CARD GAME: ATTEMPTS BY PRIMARY LEVEL EDUCATION PUPILS TO LEARN BINARY ENCODING

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ABSTRACT
This paper focuses on the learning of binary encoding by primary school pupils within a learning experiment mainly based on their being involved in playing a game. In fact, nineteen 6th Grade pupils participated in a constructivist learning experiment consisting of three phases: i) reviewing and reflecting on their knowledge about the decimal system, ii) experimenting with the binary system by being involved in playing a specially-designed card game and iii) extending their knowledge by attempting to transform decimal numbers into their binary representations. Data analysis showed that pupils successfully managed to describe the structure of numbers in the decimal system. The specific questions and materials provided also helped them to reflect and to make connections between the structure of this numerical system and the binary system. Moreover, specific interventions performed by the researcher helped them to clarify some misconceptions. In addition, the data analysis showed that pupils were involved with great pleasure in the playing of card-games and efficiently managed to calculate the binary number represented on each card. The analysis demonstrated pupil performance in binary encoding using systems consisting of one to eight binary digits. In the final phase of the experiment, pupils were stimulated to extend the knowledge they had acquired during previous phases. In fact, pupils successfully performed a variety of transformations of decimal numbers into their corresponding binary ones and also made generalizations about binary encoding. Exploiting the positive results of this experiment, we present the design of game-based educational software for the learning of binary encoding by primary level education pupils.

KEY WORDS
Binary encoding, game-design, primary education, constructivism

INTRODUCTION

Computer Science (CS) has already had an immense impact on modern life, the way we live, think and act. Yet we should not underestimate its continuing importance in the future. The conceptualization of CS concepts at all levels of education is essential. To this end, a four-level model curriculum of CS for K-12 has been proposed (Association for Computing Machinery, 2003). The aim of this curriculum is to better address the need to educate young people in the important subject area of CS and thus better prepare them for effective citizenship in the 21st century. One of the four goals of this curriculum is to introduce the fundamental concepts of CS to all students, beginning at primary level. As regards the learning of CS concepts, it is clear that whatever is achieved in high school depends upon the effectiveness of student access to technology and achievement of computer-related learning milestones at the primary level.

Level I of the previously mentioned curriculum (recommended for grades K-8) is geared to provide primary school students with fundamental CS concepts by integrating basic technology skills with simple algorithmic thinking. In addition, understanding how data from the real world should be represented in order for it to be understandable to a computer is fundamental for a preliminary understanding of computers. Within this framework, an understanding of binary numbers is critical. It follows that understanding fundamentals of binary numbers is a basis for the achievement of the goals of the CS curriculum at this education level. It is worth noting that both students in secondary education and adults have difficulties in understanding binary systems and how a computer works (Soloway & Spohrer, 1989).

The role of engaging learners in meaningful and enjoyable learning activities is acknowledged as crucial for the learning of any subject, let alone the learning of fundamental CS concepts and skills in primary education (Jonassen, 2000; Bell, Witten, and Fellows 2002). Games in particular are viewed as being the most ancient and time-honored vehicle for education (Crawford, 1982). In fact, games are among the most enjoyable activities for those who are young (Facer 2001, McFarlane, et al., 2002) as they are able to motivate players in three ways: fantasy, challenge and curiosity (Malone, 1981). Research into games and play has demonstrated that players can attain a state of 'flow' (Csikszentmihalyi, 1990) that is summarized as "the state in which we are so involved in something that nothing else matters". However, TEEM ('Teachers Evaluating Educational Multimedia') data suggests that the degree of difficulty is also important here; for children to enjoy playing, the game must be not be too difficult (McFarlane, et al., 2002a).

Appropriately-designed educational games can support student learning in terms of changing their behavior and ways of thinking, helping them achieve personal potential or developing their capacity to operate within particular communities (Smith, 1999). By being involved in such games, students can acquire essential learning 'competencies' such as logical thinking and problem-solving skills. In the context of playing games, students can also develop new approaches to collaboration (Fromme, 2003). A key contention is that, through the informal playing of games, children learn to participate in what have been called 'semiotic domains', which are shaped by their interaction within a games context and with each other (Gee, 2003).

Consequently, a key factor in most research into games and learning is a sense that playing games encourages young people to learn in different ways from those often in evidence, or explicitly valued, in the school setting (Kirriemuir and McFarlane, 2004). It is important for young people today, who seem to expect different approaches to learning (Prensky, 2001). In the TEEM report (McFarlane, et al., 2002b), teachers and parents recognized that the playing of games can support valuable skill development such as strategic thinking, planning and communication, application of numbers, negotiating skills, group decision-making and data-handling. Appropriately-designed games can also support constructivist perspectives on knowledge construction (von Glasersfeld, 1987) where learning is considered to be an active, subjective and constructive activity placed within a rich and meaningful context for learners. It is worth noting that the research outlined above raises key questions about the role of play in learning and the role of learning through activities perceived as intrinsically motivating to children, as well as the changing roles of children as learners. Moreover, the investigation of the role of play in the learning of specific subjects included in school curricula and especially in the learning of CS concepts is important (Facer, 2003a). Although a number of games regarding the learning of Computer Science concepts have been reported in the literature (Papastergiou, 2006; Grigoriagou and Maragos, 2005), a game for the learning of binary numbers has not yet been reported.

In our attempt to help primary level education pupils learn about binary numbers in a pleasurable environment, we constructed a card-game taking into account all the above and also tested it in the field with real students. For the design of this game, constructivist theories of learning were also taken into consideration (von Glasersfeld, 1987). In the next section of this paper, the context of the learning experiment is described, with an emphasis on the presentation of the design of the card-game, followed by discussion of the results and the implications of this study for the design of a computer-based game for the learning of binary numbers. Finally, conclusions are drawn.

THE CONTEXT OF THE STUDY

The focus and the methodology

This study focuses on the learning of binary encoding by primary school pupils within a learning experiment mainly based on their being involved in playing a game. In fact, nineteen 6th Grade pupils participated in a constructivist learning experiment consisting of three phases: i) reviewing and reflecting on their knowledge about the decimal system, ii) experimenting with the binary system by being involved in playing a specially-designed card game and iii) extending their knowledge by attempting to transform decimal numbers into their binary representations. The learning experiment took place in a typical primary school in Patras, Greece. The duration of this experiment was commensurate with the pupils' needs but lasted no longer than two hours. To illustrate the effect of the previously mentioned three-phase experiment on primary level education pupils' knowledge of binary numbers, qualitative methodology (Cohen and Manion, 1989) was used. Specifically, observations and reflections by the researcher were made during all phases of the experiment. Pupils participated in the experiment in groups of three. The data collected consisted of: a) the field notes of the researcher's observations covering all phases of the learning experiment, b) the pupils' written answers to all the questions posed. The various types of data were organized in accordance with the three different phases of the experiment. In each phase, individual pupils' answers to the questions posed were identified and reported. In the second phase, where pupils were involved in actually playing the card game, their interactions were also logged. Pupils' answers and interactions were analyzed in terms of how their conceptions of binary numbers developed during the experiment. In the following section the three-phase learning experiment is presented.

The learning experiment

Phase I. Decimal system: the relationship between the position of each digit and its value

This phase was designed to give pupils the opportunity to review their knowledge of decimal numbers. It was considered essential to give pupils the chance to reflect on the structure of decimal numbers and to be aware of the value of their decimal digits in relation to their position. By reflecting on their knowledge of the decimal numerical system, pupils have the chance to smoothly progress to the binary system and to make a number of connections between these systems. To accomplish the aims of this phase, the pupils were set the following tasks.

Task 1. In this task, pupils were asked to write at least 10 decimal numbers using all possible digits. Subsequently, these pupils were asked the following questions: 1) How many different digits can we use to write a decimal number? 2) What is the meaning of each digit? 3) Can you explain the meaning of each digit used in the numbers you previously wrote?

Task 2: In each of the following two cards (Figure 1), write a number and assign to each rectangular frame the number of units that each digit expresses.

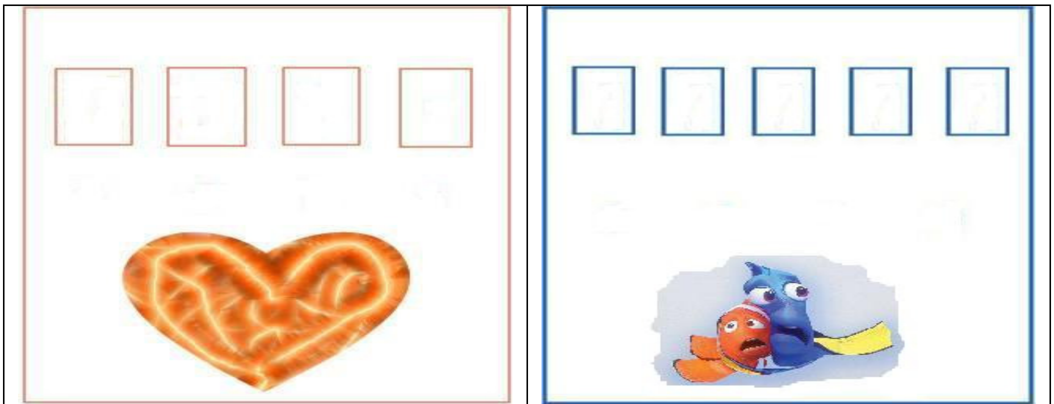


Figure 1a | Figure 1b

Figure 1. Cards used to help pupils to reflect on their knowledge of decimal numbers

The first task (Task 1) was constructed in order to give pupils the opportunity to study decimal numbers in a symbolic way, while the second task (Task 2) was constructed to help pupils visualize meanings of the value of each digit of a decimal number.

Phase II. Binary system: the relationship between the position of each digit and its value
This phase of the experiment was designed to provide pupils with opportunities to familiarize themselves with the existence of the binary system and understand its structure and the relationship between the position of each digit and its value. To motivate pupils to be engaged in this phase of the experiment, the following introductory words were used: '*All of us realized during the previous task that we can use 10 different numerical digits in order to form any number in the decimal system. However, despite the fact that we can understand the meaning of each number constructed in this way, computers understand numbers written only by using combinations of 1s and 0s. How is it possible to represent any number with such combinations? To understand this, lets play a game'*.

Task 3: Familiarization with the materials used. Here, a number of cards (such as those presented in Figure 2a) were given to the pupils to observe. Each card represents a number (from 1 to 15) in its four-digit binary form. This binary number is also represented in relation to the significance of its digits in the form of a rectangular frame including an appropriate number of dots corresponding to the position of each digit (1 dot, 2 dots, 4 dots and 8 dots correspondingly). Next, pupils were asked to observe them and to express their opinions regarding the following questions: 1) What is the meaning of dots which are inside each of the rectangular frames? 2) What is the number represented in each of the rectangular frames? 3) What do you think the relationship between these numbers is? 4) What is the number of dots that would be included if we were to add another rectangular frame to the left of the frame with 8 dots? 5) What is the value of each digit of the binary numbers represented in these cards? 6) What is the meaning of "0" and of "1" in different positions? 7) What is the value of each of the binary numbers represented on these cards?

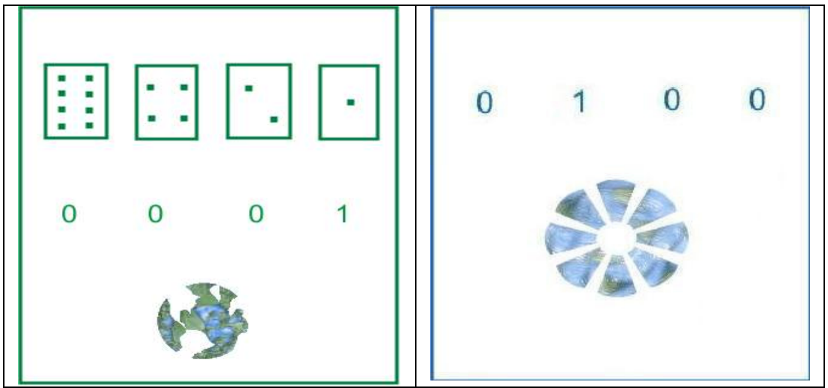


Figure 2a | Figure 2b

Figure 2. Cards used to help pupils to construct visual meanings for binary numbers

Task 4: Playing the card game. In this phase of the experiment, students were involved in playing a card game using a set of specially-designed 60 cards. More specifically, pupils were presented with 4 sets of 15 cards (60 cards in total, such as those presented in Figure 2a), each of which represented a number (from 1 to 15) in its four-digit binary form. Each group of cards contained an illustration of an attractive figure from the pupils' world. For each group of cards, the binary numbers, the figures, the rectangular frames and the dots included in these frames were colored with the same color. Pupils were encouraged to use these cards to play a game, the rules of which are presented below:
a) All cards (60 cards) have to be on the top of a table face down. b) Players have to take cards in rotation. Each player takes a card and then calculates the decimal number that corresponds to the binary number illustrated on this card. At this point, pupils are provided with a table in the first column of which they are to write these decimal numbers. On their next turn, they take another card, then translate the binary number into the corresponding decimal one, writing this decimal in the 1st column of the table, calculating the sum of these decimal numbers and writing this sum in the second column of the table. c) the score of each player at any given moment totals the numbers represented on their cards, d) the aim of each player is to acquire a score near or equal to 51, e) if the score of a player exceeds 51 then they lose and stop playing, f) a player can withdraw from the game at a specific time they

themselves select, g) the winner is the player with the highest score, but h) if more than one players have the same score then they take one more card and the winner is the player with the smaller number.

Table 1. An example of a possible three pupil card game

Player A		Player B		Player C	
Decimal number	Sum	Decimal number	Sum	Decimal number	Sum
12		7		10	
15	27	10	17	15	25
6	33	15	32	15	40
8	41	14	46 (stops)	12	52 (loser)
3	44				
6	50 (stops)				

Table 1 shows the score of three players (Player A, Player B and Player C) involved in the game mentioned above. Player C is the loser because they have gained a score greater than 51 while Player A is the winner of this game as they have gained a higher score than that of Player B.

Task 5: To help pupils to think more deeply in terms of binary numbers, this game can also be played using cards with pure binary representations of the numbers only (an example of this type of card can be seen in Figure 2b).

Phase III. Encouraging pupils to extend their knowledge of binary numbers
This phase is considered to be essential as it helps pupils reflect on and extend their knowledge of decimal and binary numbers as well as make generalizations and connections between them. In fact, during this phase, pupils were encouraged to transform decimal numbers into their binary representations and vice versa.

Task. 6. Here, pupils were presented with a variety of cards representing the numbers 1, 2, 4, 8 and 16 (Figure 3). They were asked to combine the appropriate cards in such a way as to construct the binary form of the numbers: 1, 13, 6, 15, 7, 4. This task was considered to be essential as it investigates pupils' ability to transform decimal numbers into their binary form.

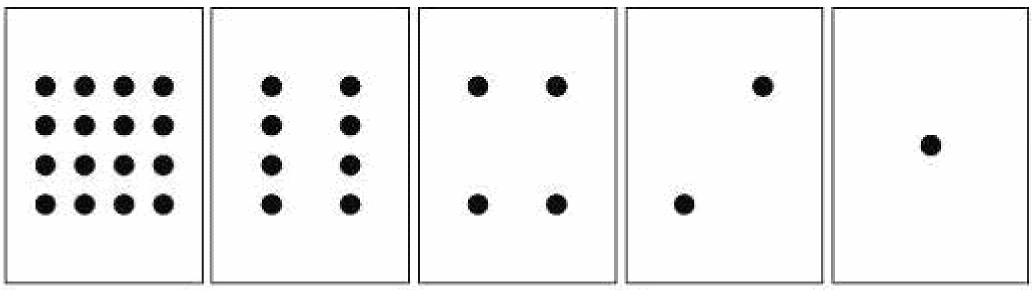


Figure 3. Cards representing basic numerical units used in the binary system

Task 7. Here, pupils were also presented with the type of cards they used in the previous task (Task 6). Next, pupils were asked to combine the appropriate cards and try to construct the binary form of the following numbers: 32, 69 and 165. After constructing each number pupils were asked to explain their constructions. As pupils had not previously used the binary representation of numbers higher than the number 15, this task was considered to be essential for investigating pupils' abilities to extend their knowledge and come up with the appropriate process implied for the construction of any binary number. Finally, pupils were asked to generalize and to present a set of rules for the translation of decimal numbers into their corresponding binary ones.

Task 8. In this final task, pupils were asked to complete Table 2 so that they would be encouraged to consolidate their knowledge by finding some similarities between decimal and binary systems. Pupils were then presented with an example of a transformation of a binary number into a decimal one, eg. 1101=1*8 + 0*4+ 0*2 + 1*1=8+0+0+1=9, (*=multiply).

Table 2. Table of similarities between the decimal and binary systems: to be completed by the pupils

Decimal system	**Binary system**
1	__
10	__
100=10*10	__=__*__
1000=10*10*10	__=__*__*__
10000=10*10*10*10	___=__*__*__*__

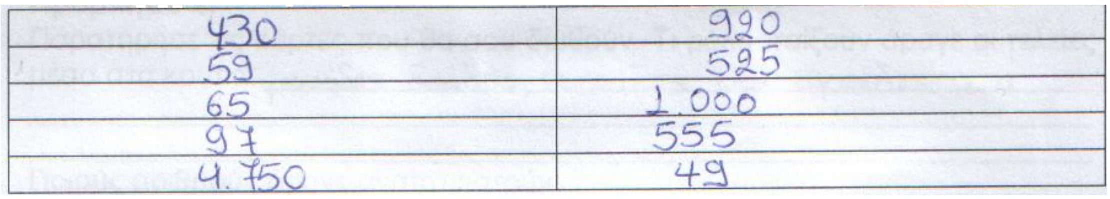
Finally, pupils were asked to analyze the following binary numbers in order to transform them into decimal numbers.

1001=1*__ + 0*__+ 0*__ + 1*__=___
0111=0*__ + 1*__+ 1*__ + 1*__=___
0101=__*__ +__*__+__*__ +__*__=___
1111=__*__ +__*__+__*__ +__*__=___

To perform this final step, pupils are required to exploit the knowledge they have acquired by trying to complete Table 2.

RESULTS

The most important data findings are summarized below:
Phase I. Providing pupils with opportunities to review their knowledge of the decimal numerical system.
Task 1. The majority of pupils (7 pupils) wrote 10 decimal numbers using all possible numerical digits and also recognized that 10 digits could be used for the formation of each decimal number. The remainder of the pupils used only four numerical digits: 0, 1, 8 and 9. These pupils were able to progress after the researcher intervened by asking them if there were "other numerical digits" that could be used and, if so, what they were.. All pupils also correctly established that the first-left digit of a decimal number represents units, the second digit represent tens, the third hundreds etc. An example of a set of decimal numbers written by a pupil is demonstrated in Figure 4.



430	990
59	525
65	1.000
97	555
4.750	49

Figure 4. An example of a set of decimal numbers written by a pupil

This pupil analyzed the number 4750 in the following way: 0: units, 5: tens, 7: hundreds and 4: thousands.

Task 2. All pupils wrote decimal numbers on the given cards and successfully assigned to each rectangular frame the number of numerical units that each digit expresses.

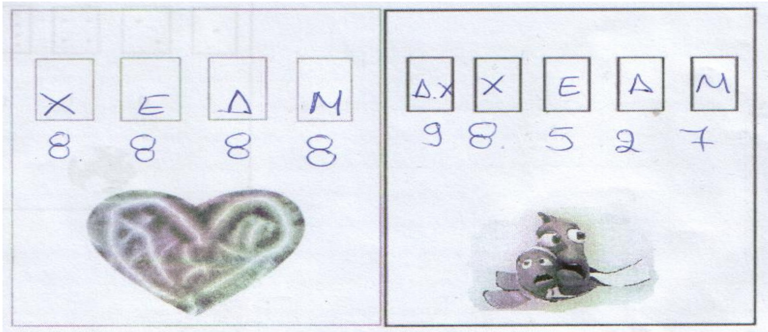


Figure 5. Pupils' attempts to perform Task 1

Figure 5 demonstrates two examples of pupils' attempts to perform this task. In this Figure, X means thousands, E means hundreds, Δ means tens, M means units and ΔX means tens of thousands.

Phase II. Experimenting with the binary system by involving pupils in playing a game
Task.3. The pupils' answers to the questions (Q) posed during this task can be summarized as follows:
Q.1. About half of the pupils (9 pupils) participating in this experiment explained that the dots which are inside each of the rectangular frames represent a number of numerical units. The rest of the pupils (pupils M1, M2, M3, M4, M5, M9, M13, M14, M16 and M19), ended up at this explanation after reflecting on the previously mentioned second task (Task 2) where similar cards were used for the representation of decimal numbers and the rectangular frames of those cards were used to represent the number of numerical units.

Q.2. Approximately half of the pupils (10 pupils) realized that the numbers 1, 2, 4 and 8 were represented by the dots inside each rectangular frame. The remainder (pupils M1, M2, M3, M4, M5, M13, M15, M19 and M20) arrived at this realization after reflecting on the second task.

Q.3. The majority of pupils expressed the view that the number of dots in each rectangular frame is related to the number of dots included inside each rectangular frame to the right of it, multiplied by two. The rest of the pupils (pupils M1, M5, M6, M13 and M19) had difficulties in understanding this relationship. At this point, these pupils were encouraged by the researcher to reflect again on these numbers and to try to find some relationship. Subsequently, upon reflection, these pupils worked out the correct answers.

Q.4. All pupils expressed the view that, if another rectangular frame were to be added to the left of the frame with 8 dots, the number of dots included would be 16 dots. They also realized that a further frame would include 32 dots.

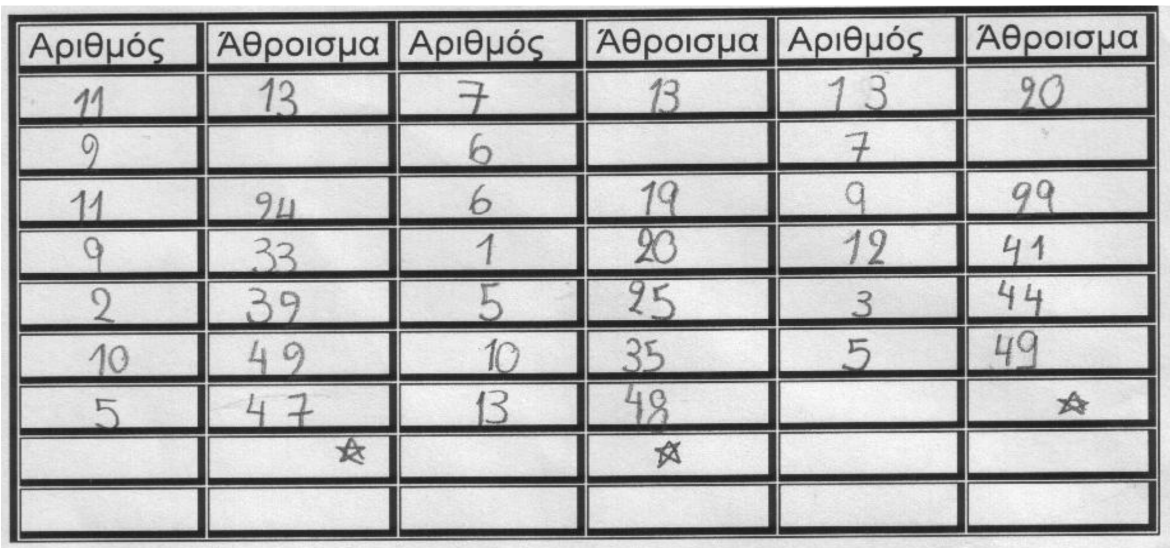
Q.5. The majority of pupils (11 pupils) understood that the number represented by each digit of a binary number, starting from its left, expresses 1 numerical unit, 2 numerical units, 4 numerical units and 8 numerical units, correspondingly. In other words, the digits of the binary number 1101 represent: 1 numerical unit, 0 set of double numerical units, 1 set of 4 units and 1 set of 8 units. The rest of the pupils (pupils M1, M2, M3, M4, M5, M14, M15 and M19) had difficulties in answering this question. At this point, they were encouraged by the researcher to reflect again on the second task and, after some reflection, these pupils did manage to come up with the correct answers.

Q.6. All pupils answered that the meaning of "0" and "1" depends on their positions in the binary number in question. In terms of a 4-digit binary number, they represent 1 unit, 2 units, 4 units and 8 units correspondingly, starting from the left.

Q.7. The majority of pupils (10 pupils) seemed to grasp the notion that, in order to be able to transform each binary number illustrated on a card into a decimal number, they have to multiply each binary digit by the number of numerical units represented in the corresponding rectangular frame eg. the binary number 1101=1*1+0*2+1*4+1*8= 13. The remainder (pupils M1, M2, M3, M4, M5, M9, M12, M13 and M19) had difficulties in performing this transformation.

At this point, it is worth noting that, while all pupils correctly found the number of units represented by each digit, some did not grasp the true value of the whole binary number in question. For example, some pupils were of the opinion that the binary number 0011 is equal to 21 in the decimal system. In fact, although they realized that this number consisted of 1 multiple of 1 unit and 1 multiple of 2 units, they wrote the number 2 and the number 1 together. They did not understand that they had to calculate the number of units eg. 0011=1*1+1*2+0*4+0*8= 3. At this point the researcher intervened by presenting the following example: '*lets study the decimal number 635. Number 6 represents 600 units, number 3 represents 30 units and number 5 represents 5 units. If we write these numbers sequentially (the way these pupils previously used) then the number produced is the number 600305. Is it correct? What do we have to do with the number of units included in a number?*' At this point, these pupils experienced cognitive conflict and answered that, in order to find the appropriate number; they would have to add together the number of units. Subsequently, they used this knowledge in the task where they transformed binary numbers into their corresponding numbers in the decimal system.

Task 4. Playing the card game
Here, it is impressive to note that all students were happily engaged in this task, within a spirit of friendly competition. Winners expressed their pleasure at winning while those who lost looked forward to playing again. Some expressed a desire to play again and again. They found it interesting because they learned a lot about binary and decimal numbers. Pupils used all type of cards provided easily, even those presenting only binary numbers (Task 5). Significantly, no-one had difficulties in calculating the binary numbers illustrated on the surface of their cards or the sum of the points illustrated on the cards they picked up during the game. An example of the calculations performed by a pupil during the experiment using cards representing only binary numbers is presented in Figure 6.



Αριθμός	Άθροισμα	Αριθμός	Άθροισμα	Αριθμός	Άθροισμα
11	13	7	13	13	20
9		6		7	
11	94	6	19	9	99
9	33	1	20	12	41
2	39	5	25	3	44
10	49	10	35	5	49
5	47	13	48		☆
	☆		☆		

Figure 6. A pupil's attempt to calculate binary numbers during the card game

Task 6. All pupils succeeded in combining the cards illustrated in Figure 3 to construct the binary form of the numbers 1, 13, 6, 15, 7 and 4.

Task 7. About half of the pupils (pupils M6, M7, M8, M10, M11, M12, M14, M15, M17 and M20) expressed the opinion that the biggest number that could be constructed using the cards provided (Figure 3) was the number 31. To construct the number 32, they decided to extend these cards by adding another frame consisting of 32 dots to the left of the frame with 16 dots. Consequently, they constructed the binary number 100000. The rest of the pupils succeeded in this task after having been asked to reflect on the answers they had given to question three (Q.3) in the third task (Task 3). To construct the binary form of the number 69, all pupils added a frame consisting of 64 dots to the left of the frame with 32 dots to help construct the binary number 1000101. Finally, all pupils added a further frame consisting of 128 dots to help construct the binary form (10100101) of the number 165.

Task 8. All pupils managed to complete Table 2, asking for similarities between the decimal and binary systems, and transform the given binary numbers into their decimal form. Moreover, half of them (pupils M2, M4, M6, M7, M8, M11, M13, M18 and M20) successfully concluded that the transformation of a decimal number into its binary form can be successfully realized by following the following rules:

- Firstly, we have to establish how many rectangular frames (each including the appropriate number of dots) are necessary. So we construct frames with dots 1, 2, 4, 8, 16…We stop when the number of dots is smaller than or equal to the number to be transformed. These frames have to be arranged in an increasing sequence.
- Secondly, we have to put the symbol '1' under the rectangular frame with the highest number of dots.
- Thirdly, we put the symbol '1' under the appropriate frames and the symbol '0' under the rest of the frames.

Finally, it is notable that some pupils explicitly expressed the view that the number 10 is a basis for the decimal system while number 2 is a basis for the binary system.

DISCUSSION

This paper demonstrated the design and the implementation of a three-phase learning experiment for the learning of introductory aspects of binary encoding by primary level education pupils. This experiment was mainly based on the design of learning tasks and materials emphasizing pupils' reflection on their primary knowledge of the decimal numerical system, the mirroring of its structures in the binary system and the extension and consolidation of this knowledge. In the first phase of this experiment, pupils were asked to express their knowledge in terms of written answers to the questions given regarding the number and the variety of digits used for the representation of any decimal number as well as the relationship between the position of a numerical digit and its value. During this phase, pupils were also provided with specially-designed cards allowing a visual representation of the number of numerical units - in terms of frames including the appropriate number of dots - implied by the position of each numerical digit of a decimal number. This phase was designed as a vehicle to help pupils to smoothly progress to the structure of the binary system. In fact, the use of the decimal system as a basis for an introduction to the binary system, in combination with the questions posed, would appear to successfully assist pupils in investigating their knowledge of decimal numbers and help them to concentrate on the structure of the decimal system while also recognizing the relationship between the position of a numerical digit and its value. As a result, all pupils correctly managed all tasks set during this phase of the experiment.

In the second phase, pupils were provided with the same type of cards as previously described, with the exception that the number of dots included in the frames assigned to each position of a binary digit was different. To clarify the structure of the binary system, a number of appropriate questions were posed to the pupils. At this point, pupils were helped to understand the value of a four-digit binary number by being encouraged to reflect on both the representations used in the cards provided and the representations of decimal numbers they performed during the first phase. After this reflection phase, pupils happily and successfully engaged in a specially-designed game using these cards. Here, it is worth noting that all pupils succeeded in calculating the value of binary numbers represented on their cards, despite the fact that some had not managed well in the previous phase. This clearly demonstrates that this pleasurable and joyful game provided them with strong motivation.

These two phases of the learning experiment also helped pupils to successfully realize the third phase of this experiment. In fact, through their experimentation in the previously mentioned two phases, pupils were helped to extend the knowledge they had acquired about four-digit binary numbers to numbers with more digits. By also trying to find similarities between the structure of the decimal and binary systems, pupils successfully managed to transform the given decimal numbers into their corresponding binary forms.

On the whole, the data analysis revealed that the use of the decimal system as a basis for the introduction to the binary system, in combination with questions helping the pupils to concentrate on the structure of both systems and on the relationship between the position of a numerical digit and its value, was appropriate for the introduction of primary pupils to basic aspects of the binary system. In addition, the card game established a playful atmosphere and was strong motivation for the pupils to consolidate these aspects. Pupils were also encouraged to extend the knowledge they had acquired in the previous phases of the experiment by being asked to make further transformations between these numerical systems.

IMPLICATIONS FOR THE DESIGN OF A COMPUTER GAME FOR THE LEARNING OF BINARY NUMBERS

The encouraging positive results of this three-phase experiment can constitute a solid base for the design of a computer game for the learning of binary encoding by primary level education pupils. In fact, the said experiment can be simulated within a computer context to provide pupils opportunities to experiment and to receive feedback for self-correction. It is widely accepted that appropriately-designed computer games can play an essential role in furthering pupils' knowledge and creativity as well as providing motivation for them to be actively and passionately engaged in their learning (Kafai, 1996; McFarlane, 2002b; Facer, et al., 2003; Fromme, 2003). In the following section the specifications of this game are presented. These specifications have to provide pupils with:

1. Opportunities to write their own decimal numbers and simultaneously ask for the use of all possible numerical digits. At this stage, pupils can receive appropriate feedback from the computer.
2. Electronic cards such as those illustrated in Figure 1.
3. The operations for writing decimal numbers and for characterizing the value of each of their digits.
4. A variety of electronic cards such as those illustrated in Figure 2a.
5. Appropriate feedback for the answers given to the questions posed in Task 3.
6. The opportunity to transform binary numbers into their corresponding decimal ones and feedback on this.
7. Opportunities to play the card game on the computer, using the two types of cards illustrated in Figure 2.
8. Opportunities for the calculation of the binary numbers picked up and the total sum of these numbers at any moment. The data is recorded in a table and feedback is provided.
9. Opportunities to experiment with cards representing random binary numbers consisting of a plethora of digits.
10. Random decimal numbers and empty cards with empty cells corresponding to the value of each digit.
11. The opportunity to fill these cells with the appropriate value of the digit in question and also the opportunity to fill in the empty card with the appropriate binary number, together with the appropriate feedback
12. Opportunities to find similarities between the decimal and binary systems by providing an interactive table (like Table 2) to complete.

CONCLUSIONS

This study presented a three-phase learning experiment for the learning of binary encoding by primary level education pupils. This learning experiment was mainly based on pupils' involvement in playing a specially-designed game. The design of this experiment emphasized the expression of pupils' primary knowledge of the decimal system, the formation of new knowledge through reflection on their primary knowledge and the connection between the decimal and binary systems, consolidation of the newly acquired knowledge within the context of a specially-designed game and, finally, extension of the knowledge acquired by focusing on transformations of numbers in these two numerical systems. More specifically, and in combination with the questions posed, the cards used were designed to provide pupils with opportunities to express their knowledge of the structure of decimal numbers and the relationship between the position of their digits and their value. These cards were also designed to help pupils to reflect on this knowledge and to make connections easily between decimal and binary numbers. The said learning experiment was realized in the field using real pupils (Grade 6 pupils) with positive results in terms of acquisition and extension of knowledge of binary numbers through successful calculation of a 4-digit binary number, and estimation of its value as well as transformation of a decimal number into its corresponding binary form. It is also worth mentioning that a considerable number of pupils succeeded in constructing a set of rules on how to transform a decimal number into its binary form. Using these promising results, we arrived at the design specifications for a computer game that could simulate this experiment within a computer environment. This simulation will provide extra opportunities for pupils, such as interactivity, feedback, colorful bright cards, automatic generation of cards representing any decimal and binary number and, of course, a play partner when they are by themselves.

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