A COMPUTER GAME FOR THE LEARNING OF BINARY SYSTEM BY BEGINNERS

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ABSTRACT

This paper describes the design and features of a computer interactive game for the learning of basic aspects of the binary system by primary level education pupils. The design of this game was based on modern social and constructivist theories of learning, at the same time acknowledging the research literature related to educational computer games. In the context of this game, pupils are asked to play against the computer with cards featuring binary numbers. To be successfully engaged with the game, pupils are provided with opportunities to review their knowledge of the basic structure of the decimal system by using cards with decimal numbers and subsequently to make connections between the knowledge related to this system and the structure and basic aspects of the binary system. Pupils are provided with immediate feedback so that they may make self corrections. Hints are also provided to assist pupils to make a smooth transition in understanding from the decimal system to the binary system.

KEYWORDS

Binary system, Primary Education, Computer Games.

1. INTRODUCTION

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 Computer Science (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 the young (McFarlane, et al., 2002) as they are able to motivate players in three ways: fantasy, challenge and curiosity (Malone, 1981). A game provides children with a compelling reason for engaging in the educational content, and children have the opportunity to exercise the targeted skills and knowledge naturally in the course of playing the game (Fisch, 2005). Moreover, 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".

Leading scholars have long argued that computer games provide a compelling context for children's learning (Papert, 1998; Jenkins, 2002; Gee, 2003). They can provide a motivating context for introducing children to new concepts, topics and skills that they can continue to explore subsequently through offline reading, discussions or activities. They have been particularly effective in raising achievement levels of both children and adults in areas such as maths and language, where specific learning objectives can easily be stated (Kirriemuir 2002). In addition, well designed computer games can serve as useful tools for both formal (i.e., classroom) and informal (i.e., outside the classroom) education (Fisch, 2005). To this end, it is worth noting that in any given week many young people spend a significant amount of leisure time playing computer games, often 7 hours or more (Walsh 2002). Some basic reasons why computer games engage learners have been established: a) they are typically fast and more responsive than other media, b) they provide a rich variety of graphic representations to generate a wide range of options and scenarios not possible with non-computer games, c) they can be played against real people anywhere in the world as well as against the computer, d) they can deal with infinite amounts of content and afford differing levels of challenge, and e) they can be instantly updated, customized and modified by individual players, so that the player becomes part of the creative team (Prensky, 2001, pp. 128–129).

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 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). By being involved in such games, students can acquire essential learning ‘competencies’ such as logical thinking and problem-solving skills. In the context of computer games, students can also change at least ten of their main cognitive styles (Prensky, 2001; pp. 51-52). It would also appear that, through playing games, young people are encouraged to learn in different ways from those often in evidence, or explicitly valued, in the school setting (Kirriemuir and McFarlane, 2004). In fact, young people seem to expect different approaches to learning (Prensky, 2001). Moreover, 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. However, the research outlined above raises key questions about the role of play in the learning of specific subjects included in school curricula and the role of learning through activities perceived as intrinsically motivating to children, as well as the changing roles of children as learners.

Computer Science (CS) has already had an immense impact on modern life, the way we live, think and act, and 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. Indeed, 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 processed by 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 also worth noting that both students in secondary education and adults have difficulties in understanding binary systems and consequently how a computer works (Soloway & Spohrer, 1989). Although a number of games regarding the learning of Computer Science concepts have been reported in the literature (Papastergiou, 2006; Grigoriagou and Maragos, 2005; Kordaki and Mpimpas, 2007), a computer game for the learning of binary numbers by primary level education pupils has not yet been reported.

Taking into account all the above, we have constructed a computer card-game, in our attempt to help primary level education pupils learn about binary numbers in a pleasurable environment. In the design of this game, social and constructivist theories of learning were taken into consideration (Vygotsky, 1974; von Glasersfeld, 1987). In the following section of this paper, the rationale for this computer game is presented and subsequently its features described using specific examples and then discussed in relation to the game’s possible use with real students. Finally, conclusions are drawn.

2. THE RATIONALE FOR THE DESIGN OF THE PROPOSED GAME

In the design of this proposed game, sociocultural and constructivist perspectives on knowledge construction (Vygotsky, 1974; von Glasersfeld, 1987) were taken into account. According to these perspectives, learning is considered to be an active, subjective and constructive activity placed within a rich and meaningful context for learners. To this end, the role of digital media in playing a determining role in the whole learning context was also acknowledged (Noss and Hoyles, 1996). However, it was considered that games should first and foremost be *fun* and then encourage learning (Prensky, 2001). To this end, it was born in mind that designers of learning games should initially ask themselves the following questions (Prensky, 2001; page 179): a) is the game *fun* enough that someone who is not in its target audience would want to play it (and would learn from it)? b) would people using it *think of themselves as 'players'* rather than 'students' or 'trainees'?, c) would the experience be *addictive*? Would it produce great 'word of mouth' among users? Would users want to play repeatedly until they won, and possibly after? d) would *players' skills in the subject matter* and learning content of the game – be it knowledge, process, procedure, ability, etc. – *significantly improve at a rapid rate* and get better the longer he or she played? e) could the game encourage *reflection* about what has been learned?

It was also acknowledged that active participation is the key; the player seeks to understand and control their play cycle while being challenged by some form of opposition (Fabricatore, 2000). Thus, intrinsically motivating games, where the game structure itself encourages learning, are preferable to extrinsically motivating games, where real or imaginary rewards are given (Dempsey, *et al*. 1994; Van Deventer and White 2002). As a result, designers of educational games should seek ways of applying incidental learning or gaming strategies to an intentional learning task. However, the learning principles and learning gains associated with computer games should be exploited when designing games for educational purposes (Fabricatore 2000). At this point, it is worth noting that a key appeal of these games is found to lie in providing learning opportunities within contexts that are relevant and attractive to learners (Kirriemuir, 2002). The combination of interactivity within a familiar and yet novel situation, with clear and agreed aims for learning, proves very effective (Kirriemuir, 2002). In addition, 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). However, the role of teacher mediation remains important, in various ways that include explaining or augmenting the game (Kirriemuir, 2002).

As regards the educational content of a game, it must be sound, age-appropriate, and well integrated into the game (Fisch, 2005). The contents to be taught can be naturally embedded within the game, with some contextual relevance in terms of the game playing, and the learning tasks have to be contextual to the game in the sense that they must be perceived by the player as a true element of the game-play (Fabricatore, 2000, p. 15). In fact, the educational content must be at the heart of game play, so that children engage in the targeted real-world behavior or thinking as they play the game (Fisch, 2005). Children come to see the educational content as the "work" they have to slog through to get to the "fun stuff".

However, what is captivating for players about games tends to be their structure rather than their content. Structure involves dynamic visuals, interaction, and the presence of a goal and rules that govern play (Becta, 2001, p.1). To this end, eleven key structural characteristics of computer games have been reported (Prensky, 2001, pp. 118–119) which, when combined, can strongly engage the player. These significant characteristics are: a) fun, b) play, c) rules, d) goals and objectives, e) interaction, f) outcomes and feedback, g) adaptivity, h) winning, i) conflict/competition /challenge/opposition, j) problem solving and k) representation or story. These characteristics can correspondingly contribute to the players' engagement in terms of: a) enjoyment and pleasure b) intense and passionate involvement c) structure d) motivation, participation in social groups e) doing, f) learning, g) flow, h) ego gratification, i) adrenaline, j) sparking creativity, and k) emotion.

When creating a game, it is important to consider not only the basic structure of the game itself, but also the feedback given in response to incorrect answers or when players request assistance. Consequently, the design of feedback and hint structures, in ways that assist and scaffold children to cope with difficult content, is essential (Fisch, 2005). In fact, it is considered that, for any game focused on learning, it is the feedback in the game which encourages the learning (Prensky, 2001). To scaffold children's performance and learning, feedback for each wrong answer should be designed to provide a little additional support for children as they continue to try to figure out the right answer. An effective and useful piece of feedback would help children understand *why* their answer was wrong, or point them gently in the right direction. Finally, the interface of the computer games must be easily usable by the target audience (Nielsen, 2002).

Taking into account all the above, we have constructed an interactive computer game that can support pupils in their learning of binary numbers by getting them to play against the computer using cards featuring binary numbers. Pupils need to use their knowledge of binary numbers if they are to play the said game effectively. To this end, pupils are provided with opportunities to review their knowledge of the decimal system (by using the "Decimal system' function) and make connections with basic aspects of the binary system (by using the "Binary to Decimal with help' function). In addition, the '"Binary to Decimal' function is provided to help pupils check their progress in learning about binary numbers. In fact, pupils are first asked to use cards with decimal numbers, so as to express their previous knowledge of the decimal system, and then to use cards with binary numbers to encourage them to think about these numbers in an analogical way. Pupils are also provided with the opportunity to convert decimal numbers into binary numbers with the use of a help pattern (by using the "Decimal to Binary with help' function). The system gives immediate feedback on pupil actions to enable them to make self-corrections. In addition, visual hints are provided to help pupils make smooth progress in their understanding of the basic structure of the binary system. The features of the proposed game are described in the following section.

3. THE FEATURES OF THE PROPOSED GAME

3.1 The 'Decimal System' Function

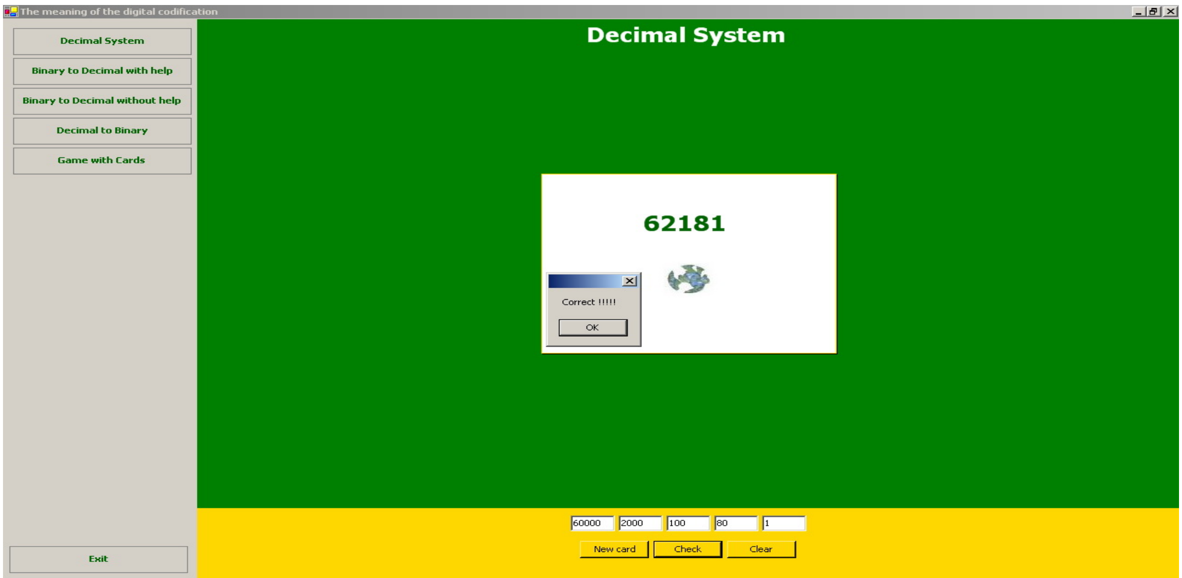

Figure 1. An example of the use of the 'Decimal System' function

The purpose of this function is to provide pupils with the opportunity to review their knowledge of the decimal system. This function was considered essential if pupils are to be given 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 progress smoothly to the binary system and to make a number of connections between these systems.

When the "New card" button is pressed, the program randomly picks a new card displaying a decimal number of up to five digits. The pupil has to break this number into tens of thousands, thousands, hundreds, tens and units. Next, when the "Check" function is pressed, the program checks the accuracy of the pupil's answer. The "Clear" button clears the table so that the pupil can start over again with an empty table. An example is presented (in Figure 1), where the program has randomly created the decimal number 62181.

Pupils have to break this number down as follows: 62181 = 60000 + 2000 + 100 + 80 + 1. Then they have to fill in the gaps with their results and press “Check” in order to see if their answer is correct.

3.2 The ‘Binary to Decimal with Help’ Function

The purpose of this function is to help pupils to understand how to convert binary into decimal numbers with the use of a help pattern. This function was considered necessary if pupils are to be provided 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.

When the “New card” button is pressed, the program randomly picks a new card displaying a binary number of up to five digits. The user has to convert this number into the equivalent decimal number. To help with this conversion, the system displays a help pattern (in the form of a drawing) below the cards. This drawing demonstrates each unit’s representation in the decimal system and makes the conversion as easy as the counting of dots on the drawing. Hence, in the case of a five digit binary number, the first digit represents the number 16 in the decimal, the second the number 8, the third the number 4, the fourth the number 2 and the fifth the number 1. The adding of all these numbers together should amount to the equivalent decimal number. Next, if the “Check” function is pressed, the program checks if the user’s answer is the correct one or not. The “Clear” button clears the table so that the pupil can start over with an empty table.

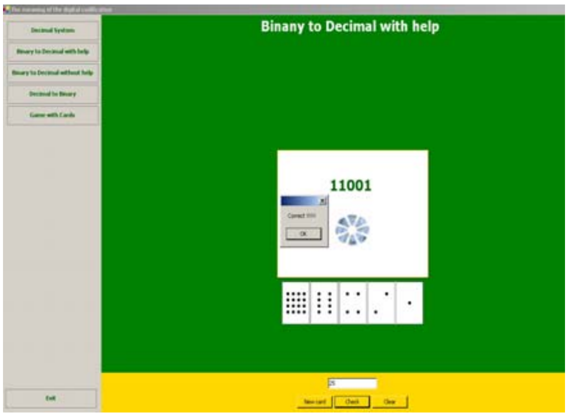

Figure 2a. An example of the use of ‘Binary to Decimal with help’ function

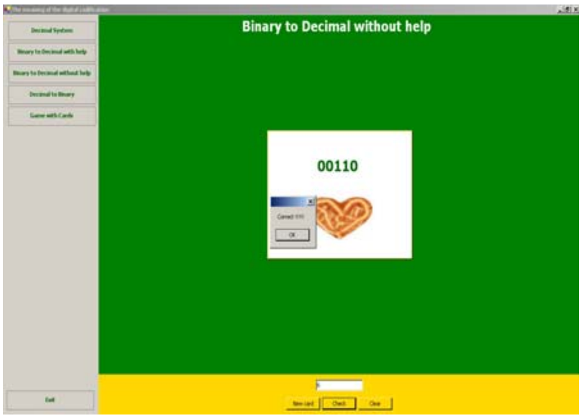

Figure 2b. An example of the use of ‘Binary to Decimal without help’ function

In Figure 2a, an example of the previously mentioned function is presented: the program has randomly created the binary number 11001. The drawing under the cards helps pupils to understand the significance of each number’s unit. The first 1 is equivalent to 16 in the decimal system, the second 1 is equivalent to 8 and the fifth 1 is equivalent to 1. Wherever there is a 0, that unit also has a 0 representation in the decimal system. Thus, for the binary number 11001, the decimal equivalent is 16+8+1 = 25. The “Check” function proves that the result is the correct one. Another way of explaining this is as follows: the binary number 11001 can be broken into: 11001 = 10000+ 1000 + 1. In the decimal system, 10000 represents the number 16, 1000 represents the number 8 and 1 represents the number 1. Thus, the result is the same. In this way, the pupil can understand the importance of each binary number unit, as shown in the help pattern (counting of dots).

3.3 The ‘Binary to Decimal without Help’ Function

The purpose of this function is to encourage pupils to learn how to convert binary into decimal numbers. This function is almost exactly the same as the previously mentioned function (Binary to Decimal with help), except for the fact that it has to be performed without the use of the help pattern. This is actually the next step, when the pupil feels confident of his understanding of how the conversion from binary to decimal system works. An example of the use of this function is demonstrated in Figure 2b.

3.4 The 'Decimal to Binary' Function

The purpose of this function is to support pupils in their learning of how to convert decimal into binary numbers with the use of a help pattern. This function was considered essential as it investigates pupils' ability to transform decimal numbers into their binary form.

When the "New card" button is pressed, the program picks at random a new card displaying a decimal number from 1 to 63. This is equivalent to a binary number of up to six digits. The pupil has to convert this number into the equivalent binary number. To assist with this conversion, the system displays a help pattern below the cards (6-card pattern this time). This helps the conversion as follows: starting from left to right, pupils need to create binary 1s in the correct positions of the six digit number so that the total decimal number (by counting the dots) is equivalent to the one created by the system. Afterwards, when the "Check" function is used, the program checks if the pupil's answer is the correct one or not. The "Clear" button clears the table so that the pupil can start over with an empty table.

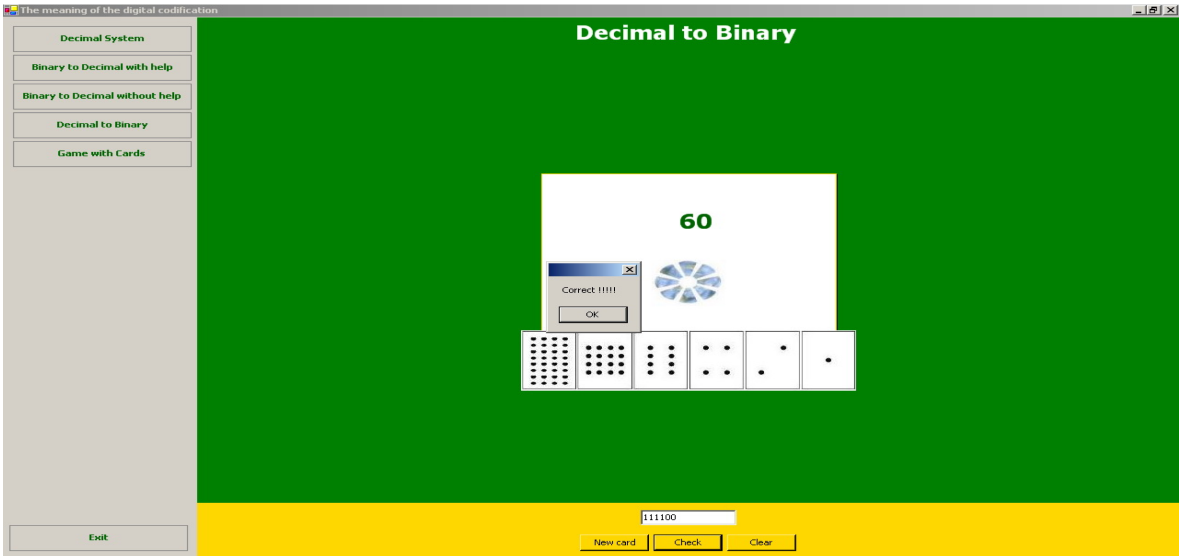

Figure 3. An example of the use of 'Decimal to Binary' function

An example of the performance of this function is demonstrated in Figure 3, Here, the program has randomly created the decimal number 60. The drawing under the cards helps the pupil create the given number step by step. In the help pattern (drawing) the first card (first digit of the binary number) represents the number 32 in the decimal system, the second the number 16, the third the number 8, the fourth the number 4, the fifth the number 2 and the sixth the number 1. Hence, by correctly adding up these numbers, which means building the actual binary number, pupils create the given decimal number 60. The number 60 can be broken into: **1**x32 + **1**x16 + **1**x8 + **1**x4 + **0**x2 + **0**x1 = 32+16+8+4 = 60 . Thus, the equivalent binary number is 111100.

3.5 The Game with Cards

After having worked on all of the above functions and having fully understood the conversions and the add functions, the pupil can play a fun and challenging card game that uses all of the previously constructed knowledge. This game is an alternative version of "Blackjack", a card game where the players collect cards and need to beat the bank ('Mama') by acquiring the target number of 21 in the cards drawn. In our game, the cards drawn are in the binary system and the target decimal number in order to win is 51.

By pressing the "New card" button, the pupil randomly picks his first card. At this point, he has to make the conversion and know what the decimal representation of this number is. By pressing the "New card" button repeatedly, he keeps drawing cards. After each card, the pupil needs to come up with the correct total sum (in the gap provided) of his cards in the decimal system if he is to continue the game. If he doesn't provide the system with the sum, or if he provides it with an incorrect one, the system will not allow him to continue the game until he has the correct answer. The player can stop drawing cards at any point convenient to his game strategy. Nevertheless, if he misjudges and draws above 51, he instantly loses the game. When the user has finished drawing cards, he can press the ‘Mama’ button. Now, its ‘Mama’s’ turn to start drawing cards automatically and try to beat him. The game has one winner and can be played as many times as the player desires. By pressing the “Clear” button, the pupil clears the table and readies it for a new round.

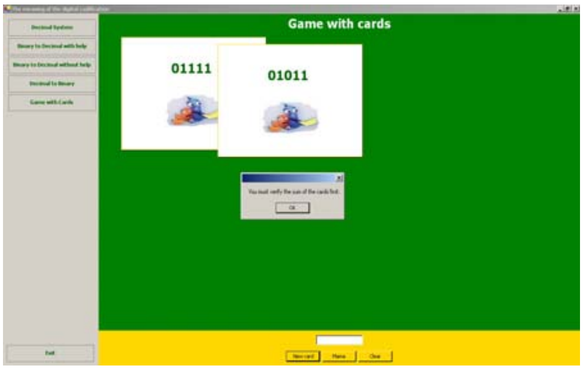

Figure 4a. An instance of play using cards with binary numbers

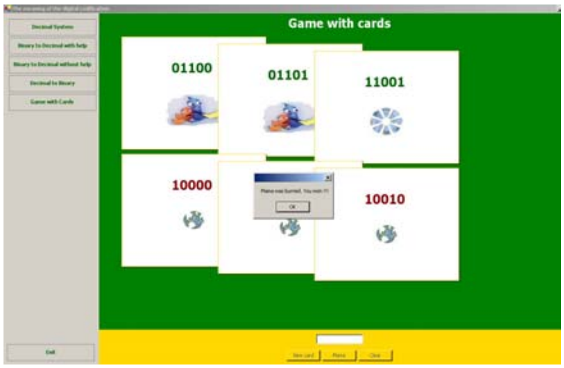

Figure 4b. An instance of play using cards with binary numbers where ‘Mama’ got burned and the pupil won!

Finally, it is worth noting that, before implementing this game in the context of the computer,an alternative version of it - using paper cards - was tested in a pilot study using real pupils with very promising results (Kordaki and Mpimpas, 2007).

4. EPILOGUE AND PLANS FOR FUTURE WORK

An interactive computer game for the learning of binary numbers by primary level education pupils has been presented in this paper. In the context of this game, pupils can have fun by playing against the computer with cards displaying binary numbers. Pupils have to convert the binary numbers featured on the cards and also add these numbers together again and again. The system provides hints to assist pupils in easily converting the binary numbers illustrated on the cards into the appropriate decimal numbers. The system also provides immediate feedback, in that pupils can check if their attempts to convert and to add binary numbers are correct. In addition, the system is structured so as to provide the pupils with the opportunity to express their previous knowledge of the decimal system in order for them to make connections with the decimal system based on analogical reasoning. The system is also structured so as to enable pupils to convert decimal numbers into binary ones and vice versa. Pupils aim at making correct conversions and additions of the binary numbers illustrated on the cards so as to have fun and gratify their egos by beating the computer. In the context of this proposed game, pupils can experience enjoyment and pleasure by being passionately and purposely involved in a challenge where they must wait to see the binary number of each new card they pick up and then add this number to the sum total of the cards they hold in order to decide if they should risk continuing their game against the computer and finally win or lose the game. It is also expected that pupils will try playing the proposed game a number of times. To verify our expectations, field studies to test the proposed game using real pupils are necessary.

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