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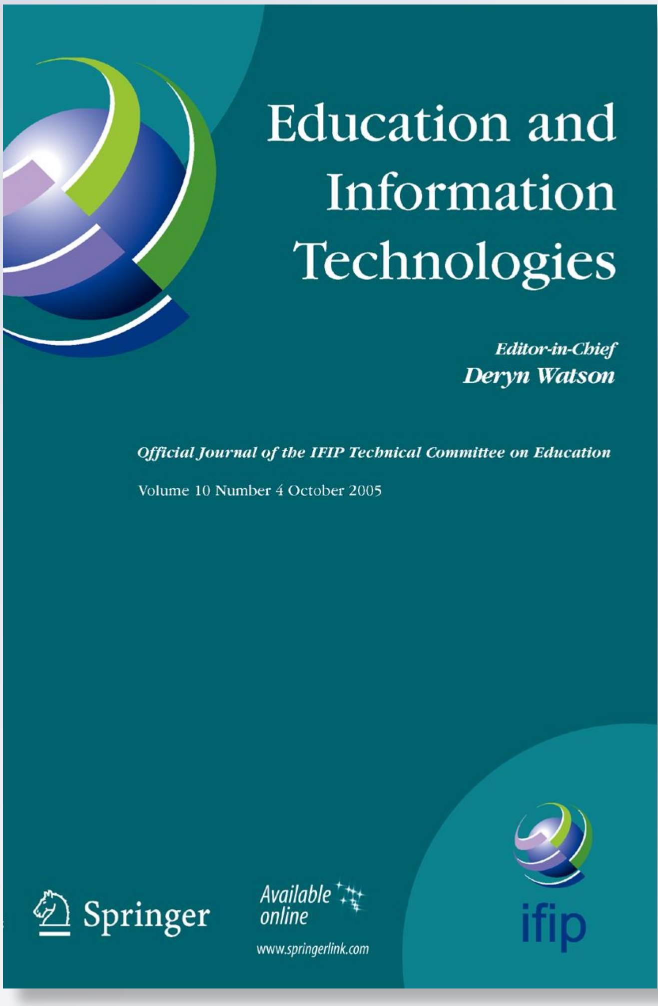

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A computer card game for the learning of basic aspects of the binary system in primary education: Design and pilot evaluation

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Abstract This paper presents the design, features and pilot evaluation study of a computer card game for the learning of basic aspects of the binary system (BS) by primary level education pupils. This design was based on modern social and constructivist theories of learning, in combination with basic game design principles. Pupils are asked to play against the computer with cards featuring Binary Numbers (BNs). To engage successfully with the game, pupils are provided with opportunities to review their previous knowledge of the decimal system and, subsequently, to use analogical reasoning to make connections between this knowledge and basic aspects of the BS. Several scaffolding elements are also provided for the pupils to construct, verify, extend and generalize their knowledge, at the same time using essential learning competencies. The game was piloted in the field using real pupils (20 6th Grade pupils) with encouraging results. Finally, an attempt has been made to address essential points of this game that have contributed to its becoming a successful learning environment. Addressing these points could be useful for both designers of educational computer games for Computer Science (CS) education and educators in Computing.

Keywords Binary system · Primary education · Computer games · Computer science education

1 Introduction

The role of engaging learners in meaningful and enjoyable learning activities is acknowledged as crucial for the learning of any subject (Jonassen 1999; Land and Hannafin 2000), let alone the learning of fundamental CS concepts and skills, and specifically in Primary Education (Proulx 1993; Bell et al. 2002). Games in

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particular are viewed as being the most ancient and time-honored vehicle for education (Crawford 1982) and are also among the most enjoyable and motivating activities for the young (McFarlane and Sakellariou 2002). However, games not only provide a source of strong motivation for student engagement in learning, but they can also essentially encourage students' social, emotional and cognitive development (DeVries 2004). Research into games and play has also demonstrated that players can attain a state of 'flow' (Csikszentmihalyi 1990) summarized as "the state in which we are so involved in something that nothing else matters".

Appropriately-designed card games also figure among the appropriate types of educational games for constructivist learning (Kamii and DeVries 1980), providing students with opportunities to develop their cognitive skills. For example, card games can help students retain, develop and improve various basic math skills and, in combination with other teaching methods of instruction, encourage students to learn high level math concepts (Gardinger 1987). In fact, card games meet several National Council for Teachers of Mathematics standards, such as number and number relationships (NCTM 2000–2004). Effective use of card games is also reported in the learning of various curriculum subjects such as Chemistry, Language and Financial studies.

Leading scholars have also long argued that appropriately-designed computer games provide a compelling context for children's learning (Kafai 2001). In the course of playing such games, children can be introduced to new concepts, topics and skills during both formal (i.e. classroom) and informal (i.e. outside class) education (Fisch 2005). To this end, it is worth noting that computer games play a central role in young people's lives (Kirriemuir and McFarlane 2004) and constitute their most popular computer activity at home (Papastergiou and Solomonidou 2005). Appropriately-designed educational computer games can become powerful learning environments because they can support student learning in terms of (Oblinger 2004): (a) multi-sensory, active, experimental learning, (b) activation and use of prior-knowledge in order to advance, (b) self-correction by providing immediate feedback on student actions, (c) self assessment by exploiting the scoring mechanisms, (d) acquisition of essential learning 'competencies' such as logical and critical thinking as well as problem-solving skills (McFarlane et al. 2002), (e) learning in different ways from those often in evidence, or explicitly valued, in school settings (Kirriemuir and McFarlane 2004), and (f) motivation and computer-based interaction.

The motivational effectiveness of computer games has been supported by the findings of various empirical studies (Facer 2003). Yet, despite this, the educational effectiveness of computer games aiming at concrete learning objectives for specific learning subject curricula is still under-researched (Papastergiou 2009). Moreover, in some cases the empirical results seem to be in contradiction (Kafai 2001; Facer 2003; Kirriemuir and McFarlane 2004). Specifically, in some studies, computer game-based learning seems to provide equivalent results to traditional face-to-face teaching (e.g. Randel et al. 1992).

In addition, concern has been raised over the drawbacks of learning through play, especially if learning becomes "too much fun" (DeVries 2004). In fact, it is possible to have play-oriented classrooms which do not support learning. Thus, the goal is not to create fun-only environments but to create appropriate tasks for students to take learning seriously. As regards educational computer games, there are major difficulties in providing the appropriate balance between gaming and learning activities, so as to provide a continuous balance between challenge and learning as well as aligning the game with subject curricula (Van Eck 2006; Kickmeier-Rust, et al. 2007). Another problem with game-based learning sometimes mentioned in the literature is that the flow of playing a computer game is a barrier to students reflecting about what they are doing/learning (Pohl et al. 2009). In addition, key questions have been raised about the role of play in the learning of specific subject curricula (McFarlane et al. 2002).

To this end, a limited number of studies that provide empirical evidence of the positive role of computer games in student learning of specific subject curricula have been reported. However, computer games have been effective in raising achievement levels of both children and adults in various areas of knowledge such as Science, Math, Language and Computer Science, where specific learning objectives can easily be stated (Rajaravivarma 2005). Experimental studies have also pointed to encouraging results from the use of educational digital card games for the learning of various subjects such as Physics (Smith and Muhro 2009), Language (McGraw et al. 2009), etc.

As regards the use of computer card games in Computer Science (CS) education, there are a limited number of studies providing empirical evidence of their use for the learning of CS concepts. Baker et al. (2005), for example, designed a card game to help learners gain some experience of software engineering. A physical competitive card game named “Problems and Programmers (PnP)” has also been constructed for software engineering (Carrington et al. 2005), the rules and methods of which are based on the Waterfall model. A Smalltalk Card Game has also been reported, aimed at learning about object-oriented thinking and learning (Kim et al. 2006). Recently, a card game about Rapid Application Development has been designed in order to assist learners in study system analysis and design (Chang et al. 2008). Finally, a study of students’ involvement in a real-world game, where digital cards displaying BNs were used to provide students with information, has also been reported (Mitsuhara et al. 2007). However, despite the fact that this study provided evidence of the effect of the whole context on student motivation, the evidence for its educational effectiveness is both weak and limited. Furthermore, in the design of the aforementioned games, modern social and constructivist views of learning (Vygotsky 1974; Jonassen 1999) were not considered.

However, CS has already had an immense impact on many aspects of modern life, and we should not underestimate its continuing importance in the future. Thus, the conceptualization of CS topics at all levels of education has been deemed essential (Association for Computing Machinery 2003). To this end, a four-level model curriculum of CS for K-12 has been proposed (ACM 2003). One of the four goals of this curriculum is to introduce the fundamental concepts of CS to all students, beginning at primary level. To this end, an understanding of basic aspects of the BS is important (Proulx 1993) and should constitute one of the pre-requisites for the achievement of the goals of this curriculum. In addition, an understanding of basic aspects of the BS is a necessary and pre-requisite background for the understanding of data representation and manipulation at the lower level of a computer system, which is an essential part of a CS curriculum at Secondary and Tertiary level.

Taking into account all the above, a computer card game has been constructed in an attempt to help primary level education pupils learn basic topics about BNs in a pleasurable environment. In the design of this game, social and constructivist learning perspectives (Vygotsky 1974; Land and Hannafin 2000; Jonassen 1999) were taken into consideration. Essential educational computer game design principles (Prensky 2001; Kirriemuir 2002; McFarlane et al. 2002; Fisch 2005) were also considered, due to the fact that there is still a lack of a set of appropriate design principles for educational computer card-games. This game was also piloted in the field using real pupils to illuminate its impact on their knowledge. Although a number of computer games for the learning of CS concepts have been reported in the literature, a computer card-game for the learning of basic aspects of the BS by primary level education pupils—based on the aforementioned learning perspectives and also field tested in terms of both its educational and motivational effectiveness—has not yet been reported.

In what follows, there is a presentation of the principles which inspired the design of the aforementioned computer card game, a demonstration of its functions and, subsequently, a description of the context of its pilot evaluation study. The results emerging from this study are then reported and discussed in relation to the design of this game, and finally conclusions are drawn.

2 Principles that inspired the game design

Taking into account the aforementioned socio-cultural and constructivist perspectives, as well as essential computer game design principles, the following issues were deemed essential for the said card game design:

(a) *Context:* Constructivism emphasizes the role of meaningful context in motivating learners to be actively engaged in their learning. It is also believed that games should first and foremost be *fun*[1] and then encourage learning (Prensky 2001; page 179). Specifically, it is suggested that learning games have to be *fun* enough to successfully encourage users to think of themselves as *players* rather than 'students', to want to *play repeatedly*, to rapidly *improve their skills* regarding the subject matter and to be encouraged to *reflect* on their knowledge.

(b) *Active and constructive participation*: For constructivist learning, *learners' active participation*—both physical and mental- in the construction of their knowledge is deemed essential (Kamii and DeVris 1980). The key appeal of computer games is also found to lie in providing learning opportunities for *active participation* (Randel et al. 1992) within *contexts that are attractive to learners* (Kirriemuir 2002). Furthermore, providing learners with opportunities to express their *previous knowledge* as a basis for the construction of new knowledge is considered crucial.

(c) *Scaffolding*: In the context of social learning perspectives, the role of *scaffolding* is of great importance in assisting students' learning (Vygotsky

[1] Italics are used in this section to highlight the key aspects considered appropriate for the design and implementation of the game described in this paper

1974). To this end, when creating a game, it is important to consider the design of appropriate *help*, *feedback and hint structures* (Fisch 2005). However, the role of teacher scaffolding remains important, and can be applied in various ways, including asking questions, explaining or augmenting the game (Hays 2005). In addition, for children to enjoy playing, the game has to be *neither too difficult/complicated nor too easy/simple* (McFarlane et al. 2002).

(d) *Content*: The educational content of a game must be *sound*, *age-appropriate*, and *well integrated* within the game (Fisch 2005). In fact, *the educational content must be at the heart of game play*, so that children engage in the targeted behavior or thinking as they play the game (Fisch 2005). The learning tasks should also be contextual to the game, in the sense that they must be perceived by the player to be a true element of the game play (Fabricatore 2000, p. 15). Constructivist design also emphasizes the *fundamental and timeless concepts* of the learning subject in question (Jonassen 1999).

(e) *Structure:* However, what is captivating for players about games tends to be their *structure* rather than their content. To this end, the following key structural characteristics of games in general (Bright and Harvey 1984), and of computer games in particular (Prensky 2001, pp. 118–119), that can contribute to players' engagement have been reported: (a) *play*, (b) *rules*, (c) *goals* and *objectives*, (d) *interaction*, (e) *outcomes*, (f) *winning*, (g) *competition / challenge / opposition*.

3 Description of the game

Taking into account all the issues regarding social and constructivist learning in combination with the principles of game design mentioned in the previous section[2], an *interactive* and *structured* computer game (see Sections 3.1. and 3.2) has been constructed to support primary school pupils in their learning of *basic aspects* of the BS by getting them *to play* against the computer using cards featuring BNs. As card games can contribute to children's construction of number and arithmetic relationships in the decimal system (Gardinger 1987), it is also considered worthwhile to design a card game to help students grasp basic knowledge of number and arithmetic relationships in the BS.

The manner in which the issues mentioned in the previous section have been addressed in the design of the said card game is reported in the following section.

(a) *Context*: In fact, it was thought that this card game would provide an *attractive, novel and meaningful context* for pupils, one where they could experience *fun* while at the same time follow specific *rules* in order to achieve the *goal* to *beat* the bank (the computer), or 'mama' as it is called in Greek. It is expected that students will *act as players* during the game play, where they will not only be in competition with 'mama' but also with their classmates (to see who can beat the bank the most times).

(b) *Active and constructive participation*: It is worth noting that this game is *fully interactive,* as all its functions *give the learner an active role*. Within the game

[2] The italics used in this sub-section highlight these issues

environment, pupils are also provided with a function (see Section 3.1.1) that could be used for the expression of pupils' *previous knowledge* of the decimal system, to help them make connections with basic aspects of the BS by *thinking analogically*.

(c) *Scaffolding*: To gain a deeper understanding of basic aspects of the BS, pupils are provided with the opportunity to convert BNs into decimal ones and vice versa with the use of *a help pattern* (see Sections 3.1.2., 3.1.4 and 3.2). The game also gives immediate *feedback* on *each pupil's* actions to enable self correction. *Visual hints* are also provided to help pupils *easily* progress in their understanding of the basic structure of the BS (see Sections 3.1.2. and 3.1.4). This game also provides meaningful *help* for each of its functions, including appropriate examples. This card game was also intended to be *neither too complicated nor too simple* with respect to pupils' age and existing knowledge, with a view to evoking their learning and motivation. It is different from other card games reported in the literature, in that a number of functions (see Sections 3.1.1, 3.1.2, 3.1.4) have been integrated to provide *scaffolding* for pupils' attempts to successfully engage with this game, as well as to construct, express, reinforce and extend their knowledge.

(d) *Content*: At the *heart of this game is the* BN content, as it has to be used if the game is to be played successfully.

(e) *Structure:* This card game has *clear learning objectives*, aiming to provide pupils with the opportunity to *learn* the following *fundamental aspects* of the BS during game *play*: (a) the base used for the construction of the BS, (b) the value (the weight) of each digit included in a BN in relation to its position, (c) the conversion procedure of a decimal number into a binary one of equal value, and vice versa, and (d) basic rules that govern both decimal and binary numerical systems. It was considered *age-appropriate*, to encourage pupils to understand the aforementioned aspects of the BS at this level of education, through game-play. Finally, as mentioned in the description of the game (see the following Section), this card game is *interactive*, has specific *rules* and *outcomes,* and is expected to inspire the pupils to *play* in order to *win* and be in *competition with, challenge* and *oppose* 'mama' and their classmates.

In the following sub-sections, the aforementioned scaffolding functions of this educational game are described and, subsequently, the features of the card game play are presented.

3.1 Scaffolding functions of the proposed card-game

3.1.1 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 is 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 decimal digits in relation to their position. By reflecting on their knowledge of the decimal numerical system, pupils have the chance both to progress smoothly to the BS and to make connections between these systems. Pupils can experiment with this function before entering the card game play.

When the "New Card" button is pressed (see Fig. 1), 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. It is worth noting that "Check" and "Clear" functions are incorporated in all functions of this game.

3.1.2 The 'Binary to Decimal with help' function

The purpose of this function is to help pupils to understand how to convert BNs into decimal numbers with the use of a help pattern. This function is considered necessary if pupils are to be provided with opportunities to familiarize themselves with the BS and understand its structure and the relationship between the position of each digit and its value. This function could be used as a scaffolding element: (a) during card-game play (b) for the extension of pupils' knowledge acquired through card game play and (c) for a 'drill and practice' activity before play commences.

When the "New Card" button is pressed, the program randomly picks a new card displaying a BN of up to five digits (see Fig. 2a). The pupil has to convert this number into its equivalent decimal number. To provide support for this conversion, the game displays a help pattern (in the form of a drawing) below the card. This drawing demonstrates the weight of each digit and can act as a '*visual hint*' that could be used to make the conversion as easy as the counting of dots on the drawing. For example, the number of dots corresponding to the weights of the digits for a 5-digit BN (starting from the right), are: 1, 2, 4, 8 and 16, respectively. Each weight

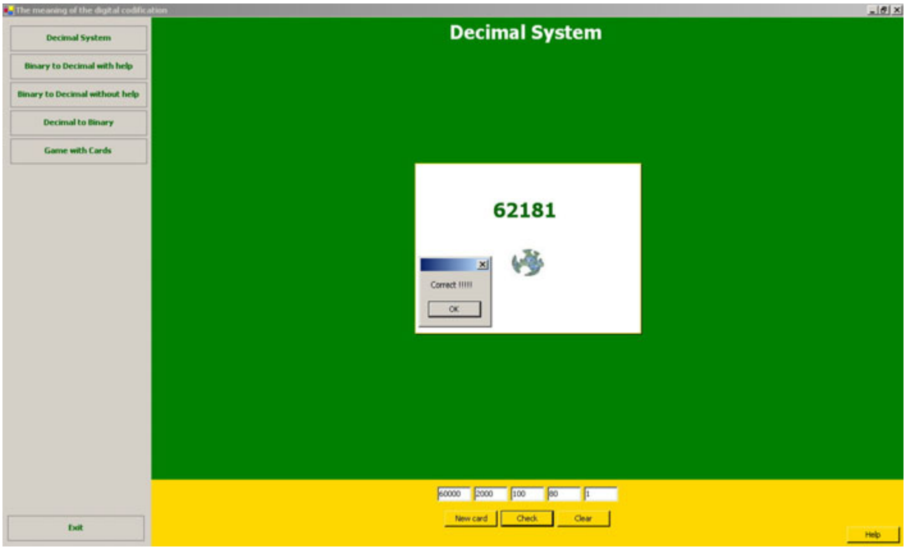

Fig. 1 An example of use of the 'Decimal System' function

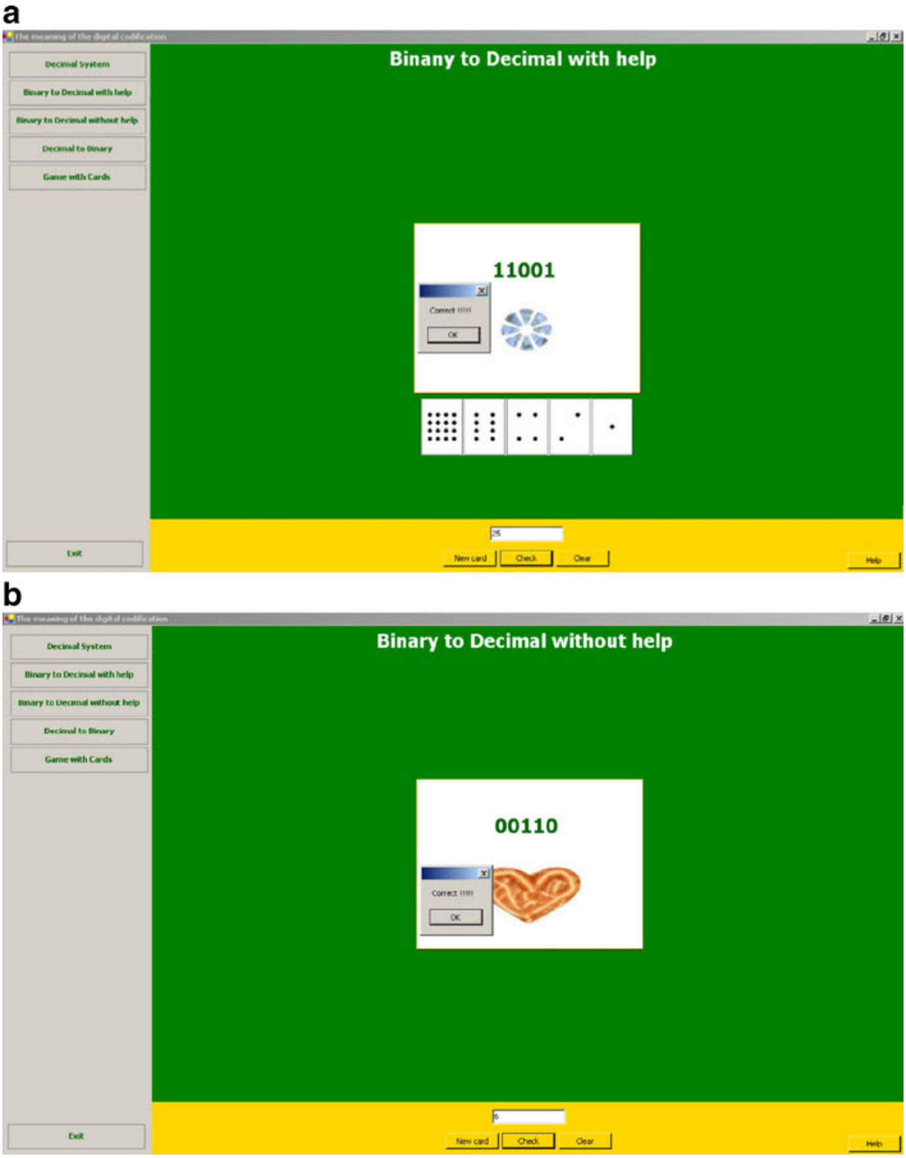

Fig. 2 **a** An example of use of the 'Binary to Decimal with help' function. **b** An example of use of the 'Binary to Decimal without help' function

has to be multiplied by the corresponding digit and the sum of all these products should amount to the equivalent decimal number.

3.1.3 The 'Binary to Decimal without help' function

The purpose of this function is to check if pupils have learnt how to convert binary numbers into decimals. This function is very similar to the previously-mentioned function (the ‘Binary to Decimal with help’ function), with the difference that it has to be performed without the use of the help pattern. This is actually the next step up, when the pupil feels confident of their understanding of how the conversion from binary to decimal works. An example of the use of this function is demonstrated in Fig. 2b. This function could also be used in two ways: (a) as a reinforcing function after pupil card game play and (b) as a ‘drill and practice’ activity before card game-play commences.

3.1.4 The ‘Decimal to Binary’ function

The purpose of this function is to support pupils in their learning of how to convert decimals into BNs with the use of a help pattern. When the “New Card” button is pressed, at random the game picks a new card displaying a decimal number from 1 to 63. This is equivalent to a BN of up to six digits. The pupil has to convert this number into the equivalent BN. To assist with this conversion, the system displays a help pattern (see Fig. 3) below the cards (a 6-card pattern this time). This pattern can act as a *visual hint* that helps the conversion of decimal numbers as follows: starting from left to right, pupils need to create binary 1 s of the six-digit number in the correct positions so that the total decimal number (by counting the dots) is equivalent to that picked by the game.

3.2 The card game play function

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 the game presented in this paper, the cards drawn are in the BS and the target decimal number in order to win is 51.

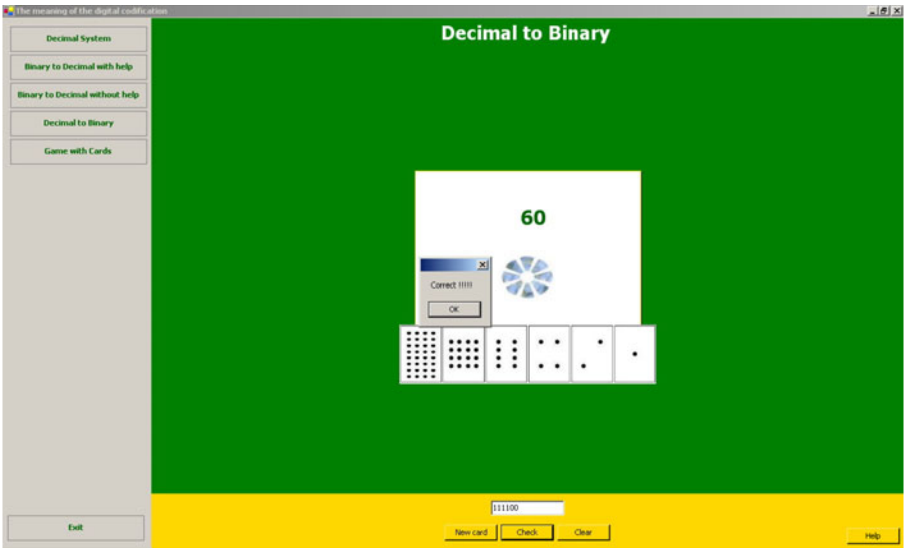

Fig. 3 An example of use of the ‘Decimal to Binary’ function

By pressing the "New Card" button, the pupil randomly picks their first card. At this point, the pupil has to make the conversion and know what the decimal representation of this number is. By pressing the "New Card" button repeatedly, they keep drawing cards. After each card, the pupil needs to both come up with and input (in the specific gap provided by the game) the correct total sum of their cards into the decimal system if they are to continue the game. To help pupils correctly make these conversions, the system provides pupils with opportunities to use the previously-mentioned 'help pattern' (see section, 3.1.2). For further assistance, pupils can experiment with the functions described in sections 3.1.2 and 3.1.3. In addition, pupils can seek help by exploring the examples provided by the 'Help' function of the game. If the pupil fails to provide the system with the sum, or if they provide an incorrect sum, the game will not allow the pupil to continue playing until they do come up with the correct answer. The player can stop drawing cards at any point convenient to their game strategy. Nevertheless, if the pupil misjudges and draws above 51, they instantly lose the game. When the pupil has finished drawing cards, they can press the 'Mama' button. Now, it is 'Mama's' turn to start drawing cards automatically and to try to beat the pupil. 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. An example of play using cards with BNs is demonstrated in Fig. 4. A brief description of the features of this game was presented in Sikiniotis et al. (2008).

Possible uses of the card game This game can be used by teachers in two ways: (a) to introduce their students to learning about BNs through playing with cards, directly after exploring their knowledge of decimal numbers, and (b) to reinforce the knowledge of BNs that pupils have already acquired during their work on all of the aforementioned functions (described in sections 3.1.2, 3.1.3, and 3.1.4) after having fully understood the conversions and the add functions for the BS. To illustrate the impact of the features provided by the game on pupil knowledge, a pilot evaluation experiment was performed using real pupils, the context of which is described in the next section of this paper.

4 The context of the pilot evaluation experiment

4.1 Research aims and questions

This study focuses on the learning of basic aspects of the BS (those supported by the said card-game [see Section 3]) by primary school pupils, within a learning experiment mainly based on their play with the computer card game mentioned in the previous section. In order to investigate the learning results based on the use of this card game, a three-stage pilot, formative, evaluation experiment has been conducted, with qualitative methodology (Cohen and Manion 1989) used to illustrate the effect. In fact, this research could be characterized as a case study. The research questions guiding this pilot study considered how this game-supported learning experiment affected pupils' knowledge of basics of the BS, such as: (a) binary digits, (b) the value of each digit constituting a BN, (c) the structure of the BS

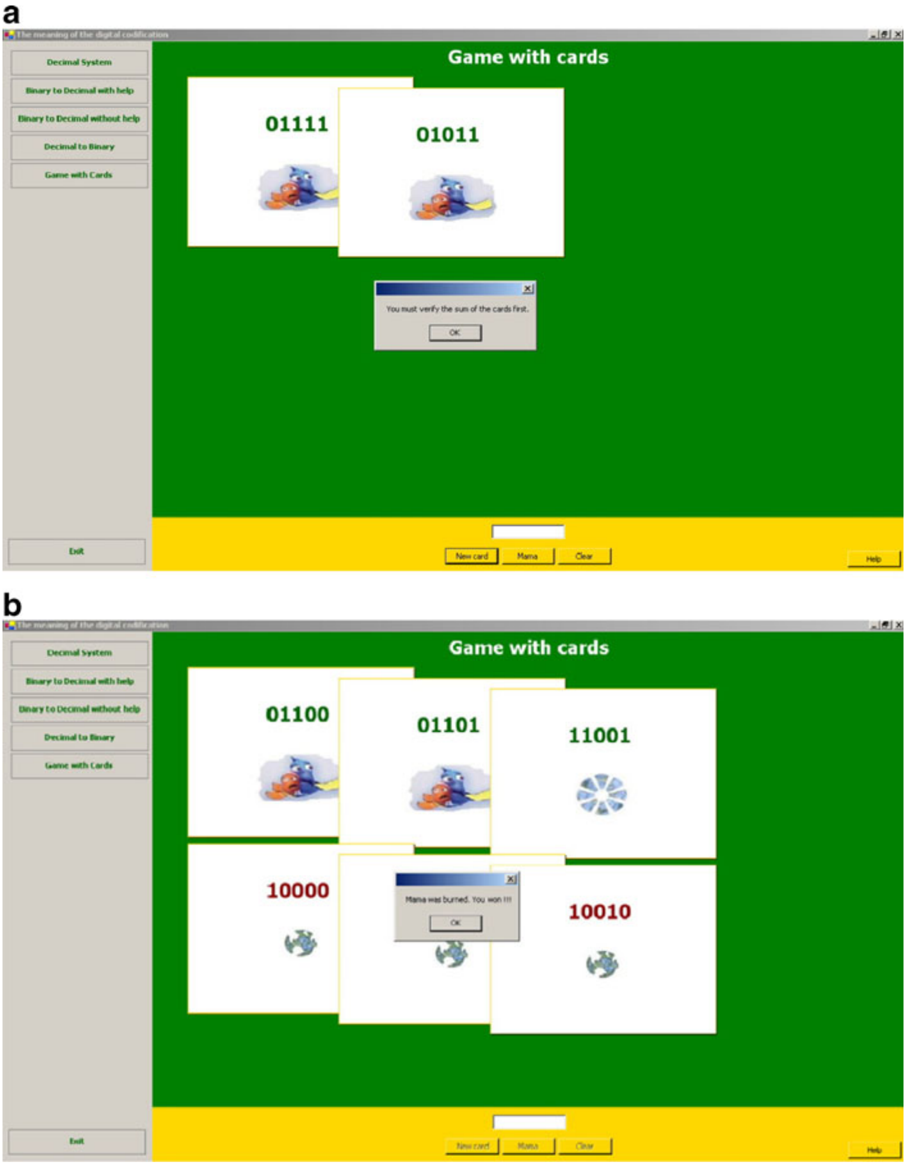

Fig. 4 **a** An example of play using cards with BNs. **b** An example of play using cards with BNs where 'Mama' got burned and the pupil won!

in terms of the relationship between the position of each digit -within a BN- and its value, and (d) the conversion of a BN into its equivalent decimal and vice versa.

4.2 Participants

Pupils Twenty 6th Grade pupils (ten males and ten females)—from a typical primary school in Patras, Greece—voluntarily participated in this pilot evaluation experiment. For the purpose of this study, these pupils are named M1, M2, M3,… M20. Pupils participated by individually interacting with the game as well as by providing written and oral answers to a number of questions posed by the researcher during the experiment. In this study, it was considered essential to explore pupils' individual/non-collaborative involvement with this game to have some evidence of its effect on each individual pupil's knowledge.

Researcher The researcher participated not only as an observer but also as a facilitator of pupil learning with the aim of performing appropriate interventions–through talk–when considered necessary. These interventions are reported in the appropriate parts of the 'Results' section. The essential role of the teacher in providing extra scaffolding through talk on student learning has also been acknowledged by other researchers (Panselinas and Komis 2009).

4.3 Procedure

This study was conducted in three stages, namely: (a) diagnostic pre-testing of pupils' knowledge of BNs (b) the card game play as a learning experiment for BNs and (c) post-testing, aiming at the assessment of knowledge acquired by pupils through the said experiment. The aforementioned stages were not integrated into their school courses, since the learning of the BS is not integrated into Greek primary school curricula. Thus, this experiment can also be used to investigate if it is possible for primary pupils to grasp primary concepts of the BS.

Pre-testing stage The pre-test took the form of a written questionnaire distributed to each individual pupil participating in this study. All the questions included in both pre- and post-test questionnaires are reported in the "Results' section of this paper, together with the answers given by the pupils.

Card-game stage The said learning experiment was based on a three-phase 'didactical scenario'. The significance of using games within a didactical scenario has been acknowledged as essential for pupil learning (Tennyson and Jorczak 2008). The design of these phases is reported below:

> *Phase1: Review and reflection of pupils' previous knowledge.* Here, pupils were encouraged to review and reflect on their knowledge of the decimal system by exploring the 'Decimal System' function. The specific aims of this phase were to stimulate pupils to: (A1) rethink about the digits used for the construction of a decimal number, (A2) analyze a decimal number into its units, (A3) realize the value (weight) of each digit, and (A4) reflect on the relationship between the value of the digits of a decimal number in relation to their positions.
> *Phase 2: Experimenting with the BS through card-game play.* Here, too, pupils were introduced to game-play using cards featuring BNs. The aim of the game play was to help pupils to: (a) become familiar with BNs, (b) consolidate the knowledge they acquired through game play by playing with cards without the 'help pattern', and (c) acquire appropriate experience that could be used in the next phase of this experiment (Phase 3).

Phase 3: Extension of pupils' knowledge of the BS. Here, pupils were encouraged to reinforce and reflect on the knowledge they had acquired during card-game play and then attempt to form appropriate extensions, generalizations and connections between this system and the decimal one through the use of the aforementioned scaffolding functions (see Sections 3.1.2., 3.1.3. and 3.1.4) and through appropriate questions posed by the researcher.

To fulfill the aims of each of the aforementioned phases, pupils were also asked a number of questions presented in the 'Results' section of this paper, along with the answers given by the pupils.

Post-testing stage Directly following the card-game stage, each pupil was given the task of completing a post-test written questionnaire. Pupils answered this questionnaire carefully, responsibly and in their own time, with each pupil taking around 40 min. The whole experiment was carried out in their familiar school environment. The duration of the experiment was commensurate with pupils' needs but lasted no longer than 2 h and 30 min.

4.4 Data collection and analysis

The data collected during the experiment consisted of: (a) the pupils' written answers to all the questions included into the pre- and post-test questionnaires, (b) the field notes of the researcher's observations covering all phases of the card-game learning experiment, (c) the video-recordings of pupil interactions during all phases of the card-game play and (d) the screen-shots of pupils' attempts, while interacting with the game, captured on the computers with the help of the participating researcher. The various types of data were organized in accordance with the aforementioned three stages of the experiment. The answers given by each individual pupil to the questions posed in the pre- and post-test questionnaires were identified and reported and subsequently each pupil's answers to these questionnaires were compared. The data that emerged from the pupils' involvement in card-game play were organized in accordance with the three-phase learning experiment performed at this stage. The videotaped data were transcribed and then pupil interactions with the game functions and their reactions to the researcher interventions were coded. Subsequently, the coded data were analyzed in terms of how each pupil's conceptions of BNs had developed during each stage of the learning experiment. The results of this learning experiment are presented in the following section.

5 Results

5.1 Pre-test stage

Pupils' answers to the pre-test questionnaire are depicted in Table 1. The questions (PT1, PT2,…, PT7) included in this questionnaire are shown in the first column of this Table, while in the second column pupils' specific answers are presented. Pupils

Table 1 Pupils' answers to the pre-test questionnaire

Pre-test results		
Questions	Pupils' answers	Pupils
PT1) Do you have any idea about the binary system or binary numbers?	No	All except M2, M8, M18
If your answer is yes, please answer also the following questions:	Yes	M2, M8, M18
PT2) Which different digits are used in the formation of any binary number?	The digits: 0, 1	M2, M8, M18
PT3) Convert the binary number 11101 into its correspondent decimal number,	I do not know	M2, M8, M18
PT4) Do you know the value of each digit of this number?	I do not know	M2, M8, M18
PT5) Convert the decimal number 67 to its correspondent binary number	I do not know	M2, M8, M18
PT6) Do you know the rules for the conversion of a binary number into its correspondent decimal number? If yes, please report them	I do not know	M2, M8, M18
PT7) Do you know the rules for the conversion of a decimal number into its correspondent binary number? If yes, please report them	I do not know	M2, M8, M18

who provided these answers are reported in column three of this Table. As emerged from their written answers to the aforementioned questionnaire, most pupils (17 pupils; all pupils except pupils M2, M8 and M18) had no idea about the BS before entering this evaluation experiment. This was to be expected, due to the fact that BNs are not considered part of the primary education curriculum in Greece.

However, pupils M2, M8 and M18 correctly answered only the question about the kind of digits used for the formation of any BN. It seems, therefore, that these pupils, '*did not know*' anything more about the BS.

5.2 Card-game stage

5.2.1 Phase 1: Review and reflection of pupils' previous knowledge

To help pupils fulfill the aforementioned aims of this phase, they were asked to answer the following questions: (QP1) *Which different digits can we use to write a decimal number*? (aim A1), (QP2) '*Click on a new card: Can you analyze the* [decimal] *number illustrated in this specific card and fill the gaps with the numerical value of each of its digits?*' (aim A2), (QP3) *What is the value of each digit constituting this number*? (aim A3) and (QP4) *What do you think the relationship between the value of these digits is*? (aim 4). Pupils' answers to the aforementioned questions are depicted in Table 2. The first column in this Table represents these questions (QPi, i=1,…,4), the second column depicts the answers given by the pupils while in the third column, the pupils who provided each answer are shown.

As shown in Table 2, the majority of pupils (all pupils except M10 and M20) recognized by their selves that 10 digits (the digits: 0, 1, 2, 3, 4, 5, 6, 7, 8, 9) could be used for the formation of any decimal number. Pupils M10 and M20 managed to

Table 2 Pupils' answers to the questions aiming at the review of their previous knowledge

QP	Pupils' answers	Pupils
QP1	The digits: 0, 1, 2, 3, 4, 5, 6, 7, 8, 9	All except M10, M20
	The digits: 0, 1, 2, 3, 4, 5, 6, 7, 8, 9, 10	M10, M20
QP2	Correct analysis of the decimal numbers illuminated on the pupils' cards	All
QP3	The first-right digit of a decimal number represents units, the second digit represent tens, the third hundreds, etc.	All except M20
	I do not know	M20
QP4	The value of the position of each digit of a number in the decimal system is related to the value of the position of the digit on its right multiplied by ten.	All except M20
	I do not know	M20

succeed, after Researcher Intervention (RI): '*reconsider your approach*' (RI: 1) and "*think if all the digits that you propose are really different*" (RI: 2). All pupils also managed to analyze the decimal numbers illuminated in their cards, in terms of units, tens, hundreds, etc. (question QP2). In addition, all but pupil M20 correctly estimated both the value of each digit constituting the number illuminated in their cards (question QP3) and the relationship between the values of the digits of this number (question QP4). Pupil M20 arrived at the correct answer by being encouraged by the researcher to '*concentrate on the number and take some time to think about it*" (RI: 3).

5.2.2 Phase 2: Experimenting with the BS through card-game play

Entering the game play The researcher prefaced the game play with the following introduction: '*As you realized during the previous task, 10 different numerical digits can be used 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 1 s and 0 s. These numbers are called BNs. Let's play this game with cards featuring BNs, to make sense of how it is possible to represent any number with such a combination*' (RI: 4). Then, the researcher explained the rules of game play (those reported in Section 3.2). Data analysis highlighted the following issues regarding pupil learning of BNs through game play: (a) familiarization and (b) pupil difficulties.

(a) Familiarization with the BNs: Here it is worth noting that each pupil clicked on a new card but immediately asked for help in understanding the BN illustrated on it. As emerged from the data analysis, pupils became familiarized with the BNs illuminated on their cards through the following three types of scaffolding support: (a) the 'help pattern', (b) the "Help' function, and (c) RI through talk.

Significantly, the majority of pupils (15 pupils: M1, M2, M4, M5, M6, M7, M8, M10, M11, M12, M13, M15, M17, M18, M19) received support in understanding the BNs illustrated on their cards by the '*help pattern*' described in a previous section (Section 3.1.2) and appropriate scaffolding–through talk–

by the researcher. In fact, pupils were asked–by the researcher–to: '*concentrate on the dots inside each of the rectangular frames used in the help pattern and anticipate the meaning of these dots by reflecting on your previous experience using the decimal system function and thinking similarly*' (RI: 5). The aim of this intervention was to help pupils understand that the number of these dots (1, 2, 4, 8, and 16 dots) represent the weight of each digit of a 5-digit BN [starting from the right]. The rest of the pupils (pupils: M3, M9, M14, M16 and M20) asked for extra help and arrived at similar familiarization with the BNs illustrated on their cards, but only after reflecting on the examples provided by the '*Help*' function of the game. However, during the familiarization procedure, pupils illuminated some extra difficulties which are presented in the following section.

(b) Pupil difficulties in understanding BNs: Pupil difficulties fall into two categories: (a) Ignoring the "0 s' within a BN: In fact, some pupils (pupils: M6, M12, M16, M20) considered only the number of "1 s' included in a BN and totally ignored its '0' digits, e.g. pupil M12 converted the BN 10101 to a decimal as follows: *1+ 0+ 2+ 0+ 4= 7* and (b) Viewing the BN as a decimal number: Specifically, other pupils (pupils: M5, M9, M14, M17) treated the BNs illustrated on their cards as decimal numbers. For example: pupil M14 converted the BN 10111 to a decimal as follows: *1+ 10+ 100+ 0+ 10000= 10111*

Pupils were helped to overcome these difficulties by the researcher, who asked pupils: '*Can you provide an explanation about the meaning of "1 s" and '0 s' in each position?* [starting from the right]. *To help you, focus on the dots included in the rectangular frames illustrated on this card'* (RI: 6).

It is worth noting that, after the aforementioned experience, all pupils managed to play the game without using the 'help pattern' and to correctly convert the BNs which were illustrated on their cards. They also succeeded in summing the numbers illustrated on the value cards they picked up during the game. Pupils used the cards provided with ease, even those presenting diverse BNs. All pupils also played continually—without interruptions—and expressed a desire to play again and again, e.g. '*Please give me the chance to play again.*' (pupil M3). Finally, in the researcher's personal opinion, all the pupils seemed happily and passionately engaged in this game, within a spirit of friendly competition.

5.2.3 Phase 3: Encouraging pupils to extend their knowledge of BNs

This phase was considered essential as it was designed to help pupils reinforce, reflect on and extend their knowledge of decimals and BNs, as well as make generalizations and connections between them.

Reinforcing pupils' knowledge about BNs Here, pupils were asked to call up the *'Binary to Decimal'* function and then click on the 'New Card' button and focus on the BN represented on it. At this point, pupils were encouraged to answer specific questions, namely: (QR1) *What is the value of the BN represented on this card*?, (QR2) *What is the numerical value of each digit of the BN represented on this card*?, and (QR3) *What is the meaning of "0 s" and of "1 s" in different positions*?

Pupils' answers to the aforementioned questions are depicted in Table 3. As shown in this Table, the majority of pupils (all pupils except M12 and M14) correctly converted the BNs illustrated on their cards. In fact, these pupils multiplied each binary digit by the number of numerical units representing its value and added the results of these multiplications.

The remaining pupils (M12 and M14) succeeded in performing these conversions, but only after appropriate interventions were made by the researcher, asking them to: '*rethink about the value of each digit of a 5-digit BN*' (RI: 7) and '*rethink about the meaning of "0 s" and of "1 s" in different positions within a BN*' (RI: 8). After this experience, all pupils—in a variety of language—correctly estimated the value of each digit of a 5-digit BN. All pupils also answered—using diverse expressions—that the meaning of "1 s" depends on their positions in the BN in question, while the meaning of "0 s" does not depend on their position, but is always zero.

Extension of pupils' knowledge Here, pupils were encouraged to extend their knowledge about BNs in terms of: (a) estimating the relationship between the numerical values of the digits of a 5-digit BN, (see question QE1, below), (b) extending knowledge beyond a 5-digit BN, (see question QE2, below) and (c) converting decimal numbers to their equivalent binary ones (see questions QE3 and Q4, below). To this end, pupils were asked to call up the *'Binary to Decimal with help'* function, then click on the 'New Card' button and focus on the BN represented on it, and next answer the following questions: (QE1) *What do you think the relationship between the numerical values of the digits of a 5-digit BN is*?, and (QE2) *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 16 dots*? Pupils' answers to the questions asked during this part of the experiment are depicted in Table 4.

Here, it is worth noting that the majority (17 pupils) expressed the view that '*the number of dots in each rectangular frame is related to the number of dots included in the frame to its right multiplied by two*'. However, the remainder of the pupils (M5, M14, and M20) had difficulties in understanding this relationship. These pupils were encouraged by the researcher to: '*Concentrate on the number of dots. Try to find a numerical relationship'* (RI: 9). Subsequently, upon reflection, these pupils successfully worked out the correct answers. As regards BNs with more than 5 digits,

Table 3 Pupils' answers to the questions aiming at the reinforcement of their knowledge of BN

Questions	Pupils' answers	Pupils
QR1	Correct conversion of the BNs illuminated on the pupil's cards	All except M12, M14
QR2	The values of the digits of a BN, starting from the right are: 1, 2, 4, 8, and 16 numerical units correspondingly	All
QR3	[In terms of a 5-digit BN, starting from the right], the '1 s' represent 1 unit, 2 units, 4 units, 8 units and 16 units correspondingly, while the '0 s' always represent 0 units.	All

Table 4 Pupils' answers to the questions aiming at the extension of their knowledge of BN

Q	Pupils' answers	Pupils
QE1	'the number of dots in each rectangular frame is related to the number of dots included in the frame to its right multiplied by two'	All except M5, M14, M20
	Correct answer after the researcher's intervention (RI: 9)	M5, M14, M20
QE2	32 dots	All
QE3	Correct conversion -to BNs- of the decimal numbers illustrated on each pupil card with the aim of the 'Decimal to Binary" function	M2, M4, M5, M6, M7, M12, M13, M14, M17, M18 and M19
	Correct conversion after the researcher's instructions (I and II)	M1, M3, M8, M9, M10, M11, M15, M16, M20
QE4	Correct conversions	All

all pupils expressed the view that, if another rectangular frame were to be added to the left of the frame with 16 dots, the number of dots included would be 32 dots and a further frame would include 64 dots, e.g. '*the next number of dots is 16*2=32 and then 64, and so on'* (answer given by pupil M10).

Conversions of decimal numbers to BNs To realize the procedure of converting decimal numbers into their binary form, pupils were advised to call up the '*Decimal to Binary*" function and click on a "New Card' button, and then answer the following question: (QE3) *'try to convert the decimal number represented on this card'*. Then, pupils were asked to: (QE4) *Select a number greater than 63 and convert it to its binary equivalent. Please explain how you realized this construction*. To convert decimal numbers—less than or equal to 63—to their equivalent binary ones, all pupils used the 'help pattern' illustrated on the cards and also visited the corresponding section of the 'Help' function. Specifically, the 'help pattern' helped most of the pupils (M2, M4, M5, M6, M7, M12, M13, M14, M17, M18 and M19) to perform such successful conversions. An indicative example is as follows:

M18: [his card illustrated the number 53] *32+16=48, 48+4=52, 52+1=53. I didn't use 8-dots and 2-dots. I have to put 0 s in these positions. Then, the number will be: 110101*

The rest of the pupils managed to perform this procedure after extra, specific instructions (two types of instructions: Instruction I and Instruction II, below) were given by the researcher.

> R [Instruction 1]*: 'Think about this decimal number as a sum of certain of the numbers 32, 16, 8, 4, 2, and 1, which corresponds to the value of each position in a 6-digit BN. Select the appropriate numbers and, in order to form the BN, fill the positions that correspond to each of the selected numbers with '1 s' and the remaining positions with '0 s'.*
> R [Instruction 2]: *'Think about this decimal number as a sum of certain of the numbers 32, 16, 8, 4, 2, and 1, which corresponds to the value of each position in a 6-digit BN. Starting from the left, check if the value of this position [number 32] is less than or equal to the decimal number you have to convert*

into its binary form. If yes, then put '1' in this position and subtract this value from the decimal number. If no, then put '0' in this position. Repeat the procedure until the initial decimal decreases to zero after the entire procedure of subtractions'.

After this experimentation, all pupils also managed to construct the binary form of the decimal numbers—higher than the number 63—given (QE4) and also provided appropriate explanations for their constructions. As pupils had not previously used BNs higher than the number 63, this task was considered essential for investigating pupils' abilities to extend their knowledge and arrive at the appropriate process implied for the construction of any BN.

Comparisons and generalizations Here, it was considered essential to provide pupils with opportunities to generalize about the rules governing the conversion of decimal numbers into their corresponding binary ones and vice versa, as well as to find some similarities between the binary and decimal systems. As regards pupils' attempts to generalize about the aforementioned rules, their approaches were identical to those included in their answers to the post-test questionnaire where they were asked to address similar issues (see questions PT5 and PT6 on Table 6). To avoid redundancy, these answers are presented in the next section, together with the results of post-testing.

Pupils were also asked to complete Table 5 (the symbol '*' denotes multiply) in order to encourage them to generalize their knowledge through attempting to find some similarities between the decimal and the BS.

It is significant that all the pupils managed to complete Table 5. However, at this point, it should be noted that some pupils (pupils: M2, M6, M11, M18 and M19)—using different words—expressed the view that the number 10 serves as a 'kind of generator' for the decimal system, while number 2 does the same for the BS. In one pupil's words:

*M19: Every decimal number can be produced by "1 s", '10 s', 10*10= 100 s'…etc. and every binary by '1 s', '2 s', '2*2=4 s', etc. It seems that* [the number] *10 acts as a kind of generator for the decimal system while* [the number] *2 acts as a kind of generator for the BS'.*

In closing this section, it would be remiss not to mention that—in terms of usability—pupils found all the functions provided easy to use, and the examples

Table 5 Table of similarities between the decimal and BSs: to be completed by the pupils

Decimal system	Binary system
1	__
10	__
100=10*10	__=__*__
1,000=10*10*10	__=__*__*__
10,000=10*10*10*10	___=__*__*__*__

reported in the ‘Help’ function meaningful and useful in illustrating the specific procedures presented.

5.3 The post-test stage

This questionnaire included the same questions which were included in the pre-test (PT1, PT2, PT3, PT4, PT5 and PT6) plus one open question concerning possible affective issues about pupil engagement in card-game play (PT7). The results of pupils’ answers to the closed questions (PT1, PT2, PT3 and PT4) are depicted in Table 6 (column 2) along with the aforementioned questions, which are presented in the first column of this Table. Pupils who provided these answers are reported in the 3rd column of this Table. Pupil responses to the open questions (PT5, PT6 and PT7) are reported below.

Table 6 Pupils’ answers to the post-test questionnaire

Post-test results		
Questions	Pupils’ answers	Pupils
PT1) Which different digits are used in the formation of any binary number?	0, 1	All
PT2) Convert the binary number 11011 into its correspondent decimal number (provide all the steps of this conversion)	1+1*2+0*4+1*8+1*16=27	All
PT3) What is the value of each digit of this number [11011]?	16, 8, 0, 2, 1	All
PT4) Convert the decimal number 73 to its correspondent binary number	73=64+0+0+1+0+0+1=1001001	All
PT5) Can you address some rules for the conversion of a binary number into its correspondent decimal number?	Game-based	M2, M4, M17
	Formal	M6, M7, M8, M13, M18, M19
	Incomplete	M9, M12, M14, M20
	No response	M1, M3, M5, M10, M11, M15, M16
PT6) Can you address some rules for the conversion of a decimal number into its correspondent binary number?	Game-based	M6, M7, M4, M13, M17
	Formal	M8, M12, M18, M19
	Incomplete	M2, M9, M10, M14
	No response	M1, M3, M5, M11, M15, M16, M20
PT7) What interested/disinterested you most during this experiment?	Interesting from diverse point of view	All

Pupils' rules for the conversion of BNs to decimal ones Pupils' answers to PT5 (see Table 6) can be sorted into four categories:

(a) *Game-based rules*: Some pupils (pupils: M2, M4 and M17) correctly described the procedure of the conversion of a BN by using terms from their experience with the 'help pattern'. An indicative example of those answers is: '*We multiply each digit of a BN by the number of dots indicating its value, and add the results*'.
(b) *Formalism-based rules*: Some other pupils (pupils: M6, M7, M8, M13, M18 and M19) correctly described the said procedure by using formalisms such as: '*We multiply each digit of a BN by its value and then add the results*'.
(c) *Incomplete rules*: Other pupils (pupils: M9, M12, M14 and M20) incompletely described the aforementioned procedure, e.g: "*We multiply the digits of the BN in question by the numbers 16, 8, 4, 2, 1*", and
(d) *No response*: The remaining pupils did not respond to this question.

Pupils' rules for the conversion of decimal to BNs Pupils' answers to PT6 (see Table 6) can also fall into four categories:

(a) *Game-based rules*: Some pupils (pupils: M6, M7, M4, M13, M17) correctly described the procedure of the conversion of a decimal number by also using terms from their experience with the 'help pattern'. An indicative example is as follows: '*We try to produce the decimal number in question as a sum of the dots included in different frames. Next, we put 1 s in the position of the digits that have as values the dots of these frames, and put 0 s in the other positions*'.
(b) *Formalism-based rules*: Some others (pupils: M8, M12, M18, M19) correctly described the said procedure by using formalisms such as: '*We select a set of numbers…from [numbers] 1, 2, 4, 8, 16, 32…so that their sum is the decimal number in question. Then, we put 1 s in the position of the digits that have these numbers as values and 0 s in the rest of the positions*'.
(c) *Incomplete rules*: Others (pupils: M2, M9, M10, M13, M14) incompletely described the aforementioned procedure, e.g: "*We try to find some numbers to add so that we produce the decimal number*'.
(d) *No response*: The remaining pupils did not answer this question.

Pupils' interest/non interest in the card-game experience As emerged from the answers to the open question PT7 (see Table 3), pupils found their game-based experience interesting. In their own words: (a) they had fun: "*It was so much fun to play with cards*!" "*During these 2 h, I have learned as much as I've learnt in the whole of my school life!"*; (b) they were motivated to be actively involved, as players in the card game: "*We liked to play in order to beat the computer";* (c) the game has rules: " *The rules of the game helped me to learn in order to win*"; (d) the game has goals, winning, competition and challenge: "*It was a challenge for me to achieve the goal of beating the bank!;* (e) the game emphasizes interaction, adrenaline, outcomes and feedback: "*I was anxious to pick the next card as well as to check the outcomes of my attempts from feedback given by the computer"*; (f) this way of learning is informal and novel in school practices: "*I like this game because it is not trivial,* *while our everyday lessons are usually boring";* (g) the learning aims were at the heart of the game play: " *We did not realize how easily we were learning about binary numbers; we played and learned together* '"; (h) the game is easy, provides scaffolding and representation: '*It was a very easy game, the dotted-cards and the help given helped me very much to understand about binary numbers* . A few pupils (M1, M4 and M12) did also express that they would prefer to play this game offline with their friends. After some discussion with their teacher, they asked me to provide them with the game to play at home.

Based on all the results emerging from this post test questionnaire, it seems that all pupils: (a) managed to convert BNs to their equal decimal numbers and vice versa (b) correctly realized the value of each digit of a BN and (c) found the game easy and motivating to use. A considerable number of pupils also managed to form some rules that govern the aforementioned conversions.

6 Discussion

Concentrating on the analysis of the data emerging from the pilot study reported in this paper, an attempt has been made to address the main issues that appeared to contribute to this game becoming a successful environment in terms of pupil motivation and learning. Addressing these issues could be useful for both the designers of educational computer games for CS education and educators in Computing. To this end, basic issues addressed during the design of both the card-game and the pilot experiment for its didactical use are re-examined here in light of the results of the said pilot study.

Context As regards motivation, the analysis of the data—especially that emerging from the post test stage—revealed that the context of this card game was pleasant, meaningful and attractive for the pupils throughout the experiment. Based on the analysis of these data, some factors that appeared to contribute to pupil motivation were revealed, namely: (a) *fun* in playing with cards against the computer, (b) pupil in the role of *player*, (c) specific *rules* for game-play, (d) establishment of *goals*, (e) *interaction*, (f) immediate *feedback* on pupils' actions for self-correction (g) specific *outcomes*, (h) *challenge/ competition/ risk/ feelings of winning*, (i) *novelty* in terms of learning approaches used and the subject of learning in question, and (j) *learning aims* at the heart of the game-play.

In terms of pupils' learning about the BS, and taking into account the fact that most of them had no idea about this system before entering this game play experiment—as emerged from the pre-test questionnaire data—their skills in this subject obviously improved through playing the game. In fact, all pupils managed to succeed in the conversion of the BNs during the post test and a considerable number of them formed appropriate generalizations about the rules that govern conversions of BNs to decimal numbers and vice versa. To this end, the *3-phase didactical scenario*–as a context of using this game–would appear to have been effective in terms of student learning. In fact, during this scenario pupils exploited their previous knowledge of the decimal system (1st phase), were softly introduced to the BS and consolidated their newly-gained knowledge about it (2nd phase) and progressed to forming extensions and generalizations of this knowledge (3rd phase).

Pupils' active and constructive participation Pupils seemed both physically and mentally active during the whole experiment. Some factors that probably contributed to this active participation were: (i) the *interactivity* of all the functions included in the said game, (ii) the *motivation* during card-game play in terms described in the previous section, (iii) the encouragement to *use essential learning competences* during the whole learning experiment; namely: (a) *reflection* on previous knowledge (by using the 'Decimal System' function), (b) *analogical reasoning* (by experimenting with the "help pattern'), (c) *reverse thinking* (by using the 'Decimal to Binary' function), (d) *consolidation and reinforcement* of knowledge (by playing against the computer using cards featuring BNs and by trying the "Binary to Decimal' function), (e) *extension* of their knowledge (using the "Binary to Decimal function) by trying to convert BNs with up to five digits into corresponding decimal numbers as well as to find relationships among the value of the position of the digits of a BN, (f) *generalizations* by attempting to formulate rules that govern the conversions from the decimal system into the BS and vice versa, and mentioning issues about the structure of these systems. The use of these competences was also stimulated by the demand to answer appropriate questions throughout the aforementioned 3-phase didactical scenario.

Scaffolding In the context of game play, pupils were provided with opportunities for *support* so as to progress smoothly in their learning through: (i) exploiting their *previous knowledge*, (ii) using the *visual hints* and the *help* provided and (iii) exploiting the *feedback* automatically given by the game. To this end, the role of the researcher's interventions–through talk–throughout the experiment was essential in scaffolding pupils in their attempts to construct, consolidate and generalize their knowledge of BNs during their card-game play.

Content Here, too, the manner in which the content was integrated into this game (in the form of *examples included in the "Help*" function) seemed to encourage pupils to progress in both playing the game and learning the basic aspects of the BS. The *use of the educational content at the heart of game play* as contributing to pupil engagement in a game *as players* is also considered essential by other researchers (Fisch 2005).

Structure The structure of this card game also seemed to encourage and support pupils to be: (a) constrained to work on *specific learning aims* by strictly concentrating on the *main points of the subject* to be learned (basic aspects of the BS), and (b) *motivated* in order to *beat* the computer and their classmates. In fact, pupil *learning* was mainly driven by the intention to win. However, their engagement was restricted to the aforementioned points of the BS.

On the whole, the general context of the said card-game including both its features and the didactical scenario for its use, seemed to encourage and support pupils to approach double-sided aims—learning and motivation—through play. In fact, the general context of this game seemed to act as a *constraint-support-*

constructive motivation context by simultaneously providing pupils with opportunities to be engaged in game-play with specific aims while being encouraged to be physically and mentally active by the various goals provided.

7 Conclusions

This paper demonstrated the design and the pilot evaluation of an educational computer card game for the learning of fundamental Computer Science concepts in Primary Education, and especially for the learning of basic aspects of the binary system. This game emphasized pupil involvement in a playful and fun interactive environment guided by the goal of beating the computer while at the same time following specific rules. More significantly, the knowledge in question was at the heart of the game, thus making pupils feel they were players rather than learners during their playing sessions. The design of the said game was inspired by modern social and constructivist theories of learning in combination with essential game design principles.

A first glance at the analysis of the data emerging from this pilot study clearly demonstrates that this computer card-game used within the frame of a 3-phase didactical scenario, in combination with a set of appropriately designed questions, could become an appropriate learning context to support pupils of Primary Education in their learning of basic aspects of the binary system.

Based on the results of this pilot study, some essential factors that seemed to contribute to successful pupil engagement in their own learning of BNs within the context of game play were revealed, namely: (a) motivation, (b) specific learning aims—purposeful learning, (c) emphasis on the basic points of the learning subject in question, (d) neither too complicated nor too simple format, (e) learning content at the heart of the game play, (f) hidden content within the 'Help' function in the form of examples, (g) double aim functions: learning and engagement, (h) activation/doing, (i) clear and appropriate didactical scenario, (j) reflection on previous knowledge, (k) introduction and consolidation of newly-gained knowledge, (l) encouragement of the acquisition of essential learning competencies, such as: reflection, analogical reasoning, reverse thinking, consolidation, self-correction, extension and generalization, (m) posing of appropriate questions to enhance learning, (n) support: visual hints/help/feedback, and (o) context: constraining-supportive-constructive-motivational. In addition, based on the results of this study, a number of specific issues relating to the design of effective educational computer games were highlighted.

Specifically, the results of this study support the idea that the design of effective educational computer games is double-sided (both motivational and educational) and, most importantly, that motivational design has to be interconnected with educational design. To this end, the formation of a motivational scenario is insufficient in itself to ensure the design of effective educational computer games; nevertheless, the formation of an interrelated appropriate 'didactical scenario' is still crucial. The '*constraining-supportive-constructive-motivational*' context of the card game reported in this paper also proved appropriate in encouraging both pupils' motivation and learning. In this context, pupils were provided with opportunities to concentrate on the main points of the learning subject in question and receive appropriate support and feedback so as to construct their knowledge about binary numbers at the same time as being interestingly engaged with the game play.

It is important to note that, due to certain limitations, it is not possible to generalize the results of this pilot evaluation study. Specifically, the size of the group of students participating in this study was relatively small, and the number of tasks they attempted during this experiment was also limited. However, the positive results of this field study can be used as a basis for further investigation of the impact of this game on the teaching and learning of introductory aspects of the binary system in Primary schools within the wider context of educating younger generations about fundamentals in Computer Science. It would be also interesting in future research to examine the differences between the use of this digital game and other types of resources and identify how different learning media affect pupils' learning in terms of binary numbers. Our future plans also include the introduction of this game into a variety of classroom settings for further investigation of its impact on pupil learning as well as its extension so as to support the learning of various aspects of the BS for use by students in Secondary Education. In addition, the specific design principles that—through this evaluation experiment—proved useful in terms of pupil learning could be used in the design of other educational games so as to investigate their effectiveness.

Finally, a brief note on the implication of this study for both designers of educational computer games and CS educators. The former could use social and constructivist learning perspectives hand-in-hand with game design principles to design educational games aligned to the needs of CS curricula at all levels of education including Primary Education. To this end, the design principles deemed essential from the empirical study reported in this paper could become useful. Primary school teachers should be trained in the didactical use of this computer game in their everyday school practices. Based on this experience, teachers also have the opportunity to see themselves as designers of computer games by participating in specific design teams where they can contribute to letting their students' voices be heard by proposing student-centered educational games for CS education.

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References

Association for Computing Machinery. (2003). *A model curriculum for K-12 computer science: Final report of the ACM K-12 Task Force* Curriculum Committee, http://www1.acm.org/education/k12/k1final1022.pdf

Baker, A., Navarro, E. O., & Van Der Hoek, A. (2005). An experimental card game for teaching software engineering processes. *Journal of Systems and Software, 75*, 3–16.

Bell, T., Witten, I., & Fellows, M. (2002). *Computer science unplugged*, http://www.unplugged.canterbury.az.nz

Bright, G. W., & Harvey, J. G. (1984). Computer games as instructional tools. *Computers in the Schools, 13*, 73–79.

Carrington, D., Baker, A., & van der Hoek, A. (2005). It's all in the Game: Teaching software process concepts. In Proceedings 35th Annual *Conference Frontiers in Education*, FIE, pp. F4G-13–F4G-18.

Chang, W.-C., Chen, Y.-L., & Lee, T.-P. (2008). Computer assisted learning with card game in system design concept. In E. W. C. Leung et al. (Eds.), *Advances in blended learning, 2008, LNCS, 5328* (pp. 93–101). Berlin: Springer-Verlag.

Cohen, L., & Manion, L. (1989). *Research methods in education*. London: Routledge.

Crawford, C. (1982). *The art of computer game design*, available as a free download from a site maintained by Washington State University at www.vancouver.wsu.edu/fac/peabody/game-book/Coverpage.html Accessed 10/02/ 2010.

Csikszentmihalyi, M. (1990). *Flow: The psychology of optimal experience*. New York: Harper & Row.

DeVries, R. (2004). What Is Constructivist about Constructivist Education? *The Constructivist*, Vol. 15, No. 1.

Fisch, M. S. (2005). Making educational computer games educational. Proceedings of the 2005 conference on *Interaction, design and children*, Boulder, Colorado, pp. 56–61.

Fabricatore, C. (2000). *Learning and videogames: an unexploited synergy*. At http://www.learndev.org/dl/FabricatoreAECT2000.PDF, accessed 10/02/ 2010.

Facer, K. (2003). Computer games and learning. http://www.futurelab.org.uk/resources/documents/discussion_papers/Computer_Games_and_Learning_discpaper.pdf [last access: 10/02/2010].

Gardinger, A. (1987). *Discovering mathematics: The art of investigation*. NY: Oxford University Press.

Hays, R. T. (2005). The effectiveness of instructional games: a literature review and discussion. *Storming Media*, pp 1–63.

Jonassen, D. H. (1999). Designing constructivist learning environments. *Instructional design theories and models, 2*, 215–239.

Kafai, B. (2001). The educational potential of electronic games: From games-to-teach to games-to-learn. *Playing by the rules*. Cultural policy centre, university of Chicago. Retrieved February 10, 2010 from http://culturalpolicy.uchicago.edu/conf2001/papers/kafai.html

Kamii, C., & DeVries, R. (1980). *Group games in early education: Implications of Piaget's theory*. Washington: National Association for the Education of Young Children.

Kickmeier-Rust, M. D., Peirce, N., Conlan, O., Schwarz, D., Verpoorten, D., & Dietrich, A. (2007). Immersive digital games: the interfaces for next-generation E-learning? *LNCS, 4556/2007*, 647–656.

Kim, S. B., Choi, S. K., Jang, H. S., Kwon, D. Y., Yeum, Y. C., & Lee, W.G. (2006). Smalltalk card game for learning object-oriented thinking in an evolutionary way. In *OOPSLA*, Portland, Oregon, USA, pp. 683–684.

Kirriemuir, J. (2002). Video gaming, education and digital learning technologies. *D-Lib Magazine*, 8(2).

Kirriemuir, J., & McFarlane, C.A. (2004). *REPORT 8: Literature Review in Games & Learning*. http://www.futurelab.org.uk/research/reviews/08_16.htm

Land, S. M., & Hannafin, M. J. (2000). Student-centered learning environments. In D. H. Jonassen & S. M. Land (Eds.), *Theoretical foundations of learning environments* (pp. 1–23). NJ: Erlbaum.

McFarlane, A., & Sakellariou, S. (2002). The role of ICT in science education. *Cambridge Journal of Education, 32*(2), 219–232.

McFarlane, A., Sparrowhawk, A., & Heald, Y. (2002). Report on the educational use of games, *TEEM*: www.teem.org.uk/

McGraw, I., Yoshimoto, B., & Seneff, S. (2009). Speech-enabled card games for incidental vocabulary acquisition in a foreign language. *Speech Communication, 51*, 1006–1023.

Mitsuhara, H., Ogata, H., Kanenishi, K., & Yano, Y. (2007). Do children understand BNs by electric card game?. Proceedings of *DIGITEL 2007: First IEEE International Workshop on Digital Game and Intelligent Toy Enhanced Learning 2007*, pp. 191–193.

National Council of Teachers of Mathematics. (2000–2004). *Communicating about mathematics using games: Playing fraction track*. Retrieved on February 10, 2010, from http://standards.nctm.org/document/eexamples/index.htm

Oblinger, D. (2004). The next generation of educational engagement. *Journal of Interactive Media in Education, 2004*(8), 1–18.

Panselinas, G., & Komis, V. (2009). Scaffolding' through talk in groupwork learning. *Thinking Skills and Creativity, 4*, 86–103.

Papastergiou, M. (2009). Digital game-based learning in high-school computer science education: impact on educational effectiveness and student motivation. *Computers and Education, 52*(1), 1–12.

Papastergiou, M., & Solomonidou, C. (2005). Gender and information and communications technology: Greek high school students' favourite internet activities. *Computers and Education, 44*(4), 377–393.

Pohl, M., Rester, M., & Judmaier, P. (2009). Interactive Game Based Learning: Advantages and Disadvantages. In C. Stephanidis (Ed.), *Universal Access in HCI*, Part III, HCII 2009, LNCS 5616, pp. 92–101.

Prensky, M. (2001). *Digital game-based learning*. New York: Mc Graw-Hill.

Proulx, V. K. (1993). Computer science in elementary and secondary schools. Proceedings of the IFIP TC3/WG3.1/WG3.5 Open Conference on *Informatics and Changes in Learning*, pp. 95–101

Rajaravivarma, R. (2005). A games-based approach for teaching the introductory programming course. *Inroads ACM SIGCSE Bulletin, 37*(4), 98–102.

Randel, J., Morris, B., Wetzel, C., & Whitehill, B. (1992). The effectiveness of games for educational purposes: a review of recent research. *Simulation and Gaming, 23*(3), 261–276.

Sikiniotis, S., Kapros, H., & Kordaki, M. (2008). A Computer Game for the Learning of Binary System by Beginners. Proceedings of IADIS International Conference "e-Learning 2008", Amsterdam, The Netherlands, 22 - 25 July 2008, Vol. 1, pp. 29–36.

Smith, D. R., & Muhro, E. (2009). Educational card games. *Physics Education, 44*(5), 479–483.

Tennyson, R. D., & Jorczak, R. L. (2008). A conceptual framework for the empirical study of instructional games. In: *Computer games and team and individual learning*, (pp. 3–20). Amsterdam: Elsevier.

Van Eck, R. (2006). Digital game-based learning: It's not just the digital natives who are restless. *Educause Review, 41*, 16–30.

Vygotsky, L. (1974). *Mind in society*. Cambridge: Harvard University Press.