing model) the information about the state, position and orientation of the fingers and AR marks to the client applications.

Before assessing the Tabletop in a real educational environment, we conducted usability tests with several groups of children. These tests allowed to set the parameters for optimal recognition of hands and fingers. They also served to check the possible interference that may occur in groups as it is a projective system. In this sense, although eventually some interference occurred, was not a significant problem and the children themselves naturally solved without needing help.

4. Didactic contents

For the study, a series of educational applications about "geometric shapes" were developed for the Mathematics subject of fifth year of primary education (10-year-old children). On one hand, a teacher application was developed, mainly to be used by the teacher to make the explanation using the

tabletop. It is a 3D interactive application that allows the different elementary geometric shapes to be manipulated and visualized. The application allows all the characteristics of the main bodies to be explored, according to the needs of the educational level that occupies us. A premise in the design of the application was that it must be very easy to use and intuitive, since in previous interviews with different teachers, all of them expressed concerns over of the complexity that they could present.

On the other hand, a set of games for students was developed to practice the concepts explained by the teacher in a fun way, thus ensuring a higher and prolonged level of attention. Four applications/games were developed: a relationship game, a classification game, a "memory" game and an action game.



Figure 2: *Students working with the 'Cannon Game'.*

Several studies show that the incorporation of tangible items improves user interaction with the system and collaboration in solving a problem [IU97] [OSF10] [PP09]. This principle applied to education helps to improve teamwork and collaborative learning, based on constructivism. For this reason, tangible items were used in the design of a game, called "cannon game", which consists of hitting with a cannonball, a geometric body requested by the system. The cannon is represented by a tangible item, which is simply an AR mark inside a drawing of a cannon on cardboard. A scroll bar is used to select the intensity of firing, so that upon release the cannonball runs in the direction pointed to by the cannon. The game is designed to be played actively by two players. One student handles the cannon and the other is responsible for controlling the power of the shot. Both of them must collaborate to solve the common problem that is hitting the requested geometric body. The rest of the group also participates in the problem resolution, generating a truly collaborative atmosphere (Figure 2).

5. Augmented desk

One of the main objectives of the research was to design a natural interface that hides the complexity of the technology, and respond to natural movements and actions of the

user. The idea is to approach a ubiquitous computing environment in which the conventional space of work of students in class, their own tables and desks, becomes an interactive surface in a natural way, allowing interaction with digital content.

In this way, we have leveraged the capabilities of using AR marks and have developed a mechanism to transform the common workspace into an interactive surface simply by placing AR marks on it. Additionally, we have associated different contents to different marks, so the conventional table is not only transformed into an interactive table, but also offers content related to marks on the surface at any time. To enhance the idea of a "natural interface" we built a prototype textbook that incorporates AR marks on its pages, so the system is able to recognize the current page, and also its position and orientation on the table.



Figure 3: Students using the textbook with AR marks.

Therefore to activate the system, the teacher simply has to switch on the system, which is situated on an elevated position over the workplace (ideally on the ceiling). From that moment, the system is active but projecting a black screen onto the workspace, which can still be used in the traditional way. To launch different applications, students (and the teacher) have a textbook that incorporates augmented reality marks on its pages. It is enough to open the book on the table at the appropriate page and the system will automatically display a menu next to the book with various applications related to the educational contents shown on the opened page, and the conventional workspace becomes an interactive surface (Figure 3).

Recently we have incorporated markerless recognition capabilities into the tabletop, so we could recognize pages of the textbook (and its positions and orientations) without the need of printed AR marks. This is interesting because it allows the use of conventional books without requiring any modifications.

6. Application development environment

One of the main problems in generating content for systems based on new technologies, such as this tabletop, is the dif-

ficulty and restrictions that arise in the content generation phase. To overcome these limitations a general multimedia production system had to be selected. Adobe Flash and ActionScript programming language was the chosen environment, which allows easy integration of teams composed of programmers, graphic designers and multimedia experts.

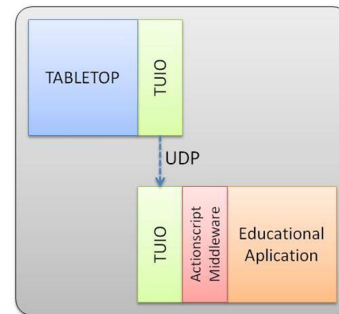


Figure 4: Tabletop architecture.

To connect the applications developed on the tabletop with ActionScript, a middleware layer based on the TUIO protocol has been developed (Figure 4), which collects the TUIO frames sent by the system, decodes them and sends events that can be easily treated by multimedia applications. Thus, the development team is freed from the tasks of communication with the system, focusing on the content itself. The system simulates mouse clicks, scroll bars, zooms, etc... Similarly, it is possible to manage different Augmented Reality markers arranged on the table, recovering their ID, position and orientation.

7. Real time identification

In collaborative learning environments it is necessary to evaluate the degree of participation of each student, which must be taken into account in their assessment. Usually it is the teacher themselves who observe the development of students' work and evaluates, among others, this component. However, observation tasks become difficult when there are several collaborative workstations. Methods of assessing the degree of participation based on analysis of video recordings have traditionally been used in these situations. However, this process is slow and not very suitable for use in a real environment in which teachers do not have the required time for this task.

In this work we propose a simple and economical system of collecting information of the degree of students' participation based on the identification of each individual using AR marks.

Each student carries an identification AR mark on his wrist, like a bracelet (Figure 5). Thus, the system is able to identify a student in real time each time his hand is within

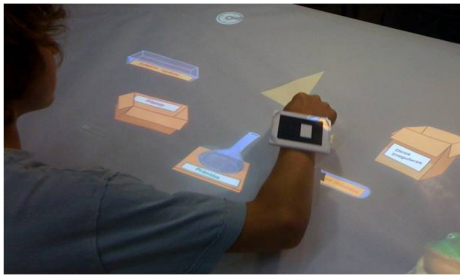


Figure 5: Student carrying the identification bracelet.

the workspace of the Tabletop, registering the chronological information of the taken actions in a database.

The system stores the data automatically in chronological order: inputs and outputs of each student over the workspace, keystrokes, gestural actions, events generated, success and failures caused by their actions, etc.

This information can be analyzed and subsequently synthesized automatically yielding results that are valuable in assessing the degree of participation of each student, and other parameters.

8. Evaluation

To analyze the impact of the tabletop on the learning process, three parameters have been selected to be studied: efficiency, usability and motivation. Their analysis is detailed in the next points.

8.1. Methodology

The experience was developed over 7 thematic units of the subject of Mathematics, in the fifth grade of primary education. All the units were developed in the traditional form, except unit 4 ("Geometric Shapes") that was developed using exclusively the Tabletop. Two tabletops were used simultaneously in the class.



Figure 6: Teacher teaching with the "Geometric Shape Examiner" on the Tabletop.

Unit 4 was taught along six sessions. In the first four sessions, the teacher used the tabletop for the explanation of concepts in the first half of each lecture (Figure 6), using the application "Geometric Shape Examiner", with groups of 10 students at a time. The teacher eventually asked questions that children had to solve using their own tabletop. In the second part of the lectures, students practiced in groups with the games, under the teacher's supervision. In the last two sessions, the teacher organized groups promoting competitiveness, and planned the order of the games/exercises. Students themselves in a collaborative way tried to solve their doubts in the games/exercises, helping each other, under the supervision of the teacher.

8.2. Efficiency

Efficiency has been evaluated from the point of view of new knowledge assimilation. For this task it's possible to use a quasi experimentally not equivalent control group design, where a group of students uses the new technology for a certain thematic unit, while another group uses the habitual didactics.

However, this approach often generates comparative grievances between students of the same course, since only a subset of them benefits from new technology. Thus finally a quasi-experimental design based on cohorts was selected, where the results obtained by two groups of students who were enrolled in the same subject but from different academic years were compared.

The group of pupils who attended the subject in the immediately previous academic year was named "group n-1" (cohort 1) and it served as the control group. On the other hand, the group of students who attended the subject in the current academic year (the year in which the assessment is made) was named "group n" (cohort 2). "Group n-1" never received teaching with the tabletop, while "group n" received teaching in a specific thematic unit with this system. The "group n-1" consisted of 27 students, 13 boys and 14 girls. The "group n" consisted of 28 students, 14 boys and 14 girls.

For the study, the results of seven thematic units of the subject of Mathematics in the fifth grade of primary education were compared. The "group n-1" was taught all the thematic units in the traditional way, whereas "group n" received traditional teaching in all thematic units except unit 4 (Geometric Shapes) in which the tabletop system was used. Both groups studied with the same teacher using the same methodology, sequence of thematic units and teaching materials (except unit 4 in year "n").

Table 1 shows the proposed quasi-experimental design scheme based on cohorts. The first row represents observations (evaluation results) for each of the seven units in the year "n-1" (cohort 1), and the second rows represents observations for the same units in the year "n" (cohort 2). By example, O15 represents observations taken after teaching

	Observations (O) and Tabletop (X)							
Cohort 1 Year n-1	O ₁₁	O ₁₂	O ₁₃		O ₁₄	O ₁₅	O ₁₆	O ₁₇
Cohort 2 Year n	O ₂₁	O ₂₂	O ₂₃	X	O ₂₄	O ₂₅	O ₂₆	O ₂₇

Table 1: Quasi-experimental design scheme based on cohorts.

the fifth thematic unit in year "n-1", and O25 represents observations taken after teaching the fifth thematic unit in year "n". The "X" on the second row represents the variation introduced before observations of unit 4 in year "n". This variation is just the use of the tabletop system as an educational tool in this unit.

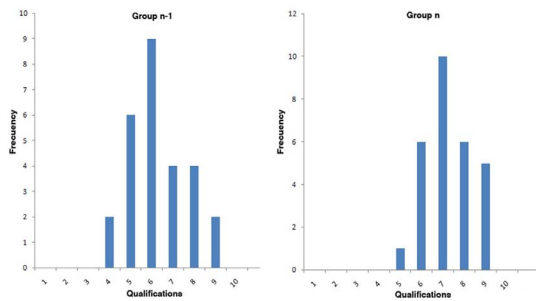


Figure 7: Histogram of the qualifications achieved by students of both groups in the thematic unit 4 "Geometric Shapes". Marks are expressed according to the Spanish grading system (range from 0 to 10). "group n-1" left, and "group n" right.

As can be seen in Figure 7, there is a positive displacement of the qualifications to higher values in "group n".

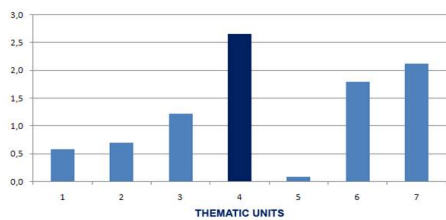


Figure 8: Differences between mean scores for the respective thematic units of "group n" and "group n-1".

For its part, Figure 8 shows the the differences between the mean scores obtained by "group n-1" and those obtained by "group n" for each thematic unit. It seems that "group n" has a slightly better level than "group n-1", in the Mathematics subject, but clearly the biggest difference in the mean

scores is in unit 4 (Geometric Shapes), where the tabletop was used. The drop of the unit 4 to unit 5 is striking, and would require further study. In the opinion of teachers, it may be because the unit 4 was very motivating for students, while the unit 5 returned in the usual way.

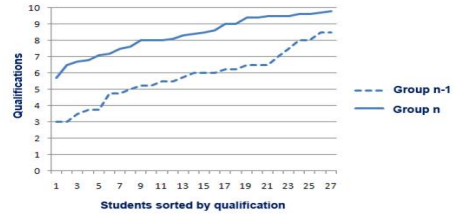


Figure 9: Qualifications in order from lowest to highest, for each of students of both groups, in the thematic unit 4.

Focusing on the results obtained by individual students in thematic unit 4, Figure 9 shows the qualifications in order from lowest to highest for each of the students of both groups. For all ranges of qualifications, scores of the "group n" are superior to those of the "group n-1".

8.3. Usability/Satisfaction

To evaluate usability and students' satisfaction, a Likert scale test of 5 values was used. Table 2 shows the ten questions of the questionnaire and results. Questions 1 through 5 assess usability, while questions 6 through 10 assess satisfaction. This questionnaire was passed to each group after students had received classes with the Tabletop.

Test	Questions	X	σ
Usability	Q1 I prefer the classic book to using the new material ¹	4,8	0,38
	Q2 I found it easy to see the geometric shapes with this technology	4,8	0,44
	Q3 I believe that this material will help me to make a better examination	4,4	0,97
	Q4 It has been easy to learn to use this material	4,3	0,82
	Q5 I would like to use this material at home	5,0	0,00
Satisfaction	Q6 In this class I have been more attentive than in other classes	4,1	0,78
	Q7 This class has seemed to me to be useful and interesting	4,4	0,78
	Q8 I would like to take more classes as those of today	5,0	0,00
	Q9 It is easier to follow the teacher's explanation in a class of this type	4,7	0,70
	Q10 In class today I behaved better than in other classes	3,8	1,06

¹ Score of this question is reversed

Table 2: Usability/Satisfaction questionnaires.

It's important to note that students had no previous contact with tabletops, and that they did not receive training on using the new system. Even so, as the results show (Figure 10), students found it easy and natural to use, achieving one of the main objectives of the research; to obtain a natural interface that hides the complexity of the technology without interfering with the process of teaching and learning. Based

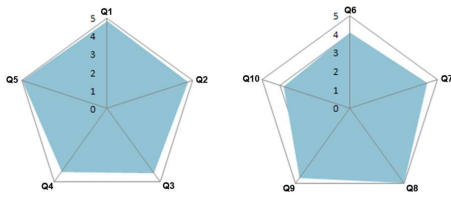


Figure 10: Usability (left) and Satisfaction (right) results.

on the usability evaluation, students clearly opt for the use of the new technology (Q1 is reversed in representation). They think that its use was simple and transparent, as seen from Q2 and Q4. According to Q3, the majority of students recognize that this tool can positively help them in improving their results, and most of them would like to use these technologies at home too (Q5).

8.4. Motivation

The assessment of motivation was performed using the Intrinsic Motivation Inventory (IMI) test [VvdMD11], specifically, the subscales "competence", "interest" and "effort". The scheme used was the classic pre-test before receiving educational content with the Tabletop and post-test having used the system. Table 3 shows the questionnaire and results obtained in the pre-test, and Table 4 shows the questionnaire and results obtained in the "post-test".

IMI Scale	Pre-Test questions	x	σ	x scale
Competence	I think I am good at school	4,00	0,67	3,77
	I think I do pretty well at school, compared to others	3,35	0,71	
	I am satisfied with my performance at school	3,87	0,63	
	I am pretty skilled at school	3,87	0,76	
	I think I am pretty good at school	3,87	0,50	
Interest	I think school is quite enjoyable	3,65	0,83	3,51
	I think school is very interesting	3,57	0,73	
	I think school is fun	3,35	0,83	
	At school I often think about how much I enjoy it	3,57	0,90	
	I think school is boring ¹	3,43	0,66	
Effort	I do my best at school	4,26	0,54	4,34
	I try very hard to do well at school	4,22	0,42	
	It is important to me to do well at school	4,61	0,50	
	I put much effort in school	4,26	0,69	

¹ Score of this question is reversed

Table 3: Intrinsic Motivation Inventory pre-test: questionnaire and results.

Each question was scored on a Likert scale of 5 values. All questions in the pre-test are related to the post-test questions in the same order. As an example "I think I am good at school" question in the pre-test is equivalent to "I think I was good in learning with the tabletop" in the post-test.

At first glance there seems to be an improvement in the three subscales of motivation in the unit in which the tabletop system was used, obtaining the best results in the subscale "interest". Teachers involved in the experience also had this perception subjectively, and they highlighted the importance of the improvement in motivation, since it leads to a higher a level of attention in students.

Considering a sample composed of several observations for the same individuals at different times where a normal distribution in the initial data is assumed, a paired sample t-tests (t Student), with a 95% confidence interval (ρ = 0.05) was applied.

IMI Scale	Pre-Test questions	x	σ	x scale
Competence	I think I was good in learning with the tabletop	4,26	0,92	4,11
	I think I did pretty well with the tabletop, compared to others	3,48	0,67	
	I am satisfied with my performance while learning with the tabletop	4,30	0,97	
	I was pretty skilled learning with the tabletop	4,35	0,71	
	I think I was pretty good learning with the tabletop	4,17	0,72	
Interest	I think learning with the tabletop was quite enjoyable	4,74	0,69	4,74
	I think learning with the tabletop was interesting	4,61	0,78	
	I think learning with the tabletop was fun	4,83	0,39	
	While I was learning with the tabletop, I often thought about how much I enjoyed it	4,74	0,45	
	I think learning with the tabletop was boring ¹	4,78	0,60	
Effort	I did my best while I was learning with the tabletop	4,52	0,73	4,60
	I tried very hard to do well learning with the tabletop	4,91	0,29	
	It was important to me to do well learning with the tabletop	4,39	0,58	
	I put much effort in learning with the tabletop	4,57	0,59	

¹ Score of this question is reversed

Table 4: Intrinsic Motivation Inventory pre-test: questionnaire and results.

IMI Scale	Pre-Test x (σ)	Post-test x (σ)	t Student	Critical t
Competence	Q1 4,00 (0,67)	4,26 (0,92)	1,03	2,07
	Q2 3,35 (0,71)	3,48 (0,67)	0,59	2,07
	Q3 3,87 (0,63)	4,30 (0,97)	1,55	2,07
	Q4 3,87 (0,76)	4,35 (0,71)	1,91	2,07
	Q5 3,78 (0,50)	4,17 (0,72)	1,82	2,07
Interest	Q6 3,65 (0,83)	4,74 (0,69)	4,08	2,07
	Q7 3,57 (0,73)	4,61 (0,78)	4,36	2,07
	Q8 3,35 (0,83)	4,83 (0,39)	7,90	2,07
	Q9 3,57 (0,90)	4,74 (0,45)	5,05	2,07
	Q10 ¹ 3,43 (0,66)	4,78 (0,60)	6,92	2,07
Effort	Q11 4,26 (0,54)	4,52 (0,73)	1,45	2,07
	Q12 4,22 (0,42)	4,91 (0,29)	7,09	2,07
	Q13 4,61 (0,50)	4,39 (0,58)	1,42	2,07
	Q14 4,26 (0,69)	4,57 (0,59)	2,08	2,07

¹ Score of this question is reversed

Table 5: t tests results over motivation questionnaire.

The variation of the competence, interest and effort variables between the pre-test and post-test was analyzed. The

alternative hypothesis, according to the above data, is that the valuation of each issue is better in the post-test than in the pre-test, while the null hypothesis is that the observed differences in these ratings are due to chance. Results for t-tests are presented in Table 5. It is found that statistically significant differences do not exist in the case of the variable "competence". Therefore the null hypothesis is accepted, and the difference in valuations is due to chance. Proceeding similarly in the case of the variable "interest", it is noted that there were significant differences between post-test assessments and pre-test ones, which is demonstrated by the alternative hypothesis, so, the assessment of post-test is better in the case of interest. Finally, in the same way, but in the case of the variable "effort", it is noted that there are statistically significant differences in Q12 and Q14 questions, so in this case the alternative hypothesis is accepted, so it is demonstrated that post-test assessments on these questions is better. However, in questions Q11 and Q13 there are no statistically significant differences between the assessments of pre-test and post-test, proving the null hypothesis, so differences in ratings of these questions are due to chance.

9. Conclusions

Results show that the use of the tabletop system contributed to a significant increase in students' motivation, raising a lot of "interest" and notably "effort". On the other hand the results of usability tests show that the proposed teaching tool is simple enough to use, hiding the inherent complexity of the technology itself, so that is a transparent tool that does not interfere in the process of teaching and learning (it does not require to devote class time to learn how to use the tool, by both students and teachers). As expected from the improvement of student motivation and good results of usability, there is also a significant improvement in the efficiency of the teaching/learning process, from the point of view of new knowledge assimilation.

In summary, it can be concluded that in general the development of this new teaching tool has increased the motivation of students without interfering with the teaching/learning process, and thus increasing the efficiency of knowledge assimilation.

Tabletop system fostered a high degree of collaboration between students and self-correction while performing the exercises. During these sessions, most of the time the teachers were playing a secondary role and they only intervened when it was strictly necessary. Here the collaborative action of several students around the table was very important, because of the feedback established between them.

10. Acknowledgments

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