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Editorial EOS

The influence of new technologies on learning and attitudes in mathematics in secondary students

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Abstract

The present article is part of a study carried out with Secondary School students in Mathematics class. Our research interest lies in exploring the influence of using ICT (Information and Communication Technology) on students' attitudes and on how they learn mathematics, as observed when they are solving contextualized problems. This is a collaborative study between a Secondary School teacher and a University professor, following an action-research methodology. The triangulation of data collected through different instruments reveals that use of ICT in the classroom helped to improve attitudes and numerical learning in a large percentage of the students who participated in the experiment.

Keywords: ICT, mathematics, attitudes, learning, competencies, secondary education.

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Resumen

El presente artículo es parte de un estudio realizado con estudiantes de Educación Secundaria en el aula de matemáticas. El interés de nuestra investigación radica en conocer la influencia del uso de las TIC (Tecnologías de la Información y la Comunicación) en las actitudes y el aprendizaje de las matemáticas que nuestro alumnado pone de manifiesto cuando trabaja la resolución de problemas contextualizados. Se trata de un trabajo colaborativo entre una profesora de Secundaria y otra de Universidad, siguiendo un esquema de investigación-acción. La triangulación de los datos recogidos con distintos insrumentos revela que el uso de las TIC en el aula ha contribuido a mejorar las actitudes y el aprendizaje numérico de un gran porcentaje de los estudiantes que participaron en la experiencia.

Palabras Clave: TIC, matemáticas, actitudes, aprendizaje, competencias, educación secundaria.

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Introduction

This article presents results from classroom research on the influence of using ICT (Information and Communication Technologies) for working on numeric content. The research was carried out by a secondary education teacher in collaboration with a profesor from the University of Almeria (Spain). The study was prompted by the secondary teacher's concern with students' lack of motivation to learn mathematical content offered at school, as well as an interest in systematic inquiry into how to overcome these attitudinal deficiencies and to enhance students' learning. A school-wide ICT program made it possible to actively pursue this inquiry using ICT.

Our study, then, revolved around two big unknowns: Can ICT improve students' learning in mathematics? And what about their attitudes in mathematics? We also tried to determine whether there was a dependency relationship between attitudinal improvement and cognitive improvement.

Based on these areas of interest, we explain below in detail the background and theoretical framework which we took into account in this investigation. Next, we describe the methodology followed and what each phase consisted of (Planning, Action, Observation and Reflection). We conclude by presenting the improvements gained in both numerical learning and in attitudes, in a large percentage of students.

Background and research objectives

In recent decades, and especially in recent years, many teachers and researchers have studied the use of ICT in mathematics. By way of example, we note the following: *Complejidad de las matemáticas escolares y diseño de actividades de enseñanza y aprendizaje con tecnología* [Complexity of school mathematics and designing teaching and learning activities with technology] (Gómez, 2005), On the use of computational tools to promote students' mathematical thinking (Santos-Trigo, 2006), La formación TIC del profesorado de matemáticas de los centros públicos de secundaria [ICT training for mathematics teachers at public secondary school] (Santandreu & Gisbert, 2005).

According to authors such as Cabero (1999b); Beltrán (2001); Kennedy, Odell and Klett (2001), using ICT in teaching presents a number of advantages when compared to more traditional educational resources used in the classroom:

- *Instructional flexibility*, they facilitate variability in the pace of learning.
- *Complementarity of codes*, allowing the student to receive information through different sensory channels.
- *Increased motivation*, accompanied by greater involvement in his or her learning process.
- *Collaborative and cooperative activities*, with greater verbal interaction and participation in the assignments, thus strengthening social relations.

We wanted to verify whether these advantages attributed to ICT would be evident in working with mathematical content, since they were in line with our objectives to enhance motivation and thereby see cognitive and attitudinal improvement in our area.

Regarding didactic material that can be developed using ICT, this can be stored in a physical format (diskettes, zip drive, CD-ROM, DVD, etc.) or it can be distributed through a network (Internet, intranets, etc.). One of the Internet utilities in the educational field is the *Knowledge Management Platform*, created to facilitate production and assimilation of knowledge. The present study required the use of one of these, the Moodle platform. Moodle is an interactive, virtual platoform where teachers can post and organize our content at all times, as well as manage an agenda and a system for announcing events and exam dates; additionally, students can upload their exercises, and grade them if this is desired. In our case, Moodle served as a platform to locate materials and activities designed for working on selected mathematics content using ICT, and to collect information from the students, where they would be able to connect not only during classtime but also from their homes.

In addition, there is an increasing amount of educational material available on the Net known as *Free Software*, free of charge to any user. For this study we focus on (1) consulting websites (interactive or not) with mathematical content, most of them prepared by other teachers, and (2) using the mathematics program Open Office Calc, a user-friendly spreadsheet.

In order to address the first of our two main research questions, Can ICT improve students' learning in mathematics?, we chose to work from within the framework of the OECD/PISA Project (2003). In this study, the focus is mathematical learning referred to as "mathematical literacy", defined as "students' capacities to analyse, reason, and communicate ideas effectively by posing, formulating and solving mathematical problems in a variety of domains and situations, using mathematics not only to solve problems but also to communicate, evaluate, appreciate and enjoy mathematics itself." This conception is at odds with mathematical knowledge and skills as they are defined in the traditional mathematics curriculum. From this perspective, "emphasis is placed on mathematical knowledge set to work in a many different contexts, for motives which are reflective, varied and based on personal intuition, that is, on personal abilities" (Rico, 2005b).

In the framework mentioned above, and in an attempt to respond to students' interests, we decided to introduce mathematical notions and concepts through contextualized problem solving, where students work with ICT in their solutions. We attempted to assess any improvement in students' mathematical learning through their problem solving, assuming that problem solving is characterized, organized and based on a series of basic mathematical competencies. Competencies are understood to be: "the processes that have to be activated in order to connect the real world, in which the problems are generated, with mathematics and thus to solve the problems, making it possible to determine the general meaning through different abilities such as analysis, reasoning and communication that students engage in when solving mathematics problems in a variety of domains and situations" (OECD, 2004b). We concur with Lupiáñez and Rico (2006) in that "the term competency alludes to the ways that school children act when doing mathematics and when confronting problems".

Mathematics competencies selected by the OECD for the PISA reports, and which we adopt for our research, are as follows: Problem solving, Using aids and tools, Communicating, Modeling, Representing, Thinking and Reasoning, Argumentation and the Use of symbolic, formal and technical language and operations. Each of these competencies can be mastered at different levels. Thus, the PISA project describes the following levels of complexity based on the types of cognitive requirements needed for solving different mathematical problems:

Table 1. ***Levels of complexity, or competency groups*.**

First Level: Reproduction Group
Students can solve questions that involve simple or familiar contexts where all the relevant information is clearly defined. They can make a rather limited interpetation of the situation and make use of a single mode of representation. They are able directly apply mathematical knowledge which they have studied, as well as literal interpretations of the results.
Second Level: Connection Group
Students can work effectively with relatively unknown situations. They can interpret and select and integrate different representations, linking them directly to real-life situations; apply simple strategies for problem solving; follow a line of reasoning or sequence of calculations as well as briefly express their interpretations, results and reasoning.
Third Level: Reflection Group
Students can work with unknown situations that require reflection and creativity. They can select, compare and evaluate appropriate strategies for solving problems, as well as design new, useful strategies; they possess a high level of interpretation; they are able to link different classes of information and representations and switch between them flexibly. Furthermore, they communicate their actions and reflections according to their own findings, interpretations and argumentations.

These competencies and levels are common to the different main strands of the mathematics curriculum: Quantity, Space and form, Change and relationships and Uncertainty. Since the content our students are working on pertains to the numeric and function area (Quantity and Change and relationships), we will explain the notion of competency in these cases. According to the PISA report, a numerically competent person is one who shows numeric sense, an understanding of the meaning of operations, a sense of the magnitude of numbers, and at the same time is able to perform elegant calculations, mental calculation and estimates. Similarly, a person is competent, or shows proper functional thinking, when he or she is able to recognize and understand the relationships and types of fundamental change (linear, exponential or logarithmic functions), as well as switch between visual representations: numerically (in a table), symbolically and graphically.

Regarding our second main question, Can ICT improve our students' attitudes in mathematics?, we adopt as our frame of reference the work by Gómez-Chacón (1998, 2002, 2005). We concur with this author in that "teachers today increasingly accept the importance and insistence given to the topic of attitudes in mathematics education, recognizing its undeniable value and interest in the teaching-learning process".

In line with Gómez-Chacón and other authors, we distinguish between two large categories in the area of mathematics: attitudes toward mathematics and mathematical attitudes (Callejo, 1994; Gómez-Chacón, 2000a; Hernández & Gómez Chacón, 1997; NTCM, 1991). Attitudes toward mathematics refers to valuing and appreciating the discipline, to an interest in the material and in learning it, with more stress on the affective than the cognitive component – what is seen in terms of interest, satisfaction, curiosity, high value, etc. It also refers to the behavioral component or to involvement, to the self-concept and the component of environmental belief. Mathematical attitudes, by contrast, have a markedly cognitive nature and refer to the way we use general abilities such as flexible thinking, mental openness, critical spirit, objectivity, perseverance, precision, creativity, etc., which are important in mathematical work.

Our intuition as teachers led us to think that students' attitudes toward mathematics and mathematical attitudes could influence or be related to their performance in mathematics, a relationship which has been addressed and confirmed in studies by Ramírez (2005) with primary students and by Akey (2006) with secondary students, to name two examples. Therefore, we thought it would be interesting to study whether the introduction of new technological resources and methodological strategies in the classroom would produce an improvement in our students' attitudes toward mathematics and in turn improve their performance in this subject.

Method

Since one of the researchers is a practicing secondary teacher, we opted for an Action-Research methodology (AR). We feel that research carried out by teachers is very important, both for their own professional development, and for generating knowledge from real-world scenarios, which can then be useful to other education practitioners. It also seemed appropriate to collaborate with the University, acting as a nexus between educational theory and practice.

According to Kemmis (1992), AR experiences take on the form of a cyclical spiral made up of research cycles, which in turn are made up of four phases: Planning, Action, Observation and Reflection. Our research was carried out in two such cycles, following Kemmis' four phases in each. Cycle 1 took place during academic year 2004-05 and was considered a kind of pilot study in order to verify the goodness of the instruments, and whether the proposed activities were suitable. Cycle 2, incorporating changes and new aspects which we deemed useful after reviewing Cycle 1, was carried out during academic year 2005-06, and is described in this paper.

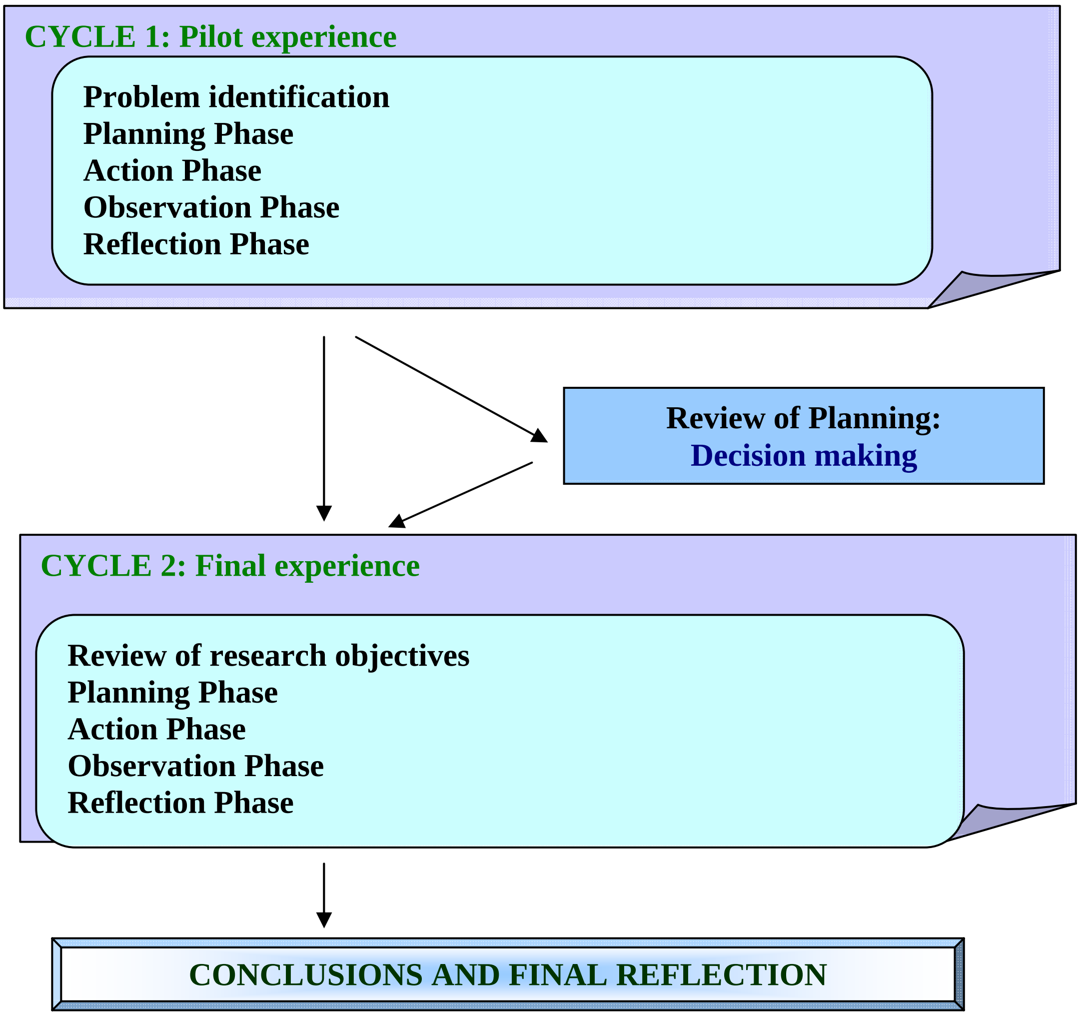


Figure 1. **Research cycles**

Planning Phase

This project was executed at a secondary school in the province of Almeria. This school had been selected as a participant in the ICT program of the Andalusia regional department of education; for this reason there are computer systems available in almost every classroom, with Internet connection, such that every pair of students has a computer assigned for their use during the schoolday. The following table shows the sample composition of students selected for the final research cycle, according to grade level.

Table 2. ***Sample by academic year and subject.***

	Subject	Number of students
9th grade, class B	Mathematics	24
9th grade, class C	Mathematics	17
10th grade	Mathematics Option B (more advanced)	16
11th grade	Mathematics I (Science & Technology track)	22

Students had not previously used ICT as a resource in the presentation of mathematic content or in working with mathematics, they were accustomed to receiving the teacher's prior explanations on the chalkboard, followed by individual work in solving exercises, with the text book as the only classroom resource.

Since we wanted to explore the influence of ICT tools on learning mathematical content, we designed activities to be carried out using ICT (hereafter, ICT activities) and others to be carried out with pencil and paper (hereafter, PP activities). In order to make comparison possible, and in order to get the information we were looking for, we were especially careful to ensure that the only difference between the two types of activities was the use of technologies. In all other aspects, the two types of activities followed the same outline:

- We posed real-world problems (which we call Projects), as a way of making evident the importance of mathematics in daily life.
- Projects were carried out by the students collaboratively and individually. This way we hoped to encourage communication between the students and get them to discover on their own the mathematics content needed for solving the problems.
- The teacher's role was for orientation and guidance and as mediator of the teaching-learning process.
- After students completed each project, a class discussion was held where the groups explained the different strategies they had followed, and these were discussed among the class group.
- The different questions or activities contained in the projects were classified according to the three complexity levels defined in the PISA report, as shown in Table 2.1. The competency level of each question was determined by consensus among different experts, taking into account in each case the grade level of the students involved. We tried to ensure homogeneity between the number of projects and questions to be worked on using ICT and using PP for each level of complexity and at each grade level, progressively increasing the number of Level 3 activities from 10^{th} to 11^{th} grade, given the cognitive maturity of students in this age group.

We also designed a list of exercises on the content worked on with ICT and with PP for each group, so that students would work at home, even though in the Observation Phase we focused on Projects executed in the classroom with ICT and with PP, in order to collect results.

The PP activities for all the groups helped us to introduce content on functions and to reinforce numerical content that corresponded in each case to the grade level curriculum. Some of these activities were selected from the PISA/OECD project and a large majority were drawn from the book: "The language of functions and graphs", from the Shell Centre for Mathematical Education (1990). The function activities addressed the following mathematical content, in greater or lesser depth: description and interpretation of word problems and graphs that analyze their meaning, recognition of the main characteristics of functions, applying function theory to problem solving in daily life, simulation and modeling of real phenomena using functions. An example of such activities can be seen in Box 1.

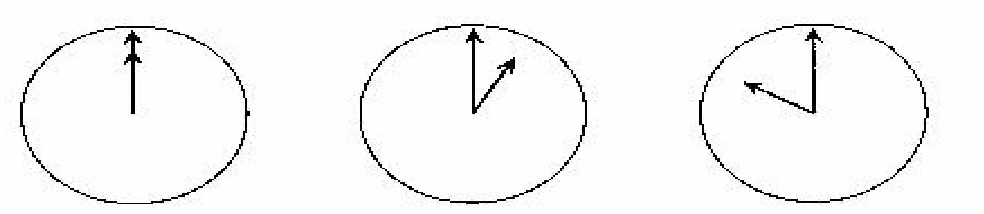
Project 1. *Carbon dating.*
This is a technique for discovering the age of an ancient object (such as a bone, a piece of furniture, a board), by measuring the quantity of Carbon 14 that it contains. While animals and plants are living, they have a constant quantity of Carbon 14, but when they die this quantity diminishes through radioactivity. The quantity of Carbon 14 in an object *t* thousand years after death is given by the formula: $a = 15.3 \cdot 0.886^t$
(Quantity "*a*" measures the desintegration speed of Carbon 14 atoms, expressed in "desintegrations per minute per gram" of carbon [dpm/g]).

1. Imagine that you have two samples of wood. One was taken recently from a tree, and the other is a carbon sample of firewood found at Stonehenge, 4000 years old. How much Carbon 14 does each sample have? (Answer in dpm/g) How long will it take the amount of Carbon 14 in each sample to be reduced by half? These two answers should be the same (why?), and they are called the half life of Carbon 14.

2. The vegetable carbon from the Lascaux caves in France gave a quantity of 2.34 dpm/g. Estimate the date that the carbon was formed and give a date for the paintings found in the cave.

3. Bones A and B are x and y thousands of years old, respectively. Bone A contains three times the amount of Carbon 14 as Bone B. What can you say about x and y?

Project 2. *Chatting online*.
Mark (from Sydney, Australia) and Hans (from Berlin, Germany) communicate often through Internet, on chat. They must connect to Internet at the same time in order to chat. In order to find an appropriate time for chatting, Mark looked for a world time zone map and found the following:



Greenwich 12 midnight | Berlin 1:00 AM | Sydney 10:00 AM

<u>Question 1</u>: When it is 7 PM in Sydney, what time is it in Berlin?

<u>Question 2</u>: Mark and Hans cannot chat between 9 AM and 4:30 PM, in their respective time zones, because they must attend school. Nor can they chat between 11 PM and 7 AM in their local time, because they are sleeping. At what times can Mark and Hans chat? Write the respective local times.

***Box 1.* Example of Paper and Pencil Projects and Activities for 10th graders**

The ICT activities helped us to introduce different content for each grade:

- 9th grade: worked especially on interpretation of statistical graphs, obtaining statistical parameters, their meaning and their application to interpreting variation in a data set.
- 10th grade: studied content from Trigonometry—recognizing and calculating trigonometry ratios, solving right triangles, real-life applications of trigonometry.
- 11th grade (students in science and technology tracks): We selected content from Statistics and Probability. We worked fundamentally on the same content as the 9th graders, but more in depth, and on other Probability content such as calculating the probabilities of simple and compound events, conditioned probability, and applying this content to real problem situations.

Project 1. Write an essay on the "History of Trigonometry" by finding information on Internet:

ORIGINS OF TRIGONOMETRY

As you will have noted, the information that I have placed in Moodle on the History of Trigonometry is very limited, and you can see that it does not clarify its origins. This is your assignment, then: write an essay on the Origins of Trigonometry so that a person who knows nothing about the topic will understand what it is, how it came about, and who is responsible for this mathematical accomplishment. You must include an appendix that shows all the webpages that were helpful to you in preparing your work.

Project 2. You must construct a *handmade protractor*, look for information on the Net that will help you build it, understand its utility and handle it correctly.

Project: Out on the Job. You must determine the height of two of the school buildings, using the protractor you constructed above and a measuring tape. [Since the students did not know trigonometry ratios, they had to look up related information on Internet that would help them formulate and solve the problems]. After they solved the problem, we posed the following question:

Errors in your results? Reflect on and discuss how a small error in measuring an angle can produce results that are far off from reality. Don't get discouraged, because the great thinkers of history also had to deal with this problem.

Project: Still on the job. Now you must calculate the height of the two buildings in the previous project using triangle similarity. Since we have not studied this method you must look for information on the Net that explains how to do it, and when you have a clear strategy, we will proceed to take the measurements outside that you think are needed for each of the buildings.

Box 2. **Example of Projects and Activities using ICT for 10th graders**

In order to organize ICT activities we used the Moodle platform, which allowed us to communicate with our students through several channels (forums, chats, e-mail, suggestion box), to post the projects and to provide links to helps or information that we foresaw some students would need for certain projects. The activities designed for working with ICT required mostly searching for information on Internet, since in order to solve many of these problems, students needed to work with content that was unfamiliar to them, or they needed free software programs such as the Open Office spreadsheet in order to solve statistical or numeric problems. Some of the ICT activities on 10th grade content are presented in Box 2.

Action Phase

We decided not to follow the same sequence of action in all groups: in some cases we began with ICT activities and in others with PP activities, in order to see whether this variable would influence results (even if it were not significant). The action phase timetable, below, shows the number of sessions involved:

Table 3. ***Implementation Schedule of the ICT and PP Activities***

	ICT Activities	Pencil and Paper Activities
9th-graders Class B	Nº Sessions: 17	Nº Sessions: 16
	Dates: April 17 – May 29	Dates: February 3 – March 17
9th-graders Class C	Nº Sessions: 18	Nº Sessions: 16
	Dates: April 18 - May 26	Dates: February 3 - March 17
10th graders	Nº Sessions: 19	Nº Sessions: 16
	Dates: January 31 - March 24	Dates: April 18 - May 23
11th graders	Nº Sessions: 17	Nº Sessions: 17
	Dates: April 24 - May 30	Dates: February 1 - March 17

As we noted earlier, our *Action Plan* for classroom intervention in mathematics involved using a combination of different methodologies, as compared to the single methodology which students were accustomed to: the master class. The teacher's role was to be a mediator of learning, encouraging students' active participation in the activities presented. Additionally, we tried to interest students in finding different mathematical strategies and to reinforce their self-esteem through feedback and by giving value to errors as a sign of work and investigation. Since most of the questions posed in the ICT and PP activities required understanding new mathematical content, we began with their previous knowledge and pointed them progressively to different tools whereby they could become the architect of their own learning. The activities gradually increased in complexity as students became more solid with the new content. We also sought to improve our students' attitudes toward mathematics by the choice of activities, posing real situations which highlight the applicability and utility of mathematics, as well as its importance over the course of history.

Observation Phase

We used different observation instruments in order to verify whether the desired improvements were taking place, both in our students' learning and in their attitudes, which we describe in more detail in the following paragraphs, in the context of their relevance to our objectives and our areas of interest.

In order to analyze a possible cognitive improvement experienced by our students, we focused on analyzing their written productions (ICT and PP activities). We also made use of written tests completed individually, covering the topics included in the present research, both prior to and over the course of the school year. In order to complement and triangulate the results from the above instruments, we drew from the information in each group's diary and in the observation records that we had designed previously (consisting of double-entry tables where we looked into the degree to which each student demonstrated each of the PISA competencies when solving the activities). We filled out the observation records for each pair during each session, and immediately afterward we noted information in the diaries which we felt was relevant for the cognitive analysis and which was not reflected through other observational methods.

In order to analyze attitudinal transformations, instruments were differentiated along two lines just as discussed above in the second section. We explored attitudes "toward mathematics" by analyzing responses to two questionnaires which we had previously designed and placed on Moodle:

✓ "Attitude toward math" questionnaire. The items were adapted from previously designed and validated scales such as the "Escala de Actitud de Carácter Verbal" ["Verbal Attitude Scale"] by Gairín (1987) which seeks to assess attitudes toward mathematics in general, and the scale by Giménez (1997a), which is an adaptation of the previous scale for the specific case of fractions, making it possible to assess the attitudinal components described in section 2: affective, cognitive, behavioral or having to do with involvement, self-concept and environmental belief. Students completed this questionnaire on two occasions: before and after the ICT experience.

✓ "I'd like to hear your opinion" questionnaire. We designed this questionnaire in order to collect information about the possible changes that students claimed to experience in the affective, cognitive or behavioral components when using ICT to work on mathematics content. Moreover, this questionnaire included items on the collaborative work component, since we were interested in their opinions about this manner of working, quite unusual in this academic subject. This instrument was completed after finishing the ICT activities.

We also had access to instruments which addressed both attitude categories: the entries in each group's diary from each session, and a suggestion box located on Moodle, where students told me their opinions about working on mathematics using ICT, and the positive or negative changes that this produced in their attitudes. Data triangulation of the information collected from the above instruments, together with that drawn from the observation records, which also contained entries having to do with attitudes, allowed us to investigate possible transformations in our students' "attitudes toward mathematics", as prompted by the use of ICT.

In order to explore possible transformations in mathematical attitudes, we also used students' written reports for each activity, in addition to the diaries and the suggestion box mentioned above. We asked them to include in these documents not only their calculations and argumentation that led to to a certain solution to the problem, but also the processes that they followed. These notes from the students provided quite useful information about their flexibility of thought and critical spirit, and also about their creativity, perseverance and precision.

Reflection Phase

Although we leaned more heavily on qualitative methodology, we also turned to statistical data analysis in order to support our conclusions. We performed different analyses of all the data collected, in terms of our initial areas of interest. First, we present our analyses pertaining to competencies, for which we had complete data from 48 students. Data from the other students had to be discarded, since some of the necessary information was lacking.

Our objective was to verify whether student competencies improved by including new technologies in the mathematics classroom, introduced using real phenomena and situations, in the line of the OECD/PISA project 2003. For this purpose, we started by determining the competency group or level for each student (1=Reproduction, 2=Connection or 3=Reflection) after carrying out ICT and PP activities, which were classified according to these same three competency groups or levels of complexity (Table 2.1). To do so, we repeated the following process twice, once for the ICT activities and again for the PP activities: for each student we corrected the different activities from one level by assigning scores of: 1=poor, 2=passable, 3=good; later we took the sum of scores obtained on activities at the same level and calculated the percentage corresponding to that score with respect to the maximum score that could be attained, thus determining a percentage score for proficiency for each student at each level. In order to illustrate this procedure, we show the scores obtained by 11th grade students on PP activities:

Table 4. ***Example of calculating the proficiency percentage at each level***

	Number of activities	**Score obtained**	**Maximum score**	**Proficiency percentage**
Level 1	2	6	6	100 %
Level 2	5	11	15	73.3 %
Level 3	5	12	15	80 %

Taking these calculated values, we went on to perform different statistical analyses, allowing us to verify whether there were significant differences between the percentages obtained using ICT and using PP, which in turn would be evidence of the positive or negative direction of learning with ICT. After performing different tests using SPSS software (*Student t* for comparing related means and two *non-parametric* tests for two related samples, Wilcoxon signed-rank test and rank-sum test) with the proficiency percentages of the ICT and PP activities at the three levels, we found significant differences only for level 3 activities. The absence of differences in level 1 (reproduction group activities) was due to the similarity of scores obtained on both types of activities: 45 and 48 students, respectively, obtained a proficiency percentage of 100 % on ICT and on PP, which is understandable since these were routine activities that presented no difficulties. At complexity level 2 (connection group), statistical differences were not found, but it is worth mentioning that 50% of the students improved their score on level 2 when using new technologies, no small matter if we consider improvement in 25% of the 9^{th}-graders in Class B, 53.85% of the 9^{th}-graders in Class C, 58.33% of 10^{th} graders, and 72.72% of 11^{th} graders. Regarding activities from level 3 (reflection group), significant differences *were* detected: 31 students (64.58%) improved when using ICT; though we must note that, despite the increase in proficiency percentages, the percentage levels were not very high, as can be seen in the following table:

Table 5. ***Proficiency percentage of the 31 students who improved on level 3 with ICT***

LEVEL 3 ACTIVITIES		**PAPER & PENCIL**		**ICT**	
		N	**%**	**N**	**%**
	< 50 %	16	51.6 %	1	3.2 %
Proficiency percentage	[50 %, 66.6 %]	14	45.2 %	26	83.9 %
	> 66.6 %	1	3.2 %	4	12.9 %

Continuing with the analysis, we classified the students from each group according to the three levels, considering that a student belonged to a given level when:

- ♦ Level 1: He or she obtained a percentage ≥66.6 % on Level 1 activities
- ♦ Level 2: Students who, having reached level 1, obtained a percentage ≥66.6 % on Level 2 activities.
- ♦ Level 3: Students who, having reached level 2, obtained a percentage ≥66.6 % on Level 3 activities.

After analyzing each student specifically, we obtained the following data regarding the level reached using ICT and using PP for the group of 48:

- 5 went down a level when using ICT
- 19 stayed at the same level they had reached with PP activities
- 24 went up a level from what they had reached with PP, when using ICT.

From this data it follows that only 10.42% of the students responded negatively to the incorporation of ICT, in terms of their competency acquisition, while 50% were able to improve the level they had reached on PP by using ICT.

We also studied whether the 24 students (50%) who improved their level in the selected mathematics competencies also improved their grade on the test administered on the content studied using ICT (hereafter, “ICT exam”), as compared to the test on PP content (hereafter, “PP exam”), and on the tests carried out over the course, as compared to the one administered before beginning the investigation. The result was that in 19 of these, that is, in 79.17% of the cases, competency improvement as evidenced by the activities carried out in class was also accompanied by high scores on the ICT exam as compared to the PP exam, and as compared to the mean score on all prior exams carried out over the year. The 5 remaining students did not improve their grades by working with ICT, despite showing progress in their competencies through using these technologies; however, their performance did not decline, that is, they maintained similar grades on all the tests which were compared.

The above data refer to analysis of the PISA competencies in general, without focusing on any one in particular. Even though we did not do an exhaustive analysis of each one separately, we can offer some specific data after triangulation of the students’ written productions (ICP and PP activities and written exams), of classroom diaries and of the competency records, which gave evidence that not all competencies improved evenly. We highlight the following competencies which showed the most notable improvement:

- <u>Use of Tools and Resources:</u> Although many teachers share the opinion that our students were born in the technological age and, therefore, they handle ICT with ease, our classroom work made evident that their use of Internet is quite biased, and the new experience gave them another perspective, less recreational but more educational, on how to make use of this valuable resource. To mention some examples, students in

10th grade improved in searching for information on the Net, going from a superficial, unstructured search to an intensive, exhaustive search, as we could see during the classroom sessions and afterward when evaluating the essays on the "History of Trigonometry". For their part, the 9th graders, who had never worked on statistical content nor with spreadsheets, demonstrated mastery in using Open Office in order to check whether their previous calculations were correct.

▪ Representing: Both in ICT activities as well as on the ICT exam, students were able to decode, code and interpret more or less familiar forms of representation of the mathematical objects involved, as well as to switch between different forms of representation. In the case of the Project *Out on the Job* (Box 2), carried out by the 16 10th-graders, they were all able to represent the problem situation on paper, identify the data needed and then transfer it to real life in order to take measurements on the school grounds which corresponded to the data required. It is also significant that, even though not everyone passed the ICT exam, they were all able to correctly represent the situations posed therein, unlike at earlier times when some only read the problem and were unable to address it at all. We believe that the advantage of ICT in structuring reality, as compared to other resources, contributed to the improvement in this competency; this was confirmed in the classroom. In summary, it is true that you learn better what you are able to see.

▪ Communicating: This improved perceptibly in all the groups, both orally and in writing, though we underscore that Class B of the 9th-graders, being the least motivated group and having the poorest academic performance in mathematics, was the group that progressed most clearly in this area. We note the following aspects reflected in most of the diary entries from this group and also in observation records for many of these students:

- How the use of ICT prompted increased participation during group discussion: many of the students that normally did not participate joined in with the usual speakers, recounting and debating different strategies for solving each activity.
- That during the ICT activities the flow of information between the student pairs was quite fluent: they shared solution strategies and helped each other, while during PP activities communication between the students was less fruitful, with exchanges limited to a small percentage of the group.
- An effort to improve how they expressed themselves, using more appropriate mathematical language than what they had normally used.

In order to conclude our analysis of competencies, we must also include those that showed least progress with the incorporation of ICT, as seen after triangulation of all the collected data, namely, Argumentation and Thinking and Reasoning. Although use of ICT prompted a number of students to reason and give arguments for their problem-solving strategies, many others still had difficulty in making correct mathematical argumentation. The deficiency in these competencies, carried forward from prior years of schooling, requires continued training and remedial action, and it was to be expected that incorporation of ICT alone would not noticeably improve these competencies, no matter how helpful it was in getting students to apply themselves more in the subject of mathematics.

Regarding particular numeric competencies, students' progress was visible in the analysis of their written work from the ICT activities and in the observation records from the sessions where these activities took place. Not only were students able to represent the situations posed and use ICT tools to search for information that would help them develop a solution strategy, they went on to consider the validity of their numeric results (even though many of these students did not take this attitude when working on activities without ICT). They demonstrated having a sense of the quantities and estimates involved, throwing out "impossible" solutions that were reached (for example, regarding the height of buildings at the school), inquiring into where the error came from, until they discovered that the data they had collected was not correct (when using the protractor, many students considered the supplementary angle instead of the angle they needed) or the data was incomplete (students did not take into account that the height obtained must be added to their own approximate height at eye level, which was where they took the measurement of the angle).

Elsewhere, analysis of the PP activities (carried out without ICT) gave us substantial information about the functional competency of our students. In general, most students did not reach an appropriate level, since they had difficulty recognizing the relationships between the variables presented in the problems, as well as in managing their different representations. In the case of the activities shown in Box 1, a high percentage of the 11^{th}-graders, when faced with Project 1, were not able to interpret the symbolic or algebraic representation of the speed of carbon 14 decomposition, or answer the questions, despite having worked earlier with logarithmic and exponential functions. On Project 2, although the first question was a simple numeric operation and everyone could answer it correctly, the second question was properly answered by only 27.27% of the group, being more complex (level 3), and involving recognition of relationships and the time change between different places. Other questions posed to this group involved recognizing linear and quadratic functions, presented in different ways: from a word problem and from diagrams. In both cases we must state that our students did not demonstrate mastery in the step of switching from one representation system to another, and consequently, a high percentage of them did not solve the problems that were posed.

As for attitudinal analysis, we look first at “attitudes toward mathematics”. We performed statistical analysis, just as for the competency levels, of the two pertinent questionnaires, and a joint analysis of both, using SPSS, triangulating this result with information contained in the diaries, in the observation records and with students’ opinions submitted to the suggestion box. The totality of students (79) was included in these considerations, since we had complete information for everyone.

When analyzing the questionnaire “attitudes toward mathematics”, we compared answers obtained on the same item before and after the ICT work, using comparison of means for related samples in order to verify whether there were significant differences in our students’ attitudes prompted by the incorporation of ICT. Such differences were found for affective components, environmental beliefs and self-concept, while these were not seen for cognitive or behavioral components. The questionnaires gave evidence that working with ICT had equipped students with a more realistic view of the usefulness and importance of mathematics in real life, and had helped them give more value to working in this area, but many of them continued to have trouble learning; these results concurred with opinions that students submitted to the suggestion box and with observation records and diaries. Nonetheless, even though the questionnaire did not reveal significant differences with regard to involvement in class work, this was not supported by the rest of the information collected, since most opinions left in the suggestion box were along these lines:

> “Working with computers made me feel more sure of myself. I understood math better and I am working more actively in class. I wish we would keep doing this kind of work using computers!” (female student in 9th grade, Class C)

On the questionnaire “I’d like to hear your opinion”, we started by calculating the mean score obtained by each student for each component (affective, cognitive, behavioral and in collaborative work): to do so we looked at responses pertaining to each of these components and figured the mean value. We considered these values representative for each component and we applied the same statistical tests to them as for the other questionnaire, thereby establishing whether there were significant differences in responses that addressed one component as compared to another. Special attention is merited by the analysis which compared the cognitive component to the affective component, where significant differences were found. Even though 24.1% expressed a negative opinion about improvement in learning mathematics by using ICT, and they did not consider computer use to be helpful in acquiring knowledge of mathematics or a better understanding, these negatives dropped to 11.4% when they were asked whether they liked this way of working on mathematics and whether they recognized to a greater degree the importance of mathematics. Other data drawn from this questionnaire concurs with conclusions from the *attitudes toward mathematics* questionnaire: 68.4% expressed a positive opinion about improving their learning using ICT, 83.5% affirmed that they liked this way of working better, and that they had come to recognize the importance of mathematics more than before, 79.8% gave a positive value to their involvement in class work, and 94.9% gave very favorable opinions about working collaboratively with their classmates. From all this data, we gather that the area which least improved from working with ICT in mathematics was the cognitive aspect; for 31.6%, the ICT work did not mean that they understood more quickly or that the subject was easier, or that they felt more sure of themselves working with mathematics on computers, a data point which confirms the competency analysis given above. Results also gave evidence of teaching advantages which have been attributed to ICT: it helped each group of students to work at their own pace and autonomously, it motivated the students and strengthened social relationships between them while they were using ICT cooperatively.

As for "mathematical attitudes", the information provided by the students in their written activity reports, in the suggestion box, and while carrying out the activities (as recorded in the diaries), reveal transformations in our students' mathematical attitudes: there were improvements in students' *flexibility of thought* as well as in *mental openness*; *critial spirit* increased, since they checked over the goodness of the solutions they had reached and they reflected on their errors and other aspects that previously were not questioned, such as information received through the media; they showed greater *perseverance*, *precision* and *creativity*, by making more effort and being more responsible for their work, not settling for a single strategy or solution method, but looking for other ways and alternatives, and assessing their value for the situations posed. On this point, we must say that *precision* is the attitude which most stands out, being demonstrated not only in students' representations but also in their numerical calculations. For example, continuing with the ICT actitives in Box 2, we were surprised that our students questioned why not everyone obtained the same height for the buildings, when this measurement is constant; on their own initiative they repeated the measurements and the calculations several times until they reached a better approximation of the real height of the buildings.

To illustrate the above, we include an excerpt from the 11th grade diary regarding ICT session number 3:

> … each group used different reasoning to defend their responses, sometimes correct and sometimes not, but I was able to observe that even when the solution was incorrect, they have developed greater critical spirit regarding the available information, and greater mental openness in searching for strategies. Moreover, they are more persevering and try to solve the questions autonomously by looking for information on Internet, in the text book, etc., but the vast majority of students do not ask for my help …

When analyzing the relationship between attitudinal improvement and performance improvement, we found that, of the students who improved their competency level in mathematics and their performance on exams as a consequence of using ICT, 63.16% also improved in attitudes. However, we cannot affirm that there is a total correlation between the two variables, because not everyone who experienced attitudinal improvements (97.47%) improved in the cognitive area.

Conclusions

The information drawn from the analyses described above, and their triangulation, provided detailed answers to our research questions, which we present below:

- Cognitive transformation was limited (50% of students improved their level of competency acquisition using ICT, although these improvements were not always noticeable), and did not occur in all students evenly. Not all the mathematical competencies studied showed improvement, although there was noteworthy progress in three: Use of Tools and Resources, Communicating, and Representing.

- Our students’ numeric competency progressed in several aspects, in working with real-life problems and obtaining results that match real values or measurements. Special progress was seen in the validity of results obtained, in estimating and in the diagnosis and treatment of errors.

- Students’ functional competency remained unchanged from class work on PP activities in these content areas. Only a few students improved, while the rest of the group was unable to understand the relationships and the fundamental types of change, and they were unable to switch from one kind of representation to another.

- Noteworthy improvement was produced in attitudes toward mathematics due to the use of ICT, in all groups of students, with a more positive view of mathematics as a science, greater interest in scientific work, and more value given to teaching methods.

- Mathematical attitudes also underwent marked transformation, since students showed greater critical spirit, perseverance, precision and creativity, as well as an increase in flexible thought and mental openness, due to the resources provided through ICT.

- Results obtained regarding a possible relationship between “improved attitudes↔improved performance” did not give evidence of a total correlation, although they do reveal a relationship between the two components of the binomial in both directions.

- In general, ICT produced increased motivation, improved behavior and an improved pace of work in the students, especially apparent in those groups that were characterized by a lack of interest in learning mathematics and other subjects.

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