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Individual, Cooperative and Collaborative Works with Educational Games of Mathematics for Computers[1]

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We analyze the possibilities of using Information and Communication Technologies as a resource in the teaching/learning of Mathematics and we show the results of concrete experiments carried out with the games: "Adibú", "La ciudad perdida" and "Drood en el planeta siete", with fourteen students and two primary school teachers in a school in Santa Cruz de Tenerife (Spain).

Our analysis of the games is made within a global framework in which individual, cooperative and collaborative learning are considered, taking as reference the theoretical frameworks set out by Piaget, Vygotsky, and the principles of collaborative learning (Computer Supported Collaborative Learning).

Keywords: learning: individual, cooperative and collaborative, computer games, educational games of mathematics, primary schools
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INTRODUCTION

This work forms part of a broader study which aims to research the advantages and disadvantages of incorporating new Information and Communication Technologies (ICT) as a support in the teaching and learning of mathematics in Primary Schools (6–12 year-olds). Our idea is to study both institutional problems as well as those problems faced by teachers and students when these new technologies are integrated within schools, and, furthermore, to analyze the enormous potential of the computer in the classroom.

In this work we present a study carried out with fourteen 8–10-year-old students (8 boys and 6 girls) and two Primary School teachers in a State Primary School in Santa Cruz de Tenerife (Canary Islands, Spain). Special consideration is given to studying the students with regard to three elements which are related but which we propose as three different questions:

1. Attitude and disposition of pupils towards mathematics and use of computers.
2. Individual and pair work with games for mathematics teaching/learning: advantages and disadvantages.
3. Study of pupils' behavior regarding mathematics class work and mathematics work done on computers.

In this work we will not specifically take into account the teachers' opinions regarding the role of the computer and games in the learning of mathematics, but we will refer to those opinions that help elucidate the third question under consideration.

New technologies are emerging which mediate the school curriculum, providing learning environments which are varied and suitable for working on different areas of knowledge as well as on areas of behavior and personality. Here the computer is a resource that allows development and stimulation of children's social and individual capacities due to its motivating potential (interactivity, variety, abundance and simultaneity).

In this work we analyze the possibility of using educational computer games as a support for mathematics teaching/learning and base our study on a broader concept of education which not only covers knowledge and skills, but also aptitudes and attitudes towards communication, interdependence, individual and team work, personal responsibility and respect for values such as pluralism and community.

We attempt to find evidence that shows progress in knowledge, both at an individual level as well as in pair work where pupils work towards a common goal, demonstrating in which situations individual and pair work lead to more enriched and complete learning when the computer is used to mediate learning, this being motivated by "interactions", "negotiations" and "dialogues" arising between individuals and the computer, and which strengthen and foment new knowledge.

New technologies give access to a large amount of information, help pupils carry out individual activities as well as communicate with one another and collaborate in common activities, strengthen social, psychological, organizational and learning aspects at individual, cooperative and collaborative levels, as computer technology helps in the process of coordination and organization of activities and can be used as an individual tool as well as an instrument that enables individuals and groups to cooperate with one another.

Furthermore, as Lomas (1996) points out, we should not forget that the multimedia revolution and means of communication in general have been configured as "substitutes" for the senses and as elements that strengthen "reality images", that is, a "mirror reality", which recreates virtually and globally an imaginary reality on which many of the preconceptions and stereotypes we encounter feed. In the educational sphere this requires from us a necessary task of decoding and neo-literacy in order to create competences and skills for reconstruction of reality (Giroux, 1990).

In this sense we view mathematics educational computer games as a factor that should be taken into account in the framework of the new information and communication technologies and study them by situating them in a global framework in which individual as well as cooperative or collaborative learning are analyzed. We take into account the theoretical frameworks of Piaget (1975; 1978; 1982) and Vygotsky (1976) regarding the child's psychological development in relation to games and the principles of collaborative learning, especially Computer Supported Collaborative Learning (CSCL). The results of our experiments with primary school pupils are shown after their use of three mathematics educational games: "Adibú", "La ciudad perdida," and "Drood en el planeta 7."

We made use of new technology (mathematics educational computer games) as a complementary work tool in a concrete mathematics learning context by means of extracurricular didactic sequences.

THEORETICAL FRAMEWORK

In order to answer the three questions asked above-attitude towards mathematics and computers, individual and pair work with mathematics games, and pupils' behavior in normal mathematics classes–we need to describe the theoretical frameworks of reference.

Attitude towards mathematics and the use of computers

From the 1970s a wide field of research has been opened regarding attitudes towards mathematics. Numerous research works have been carried out to measure this affective component and a variety of instruments have been used to collect information and analyze it. Dif ferent variables have been correlated with attitudes, such as sex, study conditions (new students and repeating students) and academic performance.

Attitudes, then, have been studied in a series of dimensions: confidence and security in mathematical work, motivation towards mathematical work, commitment to mathematical work, use of the computer in mathematical activities, etc.

By way of example we refer here to two pieces of research undertaken on students' attitudes towards mathematics and computers.

Ganguli (1992) describes research carried out with 110 students undertaking a course in algebra, who were divided into four groups. The four groups used the same textbook, did the same homework tasks, while the contents taught were the same; the difference was that two experimental groups used computers while two control groups followed the traditional course. From the results obtained the following conclusion was reached: use of computers has a positive influence on students' attitudes, as was found when students from the experimental groups gave higher valuations than the control groups when answering that "the teacher makes mathematics more interesting", "the teacher introduces the material more clearly," and "the teacher has a better grasp of mathematics." The experiment shows that for the experimental groups, the graphics generated by computers lead to more active classroom discussions and, consequently, lead to greater interaction between teacher and students than in the control group. It could also be seen from this research work that students in the experimental groups manifested less anxiety than students in the control groups.

Galbraith and Haines (1998) carried out a study on students' attitudes towards mathematics and the impact of technology on the teaching and learning of this subject. A questionnaire was passed around 156 students undertaking first-year courses in Engineering, Mathematics and Actuarial Sciences. The instrument comprised six scales for measuring confidence and motivation regarding mathematics and computers, interaction between computer and mathematics and commitment to mathematics. This study shows how students with a highly positive attitude towards mathematics prefer to work by using examples rather than merely learn the given material; they are at ease when testing and reasoning using exercises and problems; they are happy to relate their new knowledge to the knowledge they already possess; they like to make notes on the material being studied, and they regularly revise their work. S tudents with low levels of positive attitude treat mathematics as separate units which later have to be remembered; they do not take notes; they seldom check their calculations, and they prefer to revise the material all at once. Howe ver, these students acquire confidence and security through the use of computers and develop positive attitudes when carrying out mathematical activities using computers.

Generally speaking, we can see that, as the computer has greater influence in computer-mathematics interaction, it is to be expected that it would have a significant impact when incorporating use of computers and graphic calculators into mathematics study plans.

The results from the various studies are promising with regard to the incorporation of new technologies into the process of mathematics teaching/learning.

We can see how the affective domain is taken into account as an important part of cognition in Mathematical Education. On e of the pioneers in this area of research is Mandler (1989) who tries to clarify what we should refer to when we are talking about our students' affective domain. In McLeod (1992), we find a detailed summary of Mandler's theory, which can be briefly summed up by saying that "Students experience emotions that develop into attitudes, which are used to construct their own beliefs."

As Mayes (1998) points out, this vision of the affective domain, taken from the perspective of development psychology, is analogous to the constructivist view of the cognitive domain.

From a theoretical point of view, we can consider as dimensions of the affective domain: beliefs (judgment of a certain set of concepts), attitudes (emotional reaction to an object) and emotions (intense reaction caused by some stimulus). Here we do not set out to study all of these three dimensions of the affective domain but only take into account one dimension: students' attitudes towards mathematics or towards computers, these being understood as the result of emotional reactions that have been internalized and automated in order to generate feelings of moderate intensity and reasonable stability that will be reflected in a questionnaire submitted to the students. Consequently, we do not separate exhaustively the various constructs contemplated from the theoretical point of view, but rather move between the elements of beliefs and attitudes, and disregard emotions.

Individual work and interaction in the mathematics classroom

Individualized, personalized teaching has been a permanent goal of school education. As Coll (1990) shows, the constructivist perspective posits the idea of the student as an active subject who constructs his or her own knowledge. Th is is a coherent framework that allows interpretation of the interactive processes that constitute the student's and the teacher's activity in the school institution.

The social organization of learning activities has been covered from various theoretical points of view, but studies have primarily centered on three basic forms of social organization of school activities: the cooperative, the competitive and the individualist. The characteristic that differentiates cooperative situations from other learning situations is interaction between students, arising when the aim is the completion of tasks. S tudents working in other situations generally do so individually from their class chairs, and most interaction takes place between teacher and student.

Traditionally, teacher/student interaction has been considered the most decisive in achieving didactic goals (learning of contents and cognitive and social development). However, over the last twenty years it has also been shown that interaction among students plays a primary role in the attainment of educational goals.

Interaction between pairs of students and the construction of mathematical knowledge

A theoretical framework in which to study interactions between pairs of students in the mathematics classroom, and which can be placed between the two positions derived from Piaget and Vygostky, is situated between the two poles that we now analyze: "Social interaction between pairs of students and the socio-cognitive conflict" and "Social interaction between pairs of students and the process of internalization".

Social interaction between pairs of students and the socio-cognitive conflict

The socio-cognitive conflict appears as a construct arising in social interactions and which facilitates learning and cognitive development. Cogni tive conflict is basic in genetic theory and appears in Piaget's first publications. In the most extensive versions it arises as the result of a lack of agreement between the subject's schemes of assimilation and the contradiction between corresponding physical observable phenomena (Piaget, 1975). In the case that concerns us, taken from Perret-Clermont (1979), the nature of the conflict is substantially different as it is conceived as the result of the confrontation between various subjects' schemes which arises in the course of social interaction (socio-cognitive conflict).

Social interaction between pairs of students and the process of internalization

Vigotsky formulates within this framework what he considers to be the most important law in human psychic development, the hypothesis of adaptation. In social interaction, the child learns to adapt his or her cognitive process following the indications and directives issued by adults, producing a process of internalization by which what can be done or known at first with adults' help (inter-psychological adaptation) is progressively transformed into something which can be done and known by the child alone (intra-psychological adaptation). Th e social origin of cognition is absolutely clear as is the close relationship between social interaction, on the one hand, and learning and development, on the other. For Vygotsky, development takes place when inter-psychological adaptation is transformed into intra-psychological adaptation. In these brief references, we should not forget the decisive role played by language as the adapting instrument par excellence of action and thought in the hypothesis of adaptation.

With regard to interactions between pairs of students we should emphasize that, although research in this area has not been abundant, most of it has been based on Piaget's ideas. For Piaget, the interactions between peers are of more importance than adult/child interactions.

Games in Piaget and Vygotsky

For Piaget (1982) the main goal of education was to form persons capable of doing new things and not simply repeating what other generations had previously created. Thus, his aim was the formation of active children, with critical minds, capable of learning for themselves, and who are not ready to accept everything put before them indiscriminately.

In order to achieve efficient education, from Piaget's theoretical point of view, games need to be taken into account, as these generate activities that stimulate social thinking. In his work, Piaget underlines the constructive nature of knowledge, and for him fantasy is fundamental in children's lives, as this allows them to relate to a reality that is being permanently constructed, and so it is very important to take into account the undertaking of activities and social interaction by the child.

For Vygotsky (1984) learning is by its very nature a social phenomenon, through which the acquisition of new knowledge is the result of interaction between people taking part in a dialogue.

Vygotsky speaks of a Zone of Proximal Development, which is the distance between the level of development, determined by the capacity to solve a problem independently, and the level of potential development, determined by the solving of a problem under the guidance of an adult or in collaboration with another more capable individual. The Zone of Proximal Development can be understood as what the child is initially capable of doing only with adults and pairs (through teaching) and what afterwards he or she can do independently (through learning). Vygotsky (1976) puts forward a provocative hypothesis in this sense regarding the relationship between play and development, when he affirms that "*... play is the source of development and creates the Zone of Proximal Development.*" Fo r Vygotsky, play leads to development by allowing the child to test the possibilities of the use of arbitrary meanings regarding his or her immediate conception of objects and his or her actions.

However, Piaget's and Vygotsky's ideas regarding the role of play in cognitive development are radically different. For Piaget (1975) assimilation is of supreme importance: the child by playing assimilates what he or she perceives in reality, and in this sense, play is not a determining factor in the modification of structures. For Vygotsky, however, play provides alterations in structures. Nevertheless, for Piaget as well as for Vygotsky, action is the basic requirement for development in learning: games in their various guises imply action and therefore help to develop learning.

Collaborative learning

Within the present framework, we reach the end of the last century with an emerging construct "collaborative learning."

Collaborative learning emerges and responds at present to a new cultural context where "how we learn" (socially) and "where we learn" (in networks) are defined.

The concept is founded on the idea that human beings were born to live in society, their meaning of life is social and their human and professional development are fully realized when interacting with others. The same is true of learning. Although it is true that learning has individual dimensions of analysis, conceptualization and appropriation, it is best carried out in collaboration with others.

Social interaction leads to the construction of knowledge which first develops in family life (such as locomotion, speech, social behavior, *etc.*) and is a form of collaborative learning outside the classroom.

One factor of this reality is that collaboration is an eminently social concept, part of the child's process of socialization, which leads him or her to abandon infantile egocentrism and be capable of greater levels of generosity, Piaget (1978).

The incorporation of children into the school is a process that accelerates the transmission of the information needed for development of the subject for a future formation especially conceived for professional life, and thus adapted to the needs of every social layer.

In connection with this term "collaborative learning" various concepts have been developed proximate to its meaning. So there are learning groups, learning communities, peer teaching, cooperative learning and collaborative learning (Dillengbourg, 1999; Gros, 2000; Salinas, 2000, *etc.*).

We should also point out that the terms collaborative learning and cooperative learning repeatedly appear as both analogous and contradictory terms. That is, certain authors tend to treat them as synonyms, while others differentiate them markedly, in that collaborative learning responds to a socio-cultural focus and cooperative learning to Piaget's constructivism.

Brufee (1995), for example, states that the collaborative perspective is what is needed for more advanced preparation for work with groups of students. Bruf fee identifies two types of knowledge as the basis to choose between either the collaborative or cooperative perspective. Fund amental learning is the basic knowledge represented by socially justified beliefs (grammar, spelling, mathematical procedures, historical facts, *etc.*) and is foreground in present curricular plans. These materials are best learnt using structures of cooperative learning in the initial stages. However, non-fundamental knowledge is reached through reasoning and questioning instead of through memorization. New knowledge is created through actions by which students must doubt answers given to them, even by the teacher, and the students should be helped to attain concepts by means of active participation in the process of questioning and learning. T his does not occur when working with facts and information associated with fundamental knowledge. Collaborative learning changes the responsibility for learning from the teacher as expert, to the student, and assumes that the teacher is also an apprentice. The author views the two perspectives as linear and affirms that collaborative learning is designed to appear just when cooperative learning disappears or finishes. This transition might be considered as a continuum which moves from a highly controlled system centered on the teacher to a system centered on the learner where the teacher and students share authority and control over learning.

Throughout human history, the idea of working and learning together has been widespread; however, at the end of the 20th century there appears the concept of collaborative learning, which has been studied and theorized upon within a just a few short years starting from the advent of socio-cultural constructivism that has provided its theoretical framework.

The question is: what is the reason for collaborative learning to be of such importance these days, not only in theory but also in learning and production processes? Zañartu (2003) gives three answers which appear convincing: the technological revolution; the electronic learning environment which meets those requirements to make collaboration particularly powerful, such as interactivity, ubiquity and synchronicity, and, thirdly, the fact that at the end of the past century the socio-cultural perspective fore-grounded the social as a complement to the personalized cognitive process of every individual.

In this work we choose to characterize collaborative learning as a set of learning methods and techniques for use in groups (pairs), as well as a series of development strategies for mixed competences (learning, personal and social development), in which every component of the group (pair) is responsible for his or her own learning and for the learning of the group's (pair's) components. It is in this last sense that we differentiate collaborative learning from cooperative learning where one component of the group, or from outside the group, is responsible for the learning.

At present we find ourselves in a broader didactic context where communication is multidimensional and is at once based on the teacher/student, student/teacher and student/student, and this is only attained through the creation of stimuli that allow effective participation of all the components. There is already in existence an international educational association (the International Association for the Study of Cooperation in Education (IASCE), devoted to the study and practice of cooperation in learning within a field of action that includes cooperative methods in the classroom in order that students develop collaborative skills.

Similarly, from a socio-cultural perspective, significant educational consequences have been drawn: concepts like team work and collaborative learning are brandished as guidelines for new tendencies, including the use of Information and Communication Technologies (Crook, 1998). It is within this theoretical context that the new paradigm called Computer Supported Collaborative Learning (CSCL) is being developed. CSCL aims to understand learning as a social process of construction of knowledge in a collaborative manner and which can be characterized as an educational strategy by which two or more subjects construct their knowledge through discussion, reflection and decision making, and where computer resources act, together with other resources, to mediate in the play/learning process.

In collaborative learning, information resources appear as determiners as well as mediators in the educational process and provide the principle that guides this learning process: shared knowledge (personal experiences, language, teacher's and student's culture, diversity, personal and social development, *etc.*). As such, authority is always shared between teacher and students, and so the meaning of the learning process is reconstructed. Consequently, collaborative learning moves away from formal environments and approximates to informal environments where education makes use of technology, and authority pertains to the collective and is taken away from the teacher.

The didactic experiment we describe in this research report was undertaken as an experiment to study and analyze the types of learning students' adopt-individual, cooperative and collaborative — when they use mathematics educational software in the form of computer games.

The hypotheses we start from are that children like playing, are interested in computers in general and that computer games bring these two elements together. Whe n games are connected to educational software they can contribute to a heightening interest in mathematics. Conse quently, what we set out to analyze is students' attitudes towards mathematics and computers, the types of learning undertaken when they use the computer, and check whether this type of instrument–mathematics educational software–helps certain students to make progress in mathematics.

To this end, apart from the collaborative learning framework in general, we have also taken into account those theories of individual and cooperative learning derived from the work of Piaget and Vygotsky.

METHODOLOGY

In order to achieve the three research goals a design was made including qualitative techniques for information collection.

An essential part of the design was the finding of mathematics educational software in the form of games that were suitable for Primary School children, as well as the availability of State Schools where the teachers were interested in taking part in this experiment with their pupils and willing to furnish us with the valuations of the results obtained through this didactic approach.

The research design elements were as follows:

Firstly, we will show the selection of teachers, pupils and games.

We should point out that this work was carried out in two phases, the first being exploratory in nature and the second experimental, which is what we refer to in this article.

In this first stage of the experiment four teachers from State Primary Schools were selected who voluntarily attended a course on mathematics computer games, given by the researcher, so as to learn how to play the games and analyze the didactic resources they had available and the feasibility of their use in actual teaching.

Teachers

For institutional reasons, of the four teachers taking part in the first stage of the experiment two were chosen to carry out the second stage: Teacher 2 who was working with a mixed group of pupils from 3rd and 4th levels (8 and 9 years old, respectively) and Teacher 4 with a class from 4th level (9 and 10 years old).

Pupils

Our proposal was to carry out our didactic experiment on mathematics and computers outside normal school hours and the pupils volunteered to take part.

Selection of the pupils was made taking into account various criteria: pupils who liked mathematics; pupils who had computers available at home or in a friend's home; teachers' reports to assess the participating pupils, and availability of an information technology classroom in order to work with the pupils.

At first 26 pupils registered. Selection following the above criteria was made to reduce this number to 14 students (8 boys and 6 girls). Fou r students were 8 years old, nine 9 years old, and one 10 years old, of whom 6 were pupils of Teacher 2 (2 from 3rd level and four 4th level), and 8 from Teacher 4 (all from 4th level).

The school's Parents' Association had an information technology classroom available near the school containing 8 computers. This meant that no more than 14 pupils could take part as we wanted to observe students' behavior when working individually, cooperatively and collaboratively, in order to thus study the efficiency of individual and pair work. During the course of the experiment two students went absent, enabling us an acceptable design for our proposals and allowing us to observe and compare pupils' work both in pairs and individually.

Mathematics educational computer games

Following an exhaustive search through mathematics educational computer game software, analysis was made of the mathematical content and feasibility of its use as a support element for teaching mathematics through computer games. Th ree games were chosen: "Adibú" (Coktel Educative, Madrid, Spain), "Drood en el planeta 7" (Edicinco, Valencia, Spain) and "Mates Blaster–El secreto de la ciudad perdida" (Anaya Educación Interactive, Madrid, Spain), which having been experimented with in the first phase, led us to present them to the pupils in the following order: beginning with "Adibú", which was the easiest, and then "El secreto de la ciudad perdida" and completing the experiment with "Drood en el planeta 7".

A short description of the three games selected:

"Adibú" (1995) works with Windows and is accompanied by a user's manual; the summary describes 15 accesses, the types of exercises, and pedagogic activities and criteria.

Following installation, you enter the screen where there appears a house in the shape of a head, in which the mouth is a door, the eyes windows, the nose a clock, the roof a cap with a chimney and TV aerial, as well as headphones.

When you click on the front door you enter the living room where you can choose which of the educational activities you wish to do. Choosing "I Calculate," a new screen appears giving access to 15 mathematics games activities, divided into three levels of difficulty.

Among the activities are Numeration, Operations, Ordering and Comparing.

When each activity is completed a figure Adibú appears to congratulate the child when the exercise has been well done or encourage him or her to do it again if he or she has made a mistake. When a pupil completes a series of exercises correctly a prize of a virtual sweet is presented appearing on the main screen on a tree replacing a piece of fruit.

"Mates Blaster–El secreto de la ciudad perdida" (1995) is distributed by Anaya Educación Interactive in Spain. It is in CD-ROM format, and operates through Windows. Accompanying the CD is a leaflet explaining installation and a simple description of the phases of the game.

Once the game is installed, the access panel appears, and when the icon "La Ciudad Perdida" is clicked on twice, the game begins.

The game takes the form of a space adventure film in which the space ship travels through space in search of a Lost City, in the hope of being able to save the star fleet from destruction. The player has to help them by using his or her mathematical abilities in order to discover the Lost City.

To begin with, the player puts in his or her name to be able to check the final score. The mathematical activities are Addition, Subtraction, Multiplication, Division, Decimals, Fractions and Percentages. Th ree mathematical levels are presented. Use of a calculator is allowed for the more difficult operations.

First, you have to click on one of the four buildings of the Lost City, the central building, which can only be activated after having gone through the other three. The building in the foreground gives access to the search for the number based on which you can help our heroes look throughout the building for numbers and mathematical symbols. Once the first three objectives have been attained, and the buildings transformed, the player may then enter the central building. Once the final phase has been completed, and the buildings now transformed, they regroup and once joined together reveal the secret of the Lost City, a highly powerful space ship.

The arrival of our heroes at the controls of the new space ship puts the troops of General Tenebroso to flight. So the game ends and the number of points scored and date are shown.

"Drood en el planeta 7" (1996) the third game, , also operates with Windows. There is an accompanying leaflet for installation and a simple description of the different stages of the game.

The game covers all the areas of Primary School education: Mathematics, Spanish Language, Social and Natural Studies, Foreign Language (English), Extras (riddles, *etc.*) and Mix (a mix of subjects).

The game begins by showing the main screen where the figure Drood appears, and we can decide on the new data base and on the left the school level (1st, 2nd or 3rd levels).

The game begins as a film recounting that the habitants of planet RO32, threatened by an imminent catastrophe, need a place to begin a new life. This is the reason for the explorer Drood to search for a new planet for his people. Drood finally finds a place, but when returning to his planet runs out of fuel and has to land on the nearest planet to look for fuel for his space ship. After he lands, he finds a mermaid on the beach and she tells him that this is Planet 7. Drood asks her for help to find fuel and she, in exchange for this information, asks him to find 7 objects that she has lost on the beach. Thus ends the first stage of the game with Drood having to find the objects according to the mermaid's instructions.

The screen is divided into several sections. In the top right there is the map with the 9 quadrants where the search will have to take place; below are the 7 spaces to be filled in with the objects found; then a panel with holes for 7 stars that the player will have to win to complete the game, and at the foot of the screen are 7 green marks that represent the "lives" the player has with which to finish the game. In the bottom half of the screen is the panel where the mathematical questions will appear with 4 options from which to choose the correct answer. In the centre part of the screen there is the game.

Once all the objects, which the mermaid asked for, have been obtained, the player wins a star which shows the route through the caves of Planet 7 where the second stage of the game starts. The aim is to get all the stars that allow the player to reach the final stage in which the player has to place the seven stars on a shield in the correct sequence.

The player has a maximum of seven attempts to find the correct combination, and if the player cannot get this combination, this stage will have to be started once more. Once the final stage has been successfully completed, the door opens allowing Drood to enter the Gem Chamber where he finds the fuel he needs to return to his planet.

Now, we will describe how the experiment was conducted and the instruments used to collect information.

The experiment phase

The first phase was to choose the teachers, pupils and games. The second phase, which is the aim of this present study, took place in the following academic year, outside school hours, in the months of October, November and December, three days a week, there being a total of 26 sessions of 1.5 hours each, in the presence of the two participating teachers and the researcher. In the first session, the pupils answered the questionnaire, were given an explanation about the computers and the aim of the course and had their first contact with the game Adibú in the final half hour.

In order to go from Adibú to the second game, the pupils had to get at least five virtual sweets. Each sweet represented a series of 5 exercises done correctly and they also did a test at level three of the game, which was undertaken under the supervision of the researcher or teachers. In this test were several exercises by means of which checks were made of the speed of operation solving within a given time, as well as numerical sequences and mental operations.

To complete the second game the pupil had to go through all the stages using the four operations of addition, subtraction, multiplication and division.

In the third and final game, the pupil had to complete all the stages of the data base for 2nd Cycle Primary School Mathematics.

Of the 8 computers available, 6 were used for student pairs and the other two individually. Th e absence of some pupils on certain days of the week allowed the computers to be used individually, facilitating observation of pupils' individual work and pair works (cooperative and collaborative study).

When the computer was used by pairs of pupils, the rule was that while one of the pupils was carrying out the activity, the other pupil watched. They changed places when the first pupil had completed the task. However , this did not mean that the second student acted as a mere observer, but had to take part by helping out his or her partner when this pupils had any problem, or could express his or her opinion about the task when the partner was not having any problems, allowing us to collect information for the cooperative and collaborative study.

The instruments used for collecting information were as follows: a semi-open questionnaire to obtain general information about the pupils, check their level of knowledge about computers, computer games, and educational software, and also verify their attitudes towards computers and mathematics. Resea rcher's diary to observe and record the pupils individually and in pairs when playing with the games, undertaking activities in pairs and individually, the times needed to complete the games, the frequency and participation in the course, and the difficulty and ease with which they used computers. Init ial and final teachers' reports: initially to evaluate pupils behavior in class and work in mathematics, and the final report to evaluate the pupils' behavior during the computer course, their behavior in mathematics classes, their work in mathematics and the final assessment of the experiment undertaken.

ANALYSIS AND DISCUSSION OF DATA

In order to study Primary School pupils' attitudes and disposition regarding mathematics and use of computers, information was obtained from a semi-open questionnaire which collected information around four axes: general, computers, mathematics and games, and from a later interview about the data taken from the questionnaire.

A summary of the results of the questionnaire is given in the form of the tables given below: Table 1a (general information and data regarding computers) and Table 1b (data concerning mathematics and games).

In the first column appear the first fourteen capital letters of the alphabet referring to the fourteen participants. The initials of the pupils' names are related thus: DFD (A), DCV (B), EDH (C), ANGR (D), JVV (E), DDA (F), DRB (G), AGB (H), ABD (I), CNLM (J), NMVH (K), DAG (L), DSB (M), LGOS (N).

Table 1a. General information and data regarding computers

General information					Computers					
Student	Age	Sex	Year group	Teacher	Do you like them/ Why?	Access/ Where?	Study/ How?	Games/ Types	Handling	Useful
A	8	F	3 A	2	Yes/ Games	Yes/School	No	No	Easy	Yes
B	8	M	4 A	4	Yes/ Games	Yes School	No	Yes Sports	Easy	Yes
C	8	F	4A	4	Yes/ Games	Yes/Home	No	Yes/Infant Games	Difficult	No
D	8	F	3A	2	Yes/ Don't know	Yes School	No	No	Easy	Yes
E	9	M	4B	2	Yes/ Games	Yes School/ Home	Yes Puzzles	Yes War games	Easy	No
F	9	M	4A	4	Yes/ Mathematics	Yes Home	Yes Puzzles	Yes/ Strategies Sports	Easy	Yes
G	9	M	4B	2	Yes/ Games	Yes School	Yes Puzzles	Yes Infantiles	Easy	Yes
H	9	F	4A	4	Yes/ Games	Yes/ School /others	No	Yes Educational	Difficult	Yes
I	9	M	4B	2	Yes/ Don't know	Yes School/Home	Yes Reading Stories	Yes Solitaire Puzzles	Easy	Yes
J	9	M	4A	4	Yes/ Games	Yes Home	Yes Puzzles	Yes Games	Difficult	No
K	9	F	4A	4	Yes/ Images	Yes Home	No	Yes/jigsaw	Easy	Yes
L	9	M	4A	4	Yes/ Games Study	Yes Others	No	Yes War games Strategies	Not much	Yes /no
M	9	M	4B	2	Yes/ Games	Yes/ School	No	Yes/Infant Games	Difficult	Yes
N	10	F	4A	4	Yes/ Sound	No	No	No	Easy	Yes

Pupils manifest a great deal of interest in computers, which they like. The reasons they give in their answers are varied though it is noticeable that the main reason is being able to use them to play.

A need for computers is recognised by nearly all the pupils while at the same time they consider that computers facilitate learning of mathematics; only one pupil has no clear opinion. F rom their own personal point of view, 9 pupils consider computers easy to use, 4 difficult and 1 quite easy. All the pupils believe that it is useful and interesting to have computers in their homes to play and study with. In the school where we conducted this research, all the pupils had access to computers.

Table 1b. Data concerning mathematics and games

	Mathematics					Games		
Student	Do you like hem?	Do you under-stand them?	Important	Enjoyable	With computers	Do you know mathematical games?	Do you know educational games?	What do you like most?
A	Yes	Yes	Yes	Yes	Easier	No	No	Winning
B	Yes	Yes	Yes	Yes	Easier	No	No	No answer
C	No	Yes	Yes	Little	Easier	No	No	Nothing
D	Yes	Yes	Yes	Yes	Easier	No	No	No answer
E	Yes	Yes	No	Yes	Easier	No	No	War games
F	Not much	Yes	Yes	Yes	Easier	No	No	Sports
G	Yes	Yes	Yes	Yes	Easier	No	No	Enjoyment
H	Yes	Yes	Yes	Yes	Yes/ No	No	Yes	Enjoyment
I	No	No	Yes	No	Easier	No	No	War games
J	Yes	Yes	Yes	Yes	Easier	No	No	Learning
K	Yes	Yes	Yes	Yes	Easier	No	No	No answer
L	Yes	Yes	Yes	Yes	Easier	No	No	Enjoyment
M	Yes	Yes	Not much	Yes	Easier	No	No	Puzzles
N	Yes	Yes	Yes	Yes	Easier	No	No	No answer

However, during the individual interviews regarding the actual use of computers, only

8 pupils reply that they have used them some time to play, 5 in school or at a friend's home, and 3 pupils at home.

The pupils value mathematics highly. Most of them like the subject, except for two. Most have no difficulties regarding mathematics and consider it important for their lives, and also claim that they enjoy themselves in class. They believe that if they could use computers mathematics would be easier to understand.

The situation is different regarding games. None of the pupils know mathematics games but can remember some games related mainly to their language classes. When games are played on the computer the pupils make no distinction between playing and studying. However, they are clearly in favor of games (10 pupils underline the need to play games, 3 do not consider them necessary, and one student fails to give a clear opinion). Wh en it comes to choosing games, they tend to select war and sports games and puzzles.

From the replies to the survey, it can initially be seen that nearly all pupils at this age like mathematics, understand the subject and enjoy doing it; however, the reality is somewhat different, as experience in the classroom shows how bad some pupils feel doing certain mathematics tasks and how little they enjoy themselves doing them. Th ere is a marked discrepancy between what pupils express in the survey and what we really find in the classroom.

Nevertheless, working with computers does not give rise to this discrepancy between what pupils say and what happens in reality: the pupils like and are interested in computers at all times, especially when playing when they enjoy themselves, although it is obvious that they do not use computers to study. More over, they do not know any educational games, only entertainment games related to wars, sports and puzzles. Mo st pupils state that computers are easy to handle and accept playing games on computers leads them to learn some mathematics.

Turning to analysis of the advantages and disadvantages of individual and pair work with computer games for the learning/teaching of mathematics, information was gathered from the researcher's diary where data was collected based on pupils' individual and pair work when playing games, carrying out tasks in pairs and individually, the time needed to complete the game activities, the frequency and level of participation in the course and the difficulties and ease of using computers.

In Table 2 we give a summary of pupils' behavior while doing the computer course. Pupils A and G have been omitted as they did not complete the course. In order to better read the results set out in the Table, the following abbreviations and observations are used: G1, First game; G2, Second game; G3, Third game; I, Incomplete; PC, Computer; C, Activities complementary to the course; %, Percentage of participation.

Table 2. A summary of pupils' behavior while doing the computer course

	Time at game. Participation					Difficulties		Experience in games	Individual/Paired with
St.	G1	G2	G3	C	%	PC	Math		
B	10	4	11-I	0	92	Yes	Yes/many	No	H Individual
C	9	4	4	3	75	No	Yes/few	Yes	E
D	15	8	3-I	0	58	Yes	Yes/many	No	A Individual
E	9	3	5	3	70	No	No	Yes	C
F	5	4	8	3	70	No	No	Yes	L
H	9	3	5	3	90	Little	No	No	B, M ,K
I	15	10	0	0	90	Yes	Yes/many	No	Individual
J	8	6	4	2	96	No	No	Yes	Individual
K	9	8	8-I	0	100	No	Yes	No	H, N Individual
L	7	3	5	5	90	No	No	Yes	F
M	12	5	9	0	65	Yes	Yes	No	H Individual
N	10	10	5-I	0	90	Yes	Yes	No	K Individual

We should point out that during the first-week sessions, stable pairs were not formed, and it was not until the second week when they began to be formed, while most pairs remained unstable and some pupils always worked individually.

We now describe some of the types of behavior. With regard to the stable pairs, various types of behavior can be found.

Pupil E: was 9 years old and was studying in 4th grade with Teacher 2. F rom the very first day he showed interest in the computer as such as well in how to handle it. H e found it easy to use the mouse, as well as play some non-educational games. He showe d a lot of interest throughout the course and did not find the mathematical contents involved in the various games difficult. H e completed the three games with some ease. Being unable to attend on Tuesdays, he caught up by doing some complementary activities. He formed a pair with Pupil C during the three months of the course.

Pupil C: was 8 years old and was studying at 4th grade with Teacher 4. At first she showed no problems using the computer and knew non-educational games; however, she had some difficulties with mathematics. She also completed the three games with some ease. Also, being unable to attend on Tuesdays, she caught up by doing some complementary activities. She formed a pair with Pupil E during the three months of the course. Pupil C was shyer and slower working than her partner Pupil E.

Pupil L: was 9 years old and was studying at 4th grade with Teacher 4. From the start he was the pupil who showed most interest in games, as well as very good ability with the computer, as he had already used computers with non-educational games, and scarcely needed help from teachers or the researcher. The mathematics contents caused him no difficulty during the games. He completed the games with great ease. He formed a pair with Pupil F during the whole course.

Pupil F: was 9 years old and was studying at 4th grade with Teacher 4. From the first few days of the course he worked together with Pupil L in some sessions, and formed a pair with this pupil as from the second week. These two pupils also formed a pair in school classes. F was fairly familiar with computers which he already used for non-educational games, and had few difficulties with mathematics during the course. He completed the games with some ease.

The behavior of these two stable pairs formed by Pupils CE and FL, who completed the games in the least time, was different, as the first pair (CE) had different levels of mathematics and Pupil E often acted as the teacher, while the second pair (FL) had similar levels of knowledge and carried out the activities together.

The remaining pairs were unstable and were formed by pupils with different levels or at times by two pupils who had worked individually in previous sessions. Conflicts ensued which needed a teacher's or the researcher's intervention so that learning could continue positively.

Some pupils did not form pairs or preferred to remain alone. Among these pupils B, D, I, J and N failed to finish the third game, while others such as H, K and M, who formed non-stable pairs, needed more frequent help from the teacher or researcher when acting alone.

When one computer was occasionally available for every pupil, the pupils were asked to work individually and it was noted that those pupils belonging to stable groups continued to make progress at almost the same pace, while some of the pupils from unstable groups made greater progress when they were alone and others when they worked in pairs. The pupils working individually were those needing most assistance from the teachers and the researcher.

We can also find two different types of behavior with regard to pupils' individual work:

Pupil J: was 9 years old and was studying in 4th grade with Teacher 4. From the very first classes he showed himself to be independent, not liking to share the computer with other pupils. When, at the beginning of the course, he had to share with others certain problems arose as he always wanted to remain on the computer longer that his partner, only being satisfied when he had a computer for his own exclusive use. He concentrated on his work and on the computer. He found the computer easy to use as he had had experience with non-educational games. He only asked for the teacher's or researcher's help in case of overwhelming difficulty. He complete d the games without any difficulty.

Pupil I: was 9 years old and was studying in 4th grade with Teacher 2. He is another example of an individualistic pupil, who wanted a computer for his own use and always caused problems when he had to share with another pupil. He often asked for the teacher's or researcher's help with the games, not because he did not know how to solve the problem but because he often tried to attract attention. This pupil could not even get through the second game.

Pupils I and J both worked individually, but their behavior was different. Pupil J solved the problems he encountered when playing games by himself, while Pupil I could not solve these problems himself and often asked for the teachers' or researcher's help.

Information regarding students' behavior concerning work in mathematics classes and mathematics work by means of computer games was collected from teachers' initial and final reports.

As mentioned above, the teachers were asked to make an assessment by means of a closed questionnaire regarding their pupils, evaluating their behavior before the course in computer mathematics games, both in class and with particular regard to mathematics. They were asked to make new observations during the computer games course as well as fill in a register of relevant data about the pupils during the computer games course.

Table 3 gives a summary of those types of behavior that the teachers found most notable regarding the pupils before and during the games course.

Table 3. A summary of types of behavior

	Before games course		During games course		
St.	In class	In mathematics class	In class	In mathematics class	In the games course
B	Calm, obedient, tidy	Difficulty with tables, numeration, reasoning, etc.	Improves and works more fluently	Improves in numeration	Same as in class. Follows course with interest
C	Independent, hard-working	Does not know all the tables; slow in mental calculations	The same	The same	Improves
D	Interested, untidy	Problems with reasoning and mental calculations	Better, more attentive and participative	Better in mental calculations, and more autonomous	Improves; more attentive and participative

	Before games course		During games course		
E	Methodical, interested	No problems with problems or mental calculations	Better, more attentive and participative	Better, enjoys mathematics more	Improves, more participative and attentive
F	Fidgety; finished work	Difficulty with reasoning problems, tables and mental calculations	The same	The same	Improves, greater concentration
H	Tidy, hard-working	Does not know all the tables, slow in mental calculations	The same	The same	The same as in the classroom
I	Interested; untidy, easily distracted	Difficulties with problems and mental calculation	Improves, more participative and attentive	Improves in mental calculations; enjoys mathematics more	Improves, more participative and attentive
J	Disobedient, untidy	Problems reasoning, does not know all the tables, numeration	The same	The same	Much better, more concentrated and interested
K	Fidgety, distracted	Problems reasoning, does not know all the tables	Improves	Improvement in operations	Better than in class, more interested
L	Untidy, disobedient	Reasons Mental calculations. Irregular in work	The same	The same	Improves; greater application; correct behaviour
M	Interested; tidy; helpful	Difficulties solving problems, mental calculations	Greater participation	Improves in mental calculations	Greater attention; greater interest in calculation and better results
N	Distracted; little concentration; disobedient	Low level of reasoning; deficient mental calculation	Improves; tries to finish work	Improvement in concentration; still has major problems	Better than in class. Some signs of untidiness

These summaries are based on the teachers' assessments, and here are some of the teachers' general opinions.

Teacher 2

"I considered taking part in this course important from the very beginning because I would get to know how to use computers and would also be able to see how they can be used with the pupils as an educational support, and also so that their parents would become aware of this type of educational computer games and buy them for their children".

"I have seen that use of this type of mathematics games motivates pupils, consolidating mathematics contents in a playful and enjoyable way."

"I can see that this type of work has helped change pupils' attitudes and that they have become familiar with computers."

Teacher 4 made similar statements:

"My opinion is that this has also been very positive for the pupils who have taken part because there has been a change in attitude regarding the many difficulties they had and especially because most of the pupils have felt much more motivated and this has been reflected in their daily classroom activities".

To sum up these reports we can point out that Pupils B, D, I, K and N (who preferred to remain alone), E (a member of a stable group) and M (a member of an unstable group) improved in various aspects such as interest, behavior, participation, reasoning, concentration, mental calculations, numeration, operations, while some of them showed greater interest in mathematics.

Pupils C, F and L (belonging to stable pairs) did not change in the classroom or in mathematics, but did so with regard to their behavior during the course, which was better than in the classroom. Only Pupil H (another member of an unstable group) showed no change in behavior.

CONCLUSIONS

From the results obtained we can state that, generally speaking, use of computers gives a new dimension to classroom instruction by eliminating distances, awakening greater motivation in teachers and students, opening new perspectives on teaching/learning that help form persons capable of facing up to and solving new situations and understand in a natural way Information and Communication Technologies in a school context.

This short three-month experiment on working with mathematics educational computer games has led, in the opinions of the teachers, to certain changes in some pupils. Games seem to be an element that aid children's mathematical development, help their memorization capacity through repetition of exercises, increase their ability to reason when making mental calculations and impose in a pleasant way the challenge to practice more with mathematics in order to solve those problems arising during the games.

Educational computer games can act as a complement, support and reinforcement of the knowledge transmitted by the teacher in the classroom and by no means as a substitute for the teacher. Indeed, the presence of the teacher is needed to overcome gaps in children's knowledge which in the normal classroom might not be expressed.

We should point out that the three games chosen reflect in their structure and contents traditional forms of mathematics teaching/learning and do not imply any novelty in this respect. Wh at are really interesting are not their contents but their form and the background against which the activity takes place: atmosphere, suitable language, colors and forms close to the present-day social reality in which the children move and in which the culture of the image predominates. Teachers also seem to connect better with their students using technology in such playful environments.

The pupils appreciate games highly, and they all stated that they had liked them. Mathematics also plays an important role at these ages; most pupils claim that it is more enjoyable to study mathematics through games, and some affirmed that they had improved in operations (addition, subtraction, multiplication and division), while others in mental calculations and also in problem solving.

We could see that every pupil, either working individually or in pairs, was able to develop a method to make progress in mathematical knowledge: their methods were not the same but varied, even within such a small sample as fourteen pupils.

If we do not take into account the initial experimental conditions, we can say that the stable pairs improved more in behavior than the unstable pairs and these, in some cases, more than pupils who worked individually. However, the picture is not so simple. Wh at we might draw from the study is that learning was carried out in at least five different situations:

1) When pupils work individually and they come across problems which they resolve by themselves, as in the case of Pupil J.
2) When pupils work individually and they come across problems they cannot solve by themselves and ask for the teacher's or researcher's help, as in the case of Pupil I.
3) When pupils work in pairs and one of the members teaches or instructs the other by giving him or her explanations, instructions or guidelines regarding the task. In this case work management takes place. This is the case of the stable group CE.
4) When the pupils work in pairs and the roles undertaken by each of them is coordinated, there is mutual control of the work and responsibilities are shared to carry out the task. Her e there is authentic collaboration based on mutual support. This is the case of the stable pair FL.
5) When the pairs work in pairs and there are moderately diverse points of view about the tasks to be performed and when a conflict arises about how to solve the

problems which leads the pair to a consensual resolution. This type of situation is not highly explicit as in most cases the consensus is not reached between the pupils themselves, but they ask for the teacher's or researcher's help to mediate in the conflict. This is the case of the unstable groups KN and HB.

The results obtained in this work show some evidence that cooperative and collaborative learning have some elements in common but also some properties that markedly differentiate them, although the basic premise in both cases is founded on a constructivist perspective. Knowledge is discovered by the students and transformed into concepts that the student can relate one to the other; then knowledge is reconstructed and expanded through new learning experiences. We believe that each paradigm of learning represents one part of a general process of learning we consider as triangular in form, by which one side of the teaching/learning process would be cooperative learning (highly structured by the teacher), another individual learning (individual construction) and the third side collaborative learning (which places responsibility for learning onto the student, when learning is understood as a social construction).

This work is being extended at the moment as a similar experiment is being carried out in the state of Bauru in Brazil, where the question is being studied in greater depth and more concrete analysis is being made of the pupils' behavior in front of the computer screen in terms of cooperative, individual and collaborative learning.

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