Developing Computational Thinking via the Visual Programming Tool: Lego Education WeDo

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ABSTRACT

This study seeks to extend the existing research on the use of visual programming tools to work and develop computational thinking. We show the primary education students' perceptions of the use of the software Lego Education WeDo in the subject of natural sciences to promote the computational thinking. We tried to test the following hypotheses: Students will learn to build and program 3D models with Lego Education WeDo (H1), students will think creatively to solve the problems (H2), Lego Education WeDo will help pupils to know the relationship between cause and effect (H3), and the tasks developed will allow pupils to reflect about the possibilities they have and to find the correct answer (H4). Based on the result analysis there were evidences of the effectiveness of the project to increase the participants' awareness of the computational thinking. The research also concluded that according to learners' perception, the way in which activities were designed provided them possibilities to learn to build models in 3D and program them. Moreover, the findings of the study also demonstrated that the success of the project also depended on the teacher's role as a guide in the teaching-learning process.

CCS Concepts

• **Social and professional topics → Computing education → Computational thinking**

Keywords

Computational thinking; introductory programming; collaborative learning; visual programming tool; natural sciences.

1. INTRODUCTION

In the present society, technology occupies a relevant position, and this implies changes in curricula since ICT play an essential role in the way in which these curricula are implemented and taught [24].

As Butler-Kisber [4] points out there is a movement in many countries to create curricula in subject like science, technology, engineering and math (STEM) that allows our students to be prepared for the challenges of current and future society and its demands. That is one of the reasons why teaching practice must change [16], since ICT provide the resources that allow carrying out teaching-learning processes in a new way [20]. It is necessary to train students in what we can call digital language and in all the necessary skills to be part of the current digital world. They must acquire the necessary digital skills to function efficiently in this world. This includes the ability to program as a way to solve problems, and the computational thinking (CT) as working paradigm [23].

CT is a term coined by Wing [27] to describe the way in which a computational scientist thinks. She defines it as "a fundamental skill for everyone, not just for computer scientists (…). Computational thinking involves solving problems, designing systems, and understanding human behavior, by drawing on the concepts fundamental to computer science".

The Royal Society [25] also adds that the "computational thinking is the process of recognising aspects of computation in the world that surrounds us, and applying tools and techniques from Computer Science to understand and reason about both natural and artificial systems and processes." It is a complex and high-level competence linked to abstract mathematical thinking, and pragmatic-engineering thinking applied to different aspects of daily life.

As García-Peñalvo [11] points out the "computation thinking can be defined as the application of high level of abstraction and an algorithmic approach to solve any kind of problems" [12; 13; 14]. It is not just a synonym of the ability to program a computer since it requires a thinking that it is run in different levels of abstraction and is independent of technological devices [26]. It is a "problem-solving process that includes (but is not limited to) the following characteristics: formulating problems in a way that enables us to use a computer and other tools to help solve them; logically organizing and analysing data; representing data through abstractions such as models and simulations; automating solutions through algorithmic thinking (a series of ordered steps); identifying, analysing, and implementing possible solutions with the goal of achieving the most efficient and effective combination of steps and resources; generalizing and transferring this problem solving process to a wide variety of problems" [1]. Computational thinking includes abstract thinking, logical thinking, modeling thinking, and constructive thinking [10; 22].

There are different international, national and local initiatives as well as educational tools to develop the computational thinking. Almost all of them have the following points in common: the educational robotics, the visual programming tools (Scratch, Lego WeDo) and the video game programming [2; 9; 18; 21]. Our paper seeks to extend the existing research on the use of visual programming tools to work and develop computational thinking. In our research we have used Lego Education WeDo, a material designed by Lego Group in collaboration with Massachusetts Institute of Technology (MIT).

1. METHOD

The study focused on an innovative project of computational thinking, carried out in the state-funded school Santísima Trinidad in Salamanca, in the autonomous community of Castilla-León, in the academic year 2015-2016.

We selected this school because of its great experience, development, and recognition in educational innovation. It is considered a pioneer school in the use of technology in classroom, having the adequate technological resources, active innovative projects related to technology, and a teaching staff that have an appropriate training in technological resources.

The main objectives to be achieved in the Unit Forces and machines of the subject natural sciences were: 1. To understand the importance of machines, and classify them as simple and complex machines; 2. To list the most important simple machines and know how do they work; 3. To know the three types of lever; 4. To understand the contribution of technological progress to meeting people's needs; and 5. To become familiar with some mechanical movements.

In order to achieve these objectives and develop the computational thinking skills, the pupils were divided into groups. Each team was composed of three students: one of low level, one of intermediate level, and another one of advanced level. Each team had to build and program two 3D models of the visual programming tool Lego Education WeDo: Dancing Birds and Smart Spinner. The main and specific objectives of these two 3D models provided by LEGO Education WeDo Teacher's Guide are displayed in Table 1.

This study applied a quantitative approach [6, 8, 17], an ex-post-facto non-experimental design, [5]. Cooper & Schindler [7] points out that it is "a method of teasing out possible antecedents of events that have happened and cannot, therefore, be controlled engineered or manipulated by the investigator". The researchers only observe and then analyze the events as they occur in their natural context without manipulating the independent variables deliberately [19].

Table 1. Main and specific objectives of the 3D models

Dancing Birds
Main objective
To build and program two mechanical birds that make sounds and are motorized to dance using a pulley and belt drive system.
Specific objectives
Science
To trace the transmission of motion and transfer of energy through the machine.
To identify the pulleys and belt drive mechanism, and the effect changing the belt has on the direction and speed of the dancing

birds' movement.

Technology

To create a programmable model to demonstrate the knowledge and operation of digital tools and technological systems.

Engineering

To build and test the dancing birds' movement.

To modify the dancing behavior by changing the pulleys and belt to affect the speed and direction of motion.

Mathematics

To understand how the diameter of the pulleys affects the speed of the dancing birds' movement.

To compare the diameter and rotational speed as a ratio.

To understand and use numbers to represent the amount of time the motor is turned on in seconds and in tenths of seconds.

Smart Spinner

Main objective

To build and program a spinner mechanism that is motorized to spin a top and release it and that uses a motion sensor to turn off the motor when the top is released.

Specific objectives

Science

To trace the transmission of motion and transfer of energy through the machine.

To identify the gear mechanism and the effect of the gears on the length of time the top can spin.

Technology

To create a programmable model to demonstrate the knowledge and operation of digital tools and technological systems.

Engineering

To build and test the spinner movement.

To modify the spinning behavior by changing the gears to affect the speed of the top and the length of time it spins.

Mathematics

To understand how the number of teeth and diameter of the gears affect the speed of the movement.

To compare the ratio of the smaller and larger gears.

1.1 Objectives

The aim of the present study was to know students' perception about the use of the software Lego Education WeDo in the subject of natural sciences to promote the computational thinking.

We tried to test the following hypotheses:

H1. Students will learn to build and program 3D models with Lego WeDo.

H2. Students will think creatively to solve the problems.

H3. Lego WeDo will help pupils to know the relationship between cause and effect.

H4. The tasks developed will allow pupils to reflect about the possibilities they have, and to find the correct answer.

1.2 Participants

The sample in this study was composed of 52 Spanish pupils from the 4th grade of primary education at the state-funded school Santísima Trinidad in Salamanca. They were spread over two groups: A and B. 48.1% were boys (n=25) and 51.9% were girls (n=27). Of the 52 cases, 28 (53.8%) were 9, and 24 (46.2%) were 10 years old. All the participants studied the compulsory subject of natural sciences and all of them had knowledge of the use of computers, tablets and interactive whiteboard. The fifty-two pupils had participated in previous projects in which they had the opportunity to work with the visual programming tool: Scratch. Moreover, 34.6% (n=18) were enrolled in the Robotics workshop, and had experience in the use of the 3D modeling software, Sketch Up.

1.3 Variables and Instrument

To carry out the case study we used different instruments: an interview, observation, analysis of documents, a monitoring guide for the teacher, and a semantic differential for the pupils. However, in the present paper we have focused on the students' opinions collected in the

semantic differential and in the open questions asked to the pupils. This instrument was adapted from the research led by García-Valcárcel [15], and used to operationalize the variables and collect the data of the study. The final instrument contained 31 items that were divided into three parts: general details of the school, the pupils, and the project; the pupils' perception about the development of the project; and the pupils' perceptions about the strong and weak aspects of the project. The test was composed of different types of questions: open, close, short answer, and 7-point Likert scale.

We calculated the Cronbach's alpha to know the internal consistency of the test, obtaining an alpha coefficient of $\alpha=0.870$. This coefficient allowed us to infer that the items of the questionnaire had high internal consistency.

2.3.1. General Details of the Schools, the Pupils, and the Project

The first part of the questionnaire included general details about the school, the pupils, and the project. It contained 11 items: school, city, nationality, gender, age, educational level, subject, software, digital media, robotics workshop, and years enrolled in the robotics workshop. There were open and close questions.

2.3.2. Pupils' Perceptions about the Development of the Project

The second part of the test was about the pupils' perceptions about the development of the project. It was composed of 18 7-point Likert scale items. We used the semantic differential since it adapted to pupils' age.

2.3.3. Pupils' Perceptions about the Strong and Weak Aspects of the Project

The last part of the test referred to pupils' perceptions about the strong and weak aspects of the project. It included 3 items in which the participants were asked about the aspects of the tasks that they had liked more; the things they had liked least; and the problems they had had to carry out the activities developed in the project: Lego WeDo and the computational thinking. The three items were open questions.

1.4 Data Collection and Analysis

We collected the data in May 2016 when the project had finished. We coded the data and carried out the statistical analysis, using the program Statistical Package for the Social Sciences (SPPS) version 24.

We carried out the statistical analyses: descriptive statistics (frequencies and percentages), and inferential (the non-parametric test: Mann-Whitney U test).

2. RESULTS

We describe the results obtained in the descriptive and inferential analysis in the following subsections: Students' Perceptions about the Development of the Project, and Students' Perceptions about the Strong and Weak Aspects of the Project.

3.1. Students' Perceptions about the Development of the Project

In the following table (Table 2) we present the results of the 18 items of the semantic differential. We used a 7-point Likert scale in which 1 is the most negative answer, and 7 is the most positive one.

As it is shown in the results of the descriptive analysis the participants assessed very positively the project carried out about natural sciences and computational thinking.

The students considered that the project had been funny; they had loved this way of working; and wanted to learn more about the subject.

They emphasized that the teacher had explained clearly what they had to do; they considered that her help had been important; and emphasized her role as a guide, showing them what was right or wrong. The pupils also stated that the project had been useful and interesting; they had understood the activities, they had maximized time, they had learned more things than usual, and they had done them working in groups.

Regarding the items that referred to the computational thinking, we emphasized the positive results of the students' perceptions about the possibilities offered by Lego WeDo to build models in 3D and program them, as well as to learn to think creatively to make the 3D models, to reflect about the activities, to solve problems in a logical way, and to know the results of their decisions.

We calculated the Mann-Whitney U test to determine whether there were statistically significant differences (CI 95%) between boys and girls in their assessments of the items of the semantic differential. The data analysis indicated that there were statistically significant differences in the items that referred to:

- I have learned to program (item 15).
- The activities done with Lego WeDo have allowed us to reflect (item 18).
- I have learned to build models in 3D (item 24).
- The project has allowed us to solve problems in a logical way (item 26).
- I have learned to think creatively to make the 3D models (item 27)
- Lego WeDo has allowed us to know the results of our decisions (item 28).

Table 2. Semantic differential

It has been boring	6.77	It has been funny
I have lost time	6.17	I have maximized time
I have learned less things	6.52	I have learned more

than usual		things than usual
I have not learned to program	6.50	I have learned to program
It has not been interesting	6.63	It has been interesting
I have not understood what we have done	6.65	I have understood what we have done
The activities done with Lego WeDo have not allowed us to reflect	6.42	The activities done with Lego WeDo have allowed us to reflect
I am no longer interested in this topic	6.77	I want to learn more about this topic
It has been useless	6.69	It has been useful
I do not like this way of working	6.77	I love this way of working
The teacher has not helped us	5.88	The teacher has helped us
The teacher has not given us clear instructions	6.71	The teacher has explained clearly what we had to do
I have not learned to build models in 3D	6.31	I have learned to build models in 3D
We have not done the exercises well, working in group	6.46	We have done the activities well, working in group
The project has not allowed us to solve problems in a logical way	6.29	The project has allowed us to solve problems in a logical way
I have not learned to think creatively to make the 3D models.	6.37	I have learned to think creatively to make the 3D models
Lego WeDo has not allowed us to know the results of our decisions	6.38	Lego WeDo has allowed us to know the results of our decisions
The teacher has not indicated what was right or wrong in our work.	5.81	The teacher has indicated what was right or wrong in our work.

Regarding the results of the Mann-Whitney U Test (Table 3) of the items 'I have learned to program' and 'I have learned to build models in 3D', we point out that there were statistically significant differences between the mean of boys (item 15 $\bar{x}$=6.96; and item 24 $\bar{x}$=6.92) and girls (item 15 $\bar{x}$=6.07; and item 24 $\bar{x}$=5.74). The boys considered that they learned better how to build these 3D models and how to program them.

On the other hand, the results of that non-parametric test in the items that referred to 'the activities done with Lego WeDo have allowed us to reflect', 'the project has allowed us to solve problems in a logical way', 'I have learned to think creatively to make the 3D models', and 'Lego WeDo has allowed us to know the results of our decisions' showed that there were also statistically significant differences between the mean of boys (item 18 $\bar{x}$=5.88; item 26 $\bar{x}$=5.60; item 27 $\bar{x}$=5.72; and item 28 $\bar{x}$=5.76) and girls (item 18 $\bar{x}$=6.93; item 26 $\bar{x}$=6.93; item 27 $\bar{x}$=6.96; and item 28 $\bar{x}$=6.96). In these cases we emphasized that the girls assessed better all these items.

Table 3. Independent-Samples Mann-Whitney U Test

	Gender	Mean Rank	Sum of Ranks	Mann-Whitney U	Sig.	Z
item15	Boy	35.58	889.5	110.50	.000	-4.813
	Girl	18.09	488.5			
item18	Boy	14.42	360.5	639.50	.000	-6.228
	Girl	37.69	1017.5			

item24	Boy	39.04	976.0	24.000	.000	-6.465
	Girl	14.89	402.0			
item26	Boy	13.80	345.0	655.00	.000	-6.448
	Girl	38.26	1033.0			
item27	Boy	13.42	335.5	664.50	.000	-6.698
	Girl	38.61	1042.5			
Item28	Boy	13.98	349.5	650.50	.000	-6.472
	Girl	38.09	1028.5			

3.2. Students' Perceptions about the Strong and Weak Aspects of the Project

The majority of the pupils, 61.5% (n=32), stated they what they liked most about the activities developed in the project was the possibility that they had to build and program the models. Another 23.1% (n=12) considered that they could work as a team, sharing their ideas and working together. Finally, 15.4% (n=8) emphasized that this project allowed them to work playing. They believed that they learnt more than in a traditional class.
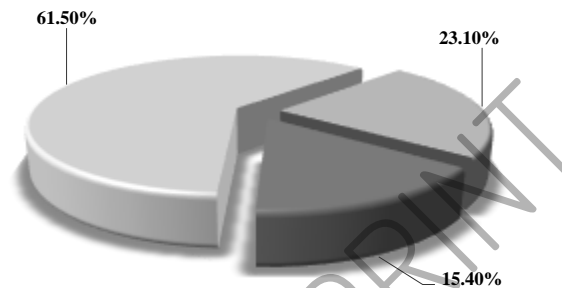

Figure 1. Students' Perceptions about the aspects they liked most

Regarding, the points that they like least, most of pupils, 46% (n=24), answered that nothing. On the other hand, 32.7% (n=17) pointed out that they did not have enough time to build and program the models, so they considered that they needed more practice to learn how to do it. 11.5% (n=6) also indicated that it was quite difficult to work as a team since they did not agree about the development of the activities or because some of the classmates wanted to do everything without taking into account their partners' opinions. 3 of the 52 cases (5.8%) stated that what they like least was the resources they had since they believed that they did not have enough tools, and it would be great to update them. Finally, just 3.8% (n=2) considered that the thing they liked least was to destroy what they had built.
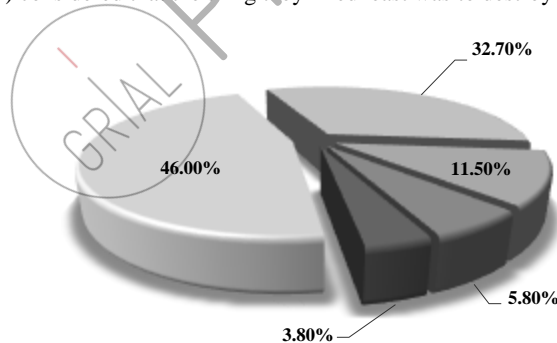

Figure 1. Students' Perceptions about the aspects they liked least

Pupils were also asked about the problems they had to build and program the working models. More than half of the pupils, 51.9% (n=27), indicated that they did not have problems. On the contrary, 15.4% (n=8) answered that they had problems to program the models and this demotivated them to carry on with the tasks. The pupils also answered that they had problems with the resources (13.5%, n=7) or to work as a team (11.5%, n=6). Just 7.7% (n=4) considered that they did not have enough time to finish.
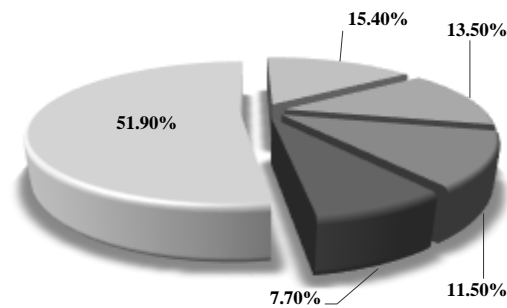
Figure 1. Students' Perceptions about the problems they had

3. CONCLUSIONS AND DISCUSSION

The results from the semantic differential suggested that the computational thinking project carried out in the subject natural sciences was effective to increase the participants' awareness of the computational thinking [28]. Specifically there were evidences of the possibilities offered to reflect and think creatively about the opportunities they had to fulfill the activities correctly, to know the results of their personal or group decisions, and to solve the problems in a logical way [3]. The research also concluded that according to learners' perception, the way in which activities were designed had provided them possibilities to learn to build models in 3D, and program them [20].

This study demonstrates that the students assessed very positively the teacher's role in the project. The research identified her role as a guide, explaining clearly what they had to do, and showing them what was right or wrong. The students concluded that her help had been fundamental for the success of the project [29].

This study provides evidence of the students' satisfaction towards the project, considering it useful and interesting [18]. The use of Lego Education WeDo have allowed them to understand better the activities, to work in groups, and to learn more things than usual. They showed great enthusiasm for the project, considering it a perfect way of learning which motivated them to learn more about the discipline of natural sciences.

To sum up, our study and its results have proved the potential of the software Lego Education WeDo in the subject of natural sciences to promote the computational thinking, and to engage primary education students in programming, and problem solving. It is important to promote this skill since it is essential in the current society and has to be developed in different subjects like science, technology, engineering and math (STEM).

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