Decimal to Binary Number Conversion can be Fun

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Abstract *- Numbering systems are of great importance in Computer Science and Engineering education. The binary numbering system can be considered as one of the most fundamental, since its understanding is essential for the understanding of other Computer Science and Engineering concepts, such as data representation, data storage, computer architecture, networking, and many more. Yet, students are having difficulties understanding it. One approach which has been shown to improve learning of different science and mathematics concepts is the use of educational games. Educational games have the potential to engage and motivate learners through fun activities. This paper presents a small exploratory survey on an electronic educational game for practicing decimal to binary number conversions.*

Keywords: undergraduate Computer Science and Engineering education; binary numbers; number systems; conversion of decimal to binary numbers; educational games.

1 Introduction

This paper builds on [16], which presents an educational game for practicing decimal to binary number conversions, called Binary Blaster. Numbering systems provide the foundation for many Computer Science and Engineering topics, making them one of the most fundamental concepts in Computer Science and Engineering education [13]. Of significant importance is the binary numbering system, which is widely used in Computer Science and Engineering. Understanding of the binary system is essential for the understanding of other Computer Science and Engineering topics, including but not limited to, data storage, computer architecture, and networking [32]. Moreover, given that at their most basic level, computer data (including computer's instructions), are represented with binary numbers (without reducing those numbers further to simple high and low voltages), the binary number system is essential for understanding data representation. Also, specific representations such as twos-complement and floating point, build on and require an understanding of binary numbers [17].

The IEEE/ACM Joint Task Force on Computing Curricula guidelines for undergraduate degree programs include machine level representation of data (machine learning) as part of one of the fundamental knowledge areas. Some of the recommended topics to be covered are numeric data representation, number bases, and twos-complement representations [8]. Computer Science and Engineering students should have an understanding of the binary number system so that they can understand the basic operations of a machine. At even a more general level, to be able to develop useful and efficient software and hardware, students should have a good understanding of the process involved in binary arithmetic and operations performed by computers.

Although the binary numbering system is at the core of many areas of Computer Science and Engineering education, students have difficulties understanding it and instructors explaining it [17, 23]. This may be an inherent difficulty, since it is an unfamiliar concept for the students. Most students are so used to performing arithmetic in the decimal system that any other numbering system seems unnatural [1] and difficult for them to comprehend [12]. Moreover, according to Petzold (2000), conversions between the common number systems can be tricky and awkward [7].

One approach that has been shown to be effective in teaching and learning different science and mathematics concepts is the use of educational technologies. By bringing the worlds of academia and technology together, we can create educational environments that were not previously possible. Technology can change the way educators and students interact and communicate with each other, the way learning materials are presented, and the place and time learning occurs [15]. Successful technology integration in education can capitalize on students' enthusiasm about technology [31] and serve as a motivation for learning.

Educational software and specifically, electronic educational games, is one kind of technology that can be used to support education even for young students [2, 11, 18, 24, 30]. Research has shown that electronic games are engaging and effective learning tools [3, 10, 22]. They can motivate, excite, and engage students in the learning process. This does not come as a surprise, taking into consideration the many hours students from very young age spent playing electronic games [25]. Moreover, games can provide an active learning environment. Actively learning, making mistakes, and learning from them, is more effective than passively listening to a lecture [29].

Educational games can be designed and developed as fun and engaging activities where students can learn or practice different concepts. Games focused on learning, incorporate information which allows students to construct knowledge during game play through the exploration of different scenarios related to the target subject area. On the other hand, games focused on practice rather than learning, incorporate questions directly related to the relevant subject area and provide students incentives to answer the questions to the best of their knowledge by either offering resources necessary to continue playing the game, moving up a skill level, or earning points.

Currently, there are many electronic resources available for teaching and learning the binary number system as well as conversions between decimal and binary numbers [4, 5, 6, 9, 14, 20, 21, 26, 27, 28, 32]. Such resources can be classified into four main categories: (a) resources which provide instructional material in a static textual and visual form [5, 9, 26], (b) resources which provide instructional material only in visual form (e.g., videos) [21], (c) resources which provide a decimal to binary converter without any instructional material [4, 20, 27, 28], and (d) resources which are only focusing on practicing number conversion [6]. A more comprehensive discussion on educational software available for binary number systems can be found in [32].

Of interest to this paper is the fourth category which includes educational software for practicing number conversions and especially, educational games. In what follows, we provide an overview of an educational game, called Binary Blaster [16], which is designed for practicing decimal to binary number conversion. We also present an exploratory survey on students' perceptions about the game.

2 The Game

2.1 Game Overview

Binary Blaster allows students to practice decimal to binary number conversion in three different forms of binary representation (straight binary, excess, and twos-complement). The game includes two playing modes (single player mode and multi-player mode) and two possible input modes (standard keyboard and video game controller).

When the game begins, players must select the binary representation they would like to practice with as well as the number of bits they would like the binary numbers to have (e.g, 3-bit, 4-bit, etc. up to 8-bit binary numbers).

During game play, a randomly generated decimal number embedded in a colored shape (e.g., star, circle, etc.) is "falling" from the top of the screen. At the same time, at the bottom of the screen there is a list of distinct binary numbers (the default size of the list is six distinct binary numbers) with a uniform number of bits, including the binary number that corresponds to the "falling" decimal number. The form of the binary numbers available depends on the player's selection at the beginning of the game (i.e., binary representation and number of bits). The goal of the player is to match the "falling" decimal number with its corresponding binary number available at the bottom of the screen (see, Figure 1).

Figure 1: A screenshot from the multi-player mode of Binary Blaster showing three different players, represented by three differently colored shapes.

Once the decimal number reaches the bottom (i.e., it is matched with a binary number), immediate visual and auditory feedback is provided to the players. To motivate players to spend more time practicing decimal to binary conversion so as to become proficient, players receive points for every correct matching and lose points for every incorrect one. The player's goal is to earn points and achieve a high score. Following feedback to the user, a new decimal number starts falling from the top of the screen and the list of available binary numbers is updated. The entire process is repeated until the players have reached a desired score or feel that they are proficient with the specific type of conversion.

Moreover, the game provides different ways to challenge the players:

(a) the speed of the falling decimal number increases as the players progress through the game and earn more points;
(b) players can increase the number of bits in the binary numbers they are practicing with;
(c) players can increase the number of available binary numbers to choose from (at the bottom of the screen);
(d) players can change the binary number representation (i.e., standard binary, excess notation, or twos-complement).

Binary Blaster is currently available for different operating systems (e.g., Linux, Windows, iOS) and although it only includes conversions from decimal to binary representation, it is easily expandable to other numbering systems such as hexadecimal and octal.

A more detailed discussion of the game and its implementation can be found in [16].

3 Exploratory Survey

3.1 Overview

To further explore the potential of Binary Blaster as well as confirm and strengthen the findings of [16], a small exploratory survey on its effectiveness and students' perception of it, was conducted with first year undergraduate computing students. The survey was part of the "Introduction to Mathematics for Computing" course, in which students are introduced to numbering systems, with emphasis on the binary system. All students taking the course (40 students) were invited to participate in the survey voluntarily. A total of 38 students accepted the invitation. Although the number of participants is not very high (i.e., the survey results may not be representative), the survey results can be used to indicate future directions.

During the course, one class period (1 hour and 15 minutes) was spent on formal instruction of the binary system and binary representations. By the end of this class period, participants were introduced to Binary Blaster and a one hour extra session was arranged for participants to play with the game. The session was scheduled two days after formal instruction and it took place in a computing laboratory. During the "play" session students were asked to use the game individually to practice decimal to binary conversions. Some students chose to play in groups (multiplayer mode) in addition to playing individually. Students were also asked to try and play the game with different number of binary bits and different binary representations, until they felt comfortable with the conversions.

3.2 Survey

Three instruments were developed for evaluating the effectiveness of the game as well as students' perceptions about the game: the pre-test worksheet, the post-test worksheet, and the post-test questionnaire. The pre-test worksheet was administered to the students at the beginning of the game play session. The post-test worksheet and post-test questionnaire were administered at the end of the game play session. Below are the three instruments.

Pre-test Worksheet:

Problem 1:
Convert the following binary numbers to decimal. On a scale of 1 (very easy) to 5 (very difficult) rate the degree of difficulty for each.
a) 110 b) 011 c) 1001 d) 1011
e) 11100 f) 10101 g) 101100 h) 110100

Problem 2:
Convert the following decimal numbers to binary. On a scale of 1 (very easy) to 5 (very difficult) rate the degree of difficulty for each.
a) 7 b) 4 c) 13 d) 10
e) 20 f) 29 g) 42 h) 45

Post-test Worksheet:

Problem 1:
Convert the following binary numbers to decimal. On a scale of 1 (very easy) to 5 (very difficult) rate the degree of difficulty for each.
a) 101 b) 100 c) 1101 d) 1100
e) 11010 f) 10011 g) 101010 h) 110011

Problem 2:
Convert the following decimal numbers to binary. On a scale of 1 (very easy) to 5 (very difficult) rate the degree of difficulty for each.
a) 6 b) 3 c) 14 d) 11
e) 18 f) 27 g) 52 h) 46

Post-test Questionnaire

Question 1: On a scale of 1 (very difficult) to 5 (very easy), how easy was Binary Blaster to use?

Question 2: On a scale of 1 (not enjoyable) to 5 (very enjoyable), how much did you enjoy playing Binary Blaster?

Question 3: On a scale of 1 (not effective) to 5 (very effective), how effective do you think Binary Blaster was for your understanding of binary numbers?

Question 4: Is there something you would like to improve about Binary Blaster? Explain your answer.

Question 5: Do you have any additional comments related to your experience with Binary Blaster?

3.3 Results

Results of participants' performance in the pre- and post-test worksheets are presented in Table 1. The table presents the percentage of participants' correct responses to the conversions (percentages are rounded to the nearest whole number) and the average participants' difficulty rating for each conversion (rounded to the nearest tenth).

As we can see from Table 1, the results are not very surprising. Participants' performance was improved after using the game, but not significantly. Moreover, according to participants' responses, their perceived difficulty with the conversions was improved, especially with conversions of 5 and 6 digit binary numbers (problem 1e-h) and large decimal numbers (problem 2e-h).

Table 1. Pre-test and post-test results

	% Correct Responses			Rating (1-5)		
	Pretest	Posttest	Change	Pretest	Posttest	Change
1a	90	90	0	1.3	1.3	0
1b	79	79	0	1.3	1.2	-0.1
1c	82	90	+8	2.4	2.2	-0.2
1d	71	79	+8	2.6	2.4	-0.2
1e	61	79	+18	3.2	2.7	-0.5
1f	68	79	+11	3.7	3.0	-0.7
1g	61	79	+18	4.0	3.4	-0.6
1h	71	90	+19	4.2	3.2	-1.0
2a	87	90	+3	1.3	1.3	0
2b	90	90	0	1.4	1.2	-0.2
2c	79	90	+11	1.9	1.5	-0.4
2d	68	68	0	2.3	1.9	-0.4
2e	71	79	+8	3.1	2.5	-0.6
2f	68	79	+11	3.4	2.7	-0.7
2g	61	79	+18	4.0	3.2	-0.8
2h	61	68	+7	4.1	3.4	-0.7

In addition to comparing participants' performance results between the pre-test and post-test worksheets, the time participants spent on each worksheet was also recorded. The average time to complete the pre-test worksheet was 18 minutes, whereas for the post-test worksheet was 11 minutes. This suggests that the game helped participants to become faster when performing number conversions (i.e., there was an improvement on participants' response time). This was also reflected on participants' comments on Question 5 of the post-test questionnaire. More than half of the participants commented that the game helped them "think faster" and become quicker while performing the conversions. Some of their responses include:

-"The game helps you think faster."

- "While playing the game you need to become quicker in doing the conversions in your mind. After playing the game for a while I became faster."

- "The game helps you find the conversions faster, you become quicker."

- "The game challenges you and helps you think fast about the conversions."

In terms of participants' feedback about the game, the results of the participants' responses to the post-test questionnaire suggest that the game was easy to use, enjoyable, and assumed to be effective by the participants. For Question 1, the average participants' response was 4.8 (i.e., participants found the game very easy to use), for Question 2 was 4.6 (i.e., participants found the game very enjoyable), and for Question 3 was 4.2 (i.e., participants' found the game effective for their understanding of binary numbers). In terms of Question 4, almost all participants responded that there was nothing they would like to change about the game because they liked the game and they felt that the game was appropriate for its purpose. Only five participants made suggestions and those were as follows:

- "I did not like the colors much. The interface is too pink for me."

- "It will be nice if the game includes some instructions on how to do the conversions rather than being just for practicing."

- "Maybe allow the players to change difficulty level while paying instead of having to exit the game and start again."

- "Include more numbers."

- "The user should be able to terminate the game when makes 3 mistakes without losing the high score."

For Question 5, the main "themes" of participants' responses were that the game was interesting and fun to play, it was challenging, and motivate them to practice more compared to a regular textbook. Some of the participants' comments are presented below:

- "It was effective for my learning because I practiced more, since I was playing to break high score."

- "I liked the game a lot. It is good and fun. The game became more effective for my learning when it was going faster. It helps your mind think fast."

- "I liked it because it reminded me of old arcade games. It was effective for learning, especially the faster it gets the more challenging and interesting it gets."

- "I liked the fact that the binary numbers were changing positions every time. It was difficult to memorize."

- "It is good that you have multiple choice. It helped me realize my mistakes and fix them."

- "The game is perfect for its purpose. I had fun playing with it. The multiplayer mode is more fun. I will use it at home also."

4 Conclusion and Discussion

One approach that has been shown to be valuable for enhancing teaching and learning, is effectively utilizing educational technologies, or more precisely, interactive multimedia and educational software in the classroom. In the last few decades, there has been a dramatic increase in the use of educational technologies available for teaching and learning different science concepts and some universities have already integrated such systems into their curricula. In this paper, an exploratory survey on the effectiveness and students' perceptions on an electronic educational game for practicing decimal to binary number conversions, called Binary Blaster, was presented. The game aims to provide a fun activity for the students which can motivate them to practice number conversions and become proficient in the subject. Although the game currently only includes decimal to binary conversions, it is easily expandable to other numbering systems such as octal and hexadecimal. The game is suitable for any age especially, high school students and first year university students.

Overall, the results of the survey suggest that the game is easy to use, enjoyable, and students' perceive it as effective for their understanding of the binary system. Moreover, it was found that students became faster in performing decimal to binary conversions after playing the game for some time. This is not a surprise, since extensive practice always results in better performances. On the other hand, according to students' comments, they only had extensive practice because of the game. In other words, the game was successful in motivating students to solve more problems and play until they felt they were proficient with the conversions. In terms of performance, there was an improvement after students played with the game, but not significant. Finally, after using the game, students found conversions easier to perform, especially with large numbers (e.g., with five and six digit binary numbers). These findings confirm and strengthen the results of [16] that students enjoy playing with Binary Blaster, the game is easy to use and fun to play with, and that in their opinion, the game is effective for their learning and understanding of binary number conversions.

For the future, a more comprehensive study will be conducted on the effectiveness of the game as well as its appeal to the students.

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6 Acknowledgements

The author would like to thankfully acknowledge the contributions of Julie Krause, Kyle Schulz, David Danford, Monica Noring, and Heidi Lewis to the development of Binary Blaster.