Attempts by Primary Education pupils to learn the concept of binary encoding within the context of drawing: a case study

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This paper focuses on the learning of binary encoding by primary school pupils within the context of drawing. In particular, twenty five 6th Grade pupils participated in a constructivist learning experiment where they were asked to draw their own colourful pictures on a rectangular grid and find ways to describe them correctly to a) a friend over the telephone and b) a computer. Pupils were asked to draw four pictures in total, using two, four, eight and sixteen colors respectively. Data analysis showed the variety of ways used by the pupils to describe their pictures and the specific interventions performed by the researcher to help them to move from incomplete to more accurate descriptions. In addition, the analysis of the data showed the diversity of attempts performed by these pupils to express their pictures using 0s and 1s and the kind of teacher intervention used to help them to move from intuitive approaches to binary ones. The analysis also demonstrated pupil performance in encoding using systems consisting of one, two, four and eight binary digits. Finally, pupils were stimulated to make generalizations about binary encoding. Pupils were also encouraged to exploit their experience within the context of the said activity to make sense of binary encoding as used in computers.

Keywords Binary encoding; painting; Primary education

1. Introduction

Understanding how real world information must be represented in order for it to be understood by a computer is fundamental for a preliminary understanding of how a computer works. It is worth noting that one of the four goals of the curriculum proposed by ACM [1] is to introduce the fundamental concepts of Computer Science (CS) to all students beginning at primary level. Understanding how 0s and 1s can be used to represent information such as binary images and numbers is viewed as a basis for the achievement of the goals of the CS curriculum at this level of education [2]. It is also worth noting that both students in secondary education and adults have difficulties in understanding how a computer works [3]. With this in mind, encouraging pupils to grasp the concept of information-encoding in general, and information-binary encoding in particular, is crucial. To this end, the role of the learning activity used is essential. Indeed, it has been mentioned by many researchers that learning activities play a central role in the whole learning context and have a significant influence on learners' actions ([4], [5], [6]). The design of learning activities has been related to the learning theories used. Traditional behaviorist theories [7] emphasize the role of 'drill and practice' schoolbook-like activities. These activities do not usually relate to the pupils' world and are meaningless to them. These activities do not usually enable pupils' higher mental functions but their recall functions, as they need a specific step-by-step recipe to be applied for their solutions.

Contrariwise, constructivism and social theories of learning acknowledge the role of authentic, meaningful, holistic learning activities in motivating learners to be actively involved in their learning ([8], [9]) Such activities usually come from the pupils' world and have a playful and enjoyable character. In addition, the role of activities where learners can use a kind of hands-on experience is acknowledged as essential [10] It is not what the pupils see but what they do that has the greatest impact on learning at the primary level [11]. In the context of this kind of activity, pupils are not passive receivers of the knowledge presented by their teachers but are provided with opportunities to take their own decisions and to

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control their learning [12]. In this way, pupils can develop their critical thinking and also be provided with opportunities to use their knowledge to solve real-life problems. As regards pupils' learning of fundamental Computer Science concepts and skills during primary education, the role of engaging learners in constructivist learning activities is also acknowledged as crucial ([2], [13], [14], [15], [16]).
To help primary level education pupils grasp the concept of binary encoding, an appropriate learning context emphasizing constructivist learning activities has been designed and tested in a real classroom setting. Said activities have been designed by taking into account modern constructivist learning theories ([8], [12]). In the design of these activities, the role of a meaningful and enjoyable learning context that motivates learners to be actively engaged in their learning was also acknowledged. To this end, the context of painting was deemed appropriate.

The context of the study is presented below, followed by the results emerging from the testing of the designed activities with real pupils and, finally, a discussion of the results and the conclusions drawn.

2. The context of the study

Twenty five 6th Grade pupils participated in a constructivist learning experiment aimed at the learning of binary encoding by primary level education pupils. More specifically, pupils were involved in a joyful painting activity constituting the following sub-tasks: 1) Pupils were asked to draw their pictures and to paint them on a rectangular grid (Figure 1a). The context of painting was chosen to provide pupils with opportunities to develop strong motivation. Next, pupils were asked to find ways to describe over the telephone these pictures to a friend who also had the same grid in their hands. At this point, it was suggested that pupils find the speediest way to describe these pictures as long telephone calls are expensive. It was decided to encourage pupils to find a short code system to interpret their paintings. 2) Owing to the fact that a computer understands only the symbols '0' and '1', how can you describe your pictures so that they can be understood by a computer?.

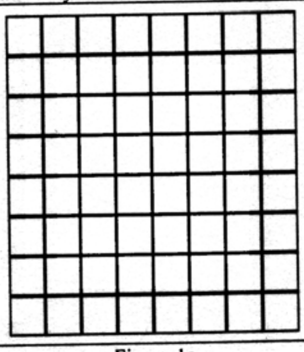

Figure 1a

0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0
0	1	1	0	0	1	1	0
0	1	1	0	0	1	1	0
0	0	0	0	0	0	0	0
0	1	0	0	0	0	1	0
0	0	1	1	1	1	0	0
0	0	0	0	0	0	0	0

Figure 1b

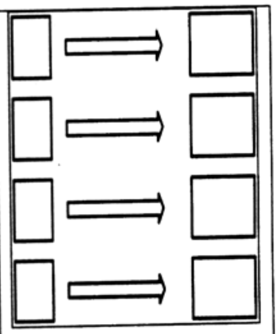

Figure 1c

At this point, pupils were given an extra empty grid to represent their pictures in terms of 0s and 1s. 3) Next, pupils were asked to transform the coded figure presented in Figure 1b into a colorful picture, on an empty grid and using two different colors, in order to enable pupils' reverse thinking. 4) Here pupils were given a set of colors and were then asked to paint the left boxes of Figure 1c in different colors of their preference and give them a code using combinations of 0s and 1s. Pupils were also asked to put these codes in the corresponding boxes on the right, illustrated in Figure 1c. 5) At this point, pupils were given an empty grid (Figure 1a) and were then asked to draw their own pictures and paint them using the four colors they had selected in the previous step. 6) Next, pupils were given an empty grid (Figure 1a) and were asked to translate their pictures using the codes they had previously assigned to these colors. In addition, pupils were asked to perform steps (5) and (6) using 8 and 16 colors. In addition, pupils were asked to estimate what they had learned through this experiment. Finally, pupils were asked to extend the knowledge they had acquired during this experiment to: (a) represent capital letters using a binary encoding system (b) to find a way to explain how circles and curves could be represented in a computer system using a grid with colored cells in combination with a binary encoding system.

3. Results

Painting and describing pictures to a friend over the telephone. First of all, it is worth noting that all pupils were happily involved in the painting context. Pupils' descriptions of their paintings fall in the following categories:

(a) *Focusing on each cell of the square grid.* For example, pupil M3 described one-by-one the color of each cell of each row of the square grid, at the same time assigning the number of row and the number of column of the said cell.

(b) *Focusing on the figure.* Some pupils described their pictures in terms of their meanings, for example: it is a flower (pupils M_7, M_9, M_{17}, M_{20}, M_{21}), while other pupils described their pictures in terms of the colors they used, for example: this picture has been painted using red, blue and green (pupil M17).

(c) *Focusing on groups of cells with a common property.* A typical example is when pupils emphasized a group of cells with a common color, for example: in the first row of the grid all cells are green, in the second row the first two cells are red and the rest are green, etc. (pupils M_2, M_5, M_6, M_{11}, M_{16}, M_{18}, M_{19}).

(d) Focusing on specific groups of cells with a common property but not succeding in the description of the entire picture (M_1, M_4, M_8, M_{10}, M_{22}, M_{23}). For example: the 14 cells in the middle of the picture are **blue (pupil M8).**

The researcher's interventions: Pupils who didn't succeed in forming an accurate description of their paintings were helped by the researcher to correct their descriptions through the following interventions:

(a)leading pupils on cognitive conflict: presenting the pupils a drawing painted according to theirs descriptions. By observing the difference between their own paintings and those made by the researcher and following their descriptions, these pupils (pupils M_1,M_4 και M_{10} M_{20}) tried more methodically and succeeded in accurately describing their pictures.

(b) stressing the large amount of time needed in some descriptions, e.g. the description made by pupil M_3.

(c) saying: I don't understand, please describe this more accurately (for pupils M_7 M_9 M_{17} M_{20} M_{22} M_{23}).

Despite the above, one pupils (pupil M_8) did not succeed in accurately describing his picture.

Pupils' attempts to represent their pictures using 0s and 1s. Nineteen pupils (pupils M_1, M_2, M_3, M_4, M_5, M_6, M_8, M_{10}, M_{11} M_{12} M_{14} M_{15} M_{17} M_{18} M_{19} M_{20} M_{21} M_{22} M_{23}.) succeeded in encoding their pictures in the grid given by using 0s and 1s. However, some pupils had difficulties conceiving the fact that a number can describe a color: "*there is no color named 1*' (pupil M_7, M_9) and some other pupils (pupils M_{13}, M_{16}) were puzzled by the concept of a binary representation being an alternative representation of a colorful picture: '*how can we represent this picture without the use of colors*'.

Pupils' binary encoding attempts for their paintings using 4 colors

Some pupils (pupils M_4, M_5, M_7, M_{13}, M_{14} M_{16} M_{17} M_{20}), tried to code the four colors using one-digit codes but it has as a result the use of the same digit for two different colors. As they conflicted by the results of their actions they moved on to the use of two-digit codes using combinations of 0s and 1s. The rest pupils were succeded from the beggining of this sub-task.

Pupils' binary encoding attempts for their paintings using 8 colors

(a) Some pupils (pupils M_7, M_9), instead of using 3-digit codes and combinations of 0s and 1s, used only the zero digit (0) and produced 8 codes by adding one more zero at a time. Consequently, they used the following coding system (0,00,000,0000,00000,00000,0000000,00000000).

(b) One pupil (pupil M_{20}) used more numbers than combinations of 0s and 1s to produce the associated codes such as 0,1,10,11,13,17,19,18. This pupil was helped to grasp the 3-digit combination of 0s and 1s binary system by an intervention made by the researcher, who asked him to rethink the procedure: if, for two colors, a one-digit binary system was used, and for four colors a 2-digit binary system was used, how many digits are needed to represent 8 different colors?

Pupils' binary encoding attempts for their paintings using 16 colors. All pupils succeded in binary encoding at this stage, which implies they overlooked their difficulties in the previous stages of this experiment.

General points mentioned by the pupils. Pupils reported that they had learned:

- That a computer understands only in terms of 0s and 1s (pupils M_2, M_3, M_6, M_{10}, M_{12}, M_{16}, M_{17}, M_{18}, M_{21}, M_{22} και M_{23})
- That a computer can code colors using 0s and 1s (pupils M_1, M_3, M_4, M_5, M_{10}, M_{11}, M_{12}, M_{15}, M_{21}, M_{22} and M_{23}).
- That figures can be represented in terms of 0s and 1s (pupils M_7, M_{11}, M_{12}, M_{14} and M_{16})
- To represent more than one color, we have to use more than one binary digit and vice versa (pupils M_{13}, M_{20})
- That, by combining 0s and 1s, we can produce a variety of numbers (pupils M_7, M_9)
- The information processed by a computer must be in a form of combinations of 0s and 1s (pupils M_8, M_{12} , M_{19})
- That we can communicate with codes (pupil M_6)
- How to construct an abstract description of a picture (pupils M_3 ,M_4)
- How to describe a picture to a friend (pupil M_9)
- How to effect a short communication over the telephone (pupil M_5)
- How to draw easily and fast using codes (pupil M_2)

Extension

(a) Representing letters using 0s and 1s. Most pupils correctly represented capital letters using 0s and 1s on an empty grid (pupils M_1 M_2 M_5 M_6 M_{10} M_{11} M_{12} M_{13} M_{14} M_{19} M_{20} M_{21} M_{23}). However, some pupils reported a difficulty in understanding that letters can be represented with numbers (pupils M_3 M_4 M_{22}). The rest of the pupils were not immediately able to transfer the knowledge they acquired from the previously mentioned experiment to the encoding of capital letters using a binary encoding system. However, all of them went on to correctly encode these letters after an intervention was made by the researcher, asking them to remember their previous experience.

(b) Representing circles and curves using 0s and 1s. About half of the pupils responded that we can use the same method as in pictures and letters but minimizing the length of the cells of the square grid used (pupils M_2 M_6 M_{10} M_{12} M_{14} M_{15} M_{17} M_{19} M_{20} M_{21}). Some pupils recognized the fact that the square grid can be used in combination with the representation of its cells with 0s and 1s, but expressed the opinion that using these grids (with large cells) would not create such a smooth curve. Consequently, the researcher took the opportunity to explain that the size of each cell could be minimized to a pixel (pupils M_1 M_5 M_9 M_{13}). However, there were some pupils who were not able to transfer their previous knowledge to perform this task (pupils M_3 M_4 M_7 M_8 M_{11} M_{16} M_{18} M_{22} M_{23}).

4. Discussion and conclusions

This paper presented the design and the implementation of a constructivist teaching experiment for the learning of binary encoding by primary level education pupils. The context of painting was selected as a framework for the proposed learning activities. These activities were tested in a real classroom using 25 6th Grade pupils. More specifically, pupils were asked to draw and paint a picture of their preference on a square grid and to describe it firstly to a friend - who has the same grid - over the telephone and next to a computer who understands only in terms of 0s and 1s. Pupils were asked to repeat this last task using two, four, eight and sixteen colors. After this experimentation, pupils were asked to estimate what they had learned from this experiment as well as to perform two other tasks regarding binary encoding of capital letters and of circles and curves. The analysis of the data showed that all pupils were happily involved in all tasks given. The analysis of the data also showed that, through the appropriate interventions, all students correctly performed binary encoding of their pictures and finally understood in a variety of ways that computers can at least understand a picture in terms of 0s and 1s. Some pupils also made generalizations about the fact that the information processed by a computer must be in a form of combinations of 0s and 1s. The majority of pupils also seemed to be able to transfer their knowledge to binary encoding letters and also to explain how circles and curves can be represented in a computer system using a grid with colored cells in combination with a binary encoding system.

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