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RESEARCH ARTICLE

The effect of programming on primary school students' mathematical and scientific understanding: educational use of mBot

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Abstract
This study highlights the importance of an educational design that includes robotics and programming through a visual programming language as a means to enable students to improve substantially their understanding of the elements of logic and mathematics. Gaining an understanding of computational concepts as well as a high degree of student participation and commitment emphasize the effectiveness of introducing robotics and visual programming based on active methodologies in primary education. Implementation of this design provides sixth-grade elementary education students with activities that integrate programming and robotics in sciences and mathematics; these practices allow students to understand coding, motion, engines, sequences and conditionals. A quasi-experimental design, descriptive analysis and participant observation were applied across various dimensions to 93 sixth-grade students in four primary education schools. Programming and robotics were integrated in one didactic unit of mathematics and another in sciences. Statistically significant improvements were achieved in the understanding of mathematical concepts and in the acquisition of computational concepts, based on an active pedagogical practice that instills motivation, enthusiasm, commitment, fun and interest in the content studied.

Keywords Computational thinking · Elementary education · Programming and programming languages · Robotics · Teaching/learning strategies

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Introduction

Block visual programming environments allow us to experiment, share and create particular products with code. Computational models and methods enable us to solve problems and design systems that humans could not do alone; coding literacy at its base level can also help students build transferable skills (Freeman et al. 2017). Programming and robotics are used to support learning in schools, especially in the subjects of science, technology, engineering, mathematics and informatics (Kimet al. 2015; Kucuk and Sisman 2017). Programming highlights the advantages of logical thinking, mathematics and creativity.

Teaching approaches such as project-based learning, problem-based learning and collaborative learning strategies can be applied to allow greater autonomy and active learning experiences, in order to promote uncertainty and active methodologies centred on the student (Grant 2011; Mergendoller et al. 2006; Weng-yi Cheng et al. 2008). Based on these student-centered learning strategies, computational thinking can be applied from a logical analysis of data, abstractions and problem solving. All of these practices in an educational context allow students to develop skills to solve complex problems (Johnson et al. 2014). Recent years have seen a growing interest in developing problems, applications and games oriented towards learning to program, due to the many advantages and possibilities they offer, as well as the opportunities they provide in the present and future world of work.

Pedagogical design and computational thinking

The pedagogical model applied is one based on the theory of meaningful learning (Ausubel 1978), highlighting the essential importance of social interactions in learning environments from the perspective of sociocultural theories and constructivism (Vygotsky 1978). Constructivism is a child-centered theory of education in which the child actively processes meaning and learning, proceeds at his/her own pace without deliberate instruction or a prescribed curriculum.

Papert (1980) developed the constructionist theory of learning which demonstrates that learning occurs when learners are engaged in the creation of meaningful artifacts that can be probed and shared. The constructionist theory holds that when children work with materials that allow them to design and construct meaningful artifacts, they learn better (Rogers and Portsmore 2004). Knowledge is built in the mind through learning, with the use of specific tools such as robots and computers; this approach is in opposition to the traditional method of instruction in which students remain passive. Papert's theory can be summarized in his vision of a new educational environment in which learners build meaningful knowledge artifacts (Parmaxi and Zaphiris 2014, p. 452).

From these essential foundations, some authors proposed a methodological strategy centered on project-based learning (Jonassen 1977), with educational activities oriented to solving problems in real contexts with learning opportunities. This approach is based on inquiry, to ensure that learning occurs when the subject actively discovers and resolves situations. According to these fundamentals, learning-by-doing involves an active approach to teaching and learning as the student seeks to acquire knowledge and skills through the educational process.

These approaches encourage the development of activities that involve skills and logical thinking. Computational thinking is defined as problem solving, system design and the understanding of human behavior achieved by applying the fundamental concepts of computing (Wing 2006, p. 33). The International Society of Technology in Education and the Computer Teachers Association (2011) both define computational thinking as: the formulation of problems in a way that allows us to use a computer and other tools to help solve them; the organization and logical analysis of the data; the representation of the data through abstractions such as models and simulations; the automation of solutions through algorithmic thinking (a series of ordered steps); the identification, analysis and implementation of possible solutions with the objective of achieving the most efficient and effective combination of measures and resources; and, the generalization and transfer of this problem-solving process to a wide variety of problems.

Computational thinking is based on processes, computational methods and models that enable the solving of problems and design of systems that we cannot do alone. Therefore, it is a matter of using a computer to solve a series of tasks through problem representation, prediction and abstraction (Kafai and Burke 2014; Sengupta et al. 2013). In this regard, we ask some questions: why is it important to teach computational thinking in elementary school? What is it about the world today that requires people who are computational thinkers? Why is computational thinking such a valuable skill?

The importance of teaching computational thinking skills from an early age is a key element that has captured the attention of researchers (Fletcher and Lu 2009). Programming is not only a fundamental skill of computational science and a key tool to support the cognitive tasks involved in computational thinking, but also a demonstration of computational competencies (Grover and Pea 2013). These practices can be a great advantage when integrated into pedagogical activities to improve skills in logic, mathematics, problem solving and critical thinking.

Some studies have focused on computing and computational thinking in primary education (Han et al. 2016; Maya et al. 2015; Sáez-López et al. 2016), and there is growing evidence to support the integration of computer science into education. Sengupta et al. (2013) highlight the significant advantages in acquiring an understanding of scientific, mathematical and computational concepts. Several researchers have emphasized positive computer-related outcomes (Calder 2010; Chiang and Qin 2018). Lambert and Guiffre 2009; Lin et al. 2005) and the acquisition of skills related to computer concepts (Baytak and Land 2011; Kwon et al. 2012). Teachers have provided positive feedback on Scratch due to its usability and accessibility (Clark et al. 2013; Lee 2011; Maya et al. 2015).

In these contexts, visual programming can be used to solve problems, and it enables coding to be taught in primary schools. When students manipulate pieces in order to fit them together, this visual block system avoids the compiler error messages that commonly appear in textual languages. Coding with such applications is easier than using traditional programming languages because students can play and interact with colored blocks to create scripts. One of the most popular applications for block programming language is Scratch, created by the Lifelong Kindergarten group of the MIT Media Lab. Scratch has blocks in eight different categories: motion, look, sound, control, sensing, operators and variables. mBot provides the application mBlock, a variant adapted to Scratch 2.0 and which includes an extra category called 'robots'.

Programmable educational robots

Papert (1980) suggests that at the same time children actively construct their intellect, they also construct their meta-cognitive skills. When students master the use of computers, they transfer their learning to real-life situations, especially to problem solving. Rusk et al. (2008) define robotics as programmable devices that perform actions depending on sensor inputs. Programming can be defined as providing the solution to a specific problem, in which the problem must first be understood and analyzed; eventually, the algorithm of the solution is translated into code (Oddie et al. 2010).

Robots can be used as a resource for programming. Students can probe complex concepts by editing codes and manipulating robots. Robots used in the teaching of programming can provide interesting opportunities and authentic practice situations with immediate feedback. Empirical evidence suggests the effectiveness of robotics as a learning complementary tool (Mazzoni and Benvenuti 2015; Spolaôr and Vavassori-Benitti 2017) also with elementary students (Chen et al. 2017; Kucuk and Sisman 2017). These resources fulfill a supportive role in classroom learning that encourage motivation, good impressions, positive attitudes (Lin et al. 2005) and can even improve student performance (Kanda et al. 2004).

Rogers and Portsmore (2004) introduced a curriculum for robotics lessons that first taught students to be curious and creative, and then made the means and engineering skills available to them to enable them to satisfy their own curiosity. They noted that, in addition to being exciting, robots make it possible for students to create products and test them immediately, which engenders collaborative, creative and authentic learning experiences (Skelton et al. 2010). On the other hand, in terms of academic qualifications, robotics have not been found to statistically improve student outcomes (Fagin and Merkle 2003).

A series of educational resources and robots can be programmed and manipulated through block visual programming (Tickle, Blocky, Scratch, M block…), and can facilitate easy experimentation in primary education settings due to the intuitive nature of this type of programming (Table 1). Examples of educational robots that use this type of visual programming are:

- Dash and dot: this pair of robots teaches young children the basics of programming on the iPhone, iPad and on some Android devices (https://www.makewonder.com/dash). Students program robots using the Blockly language.
- Ozobots is an interesting option for robotic programming in class (http://ozobot.com/). This robot has a unique way of being programmed that makes it easy to use.
- Sphero SPRK and BB8 are excellent resources for any type of coding (http://www.sphero.com/sphero-sprk). These small robots are programmable and can be used or combined with applications such as Tickle.

Table 1 Applications and robots sequenced in early childhood and primary education

Application		Primary school					
		1st	2nd	3rd	4th	5th	6th
Dash and dot	https://www.makewonder.com/dash						
Ozobot	http://ozobot.com						
Sphero SPRK	http://www.sphero.com/sphero-sprk						
mBot	http://www.makeblock.cc/mbot/						

mBot robot: application in primary school

Here are some examples of the mBot, which focuses on primary education and a visual block programming, with an adapted version of Scratch 2.0 (mBlock).

This resource is relatively inexpensive and very attractive. The mBot robot (http://www.makeblock.cc/mbot/) has a great advantage in that you can work with an intuitive visual language with the 'mBlock' app (version 3.2.2.) that is adapted or similar to Scratch 2.0. With these resources, students find it easy to experiment with it, and it is suitable for use by students of levels 3 and 4 of primary education onwards. It is an ideal introduction to robotics, programming and electronics based on Arduino UNO (Fig. 1).

The mBot consists of an Arduino board (see Fig. 1), so all the materials, resources and advantages of working with this board are actively in use when working with this robot. Its resources include:

- Brightness sensor
- Proximity sensor
- Sensor that follows lines
- 2 RGB LEDs with choice of color
- Allows user to play musical notes (buzzer)
- A button on the plate

These resources have advantages when it comes to technological integration in educational contexts, allowing the development of computational thinking, digital competence, logical thinking and problem solving. In terms of curricula, the International Association of Technologies in Education (ISTE) standards can readily be applied. Some of these standards relate directly to the practices and activities proposed:

6.a To understand and use technological systems.
6.b To solve systems and applications.
6.c To transfer current knowledge for the learning of new technologies.

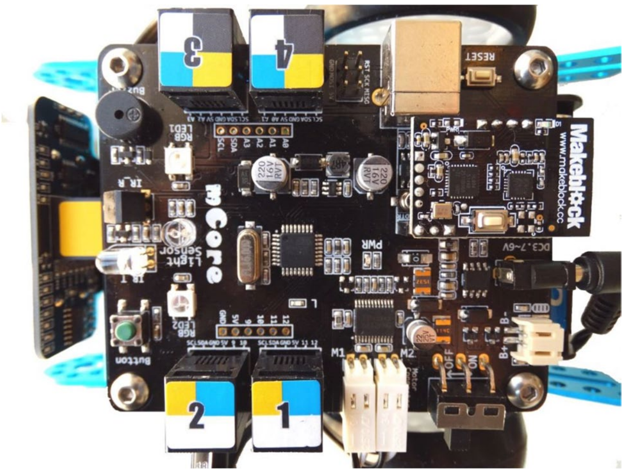


Fig. 1 mBot, Arduino board details

The general perspective of these standards can be of interest and add value to overall planning. In addition, and specifying different elements, we can distinguish between algorithms, loops and events in the stages of primary education. Some standards (CSTA K-12 Computer Science Standards) that can be applicable to primary education are:

- CT.L2-06—Describing and analyzing a sequence following instructions (algorithm or sequence).
- CPP.L1: 6-06—Implementing solutions to problems using a block-based visual programming language.
- CT.L2-01—Using basic steps in solving an algorithmic problem in order to design solutions.

In short, research affirms that there are advantages to these approaches for science, technology, engineering and mathematics, as they enable the acquisition of the basic knowledge and skills considered important for success in today's society, through effective communication, use of critical thinking skills, problem solving and digital competence.

Aims

The main objective of this study is to analyze the potential of visual block programming and robotics for use in primary education. The specific objectives are:

- To evaluate activities with programming and robotics, checking their effectiveness when integrated into science and math.
- To evaluate the acquisition of basic computational concepts through visual block programming in primary education.
- To analyze motivation, commitment, participation, critical thinking and problem solving on the integration of programming and robotics into pedagogical practice.
- In line with these aims, the specific research questions of this study are the following:
- Are there significant improvements in students' academic results in math with the application of programming and robotics?
- Are there significant improvements in students' academic results in science with the application of programming and robotics?
- Are there improvements related to computational concepts with the application of programming and robotics?
- Do programming and robotics enable active methods, motivation, critical thinking skills and problem solving?

Method

This research process focused on the application of complementary methods that contribute to the understanding of the interactions taking place in the learning processes. The research is conducted in the natural setting. Mixed and complementary methods were applied on the basis of quantitative and qualitative data and instruments (Table 2). In dimension 1, a quasi-experimental design was applied that analyzed data through the Student's t test, assessing the results of exams in mathematics and sciences. In dimension 2, the results

Table 2 Dimensions, indicators and instruments

Dimensions	Indicators	Instruments
1. Robotics and programming in sciences and mathematics	Whole numbers Coordinates Negative numbers Electronic devices Motors and electricity Circuits	Tests: math and science Quasi-experimental design - Pretest-post-test - Control group-experimental group Student's *t* test Descriptive analysis
2. Computational concepts and practices	Sequence Iteration (looping) Conditional statements Threads (parallel execution) Event handling Robot programming	Participant observation - Scale of estimation Descriptive analysis Mann–Whitney *U* test
3. Robotics and interactions in classroom	Active methods Motivation Critical thinking skills Problem solving Interest in the subject Participation Encouragement Fun	Data triangulation Participant observation - Scale of estimation

obtained from a scale of estimation after participant observation were compared to the control group (Mann–Whitney *U* test) from data and categorical variables, in order to analyze improvements in the acquisition of computational concepts. Dimension 3 detailed information and data obtained through participant observation in the intervention. The use of participant observation in dimensions 2 and 3 facilitated an assessment based on a naturalistic evaluation model approach, which is carried out with the collaboration of the participating students and teachers (Guba and Lincoln 1981). Iterative cycles of testing and refinement of solutions in practice are related to dimensions, indicators and instruments (Table 2).

The proposed evaluation combines methods of qualitative and quantitative assessment, and participant observation (Fig. 2). The triangulation of data ensures that there is evidence to support the validity of the results and minimum error variance (Goetz and LeCompte 1988). The triangulation of data by Cohen et al. (2000) was implemented using quantitative information collected in tests.

Participants

The study sample consisted of 93 sixth-grade students in primary education attending four educational centers in Spain, two in the Community of Madrid and two in the autonomous region of Castilla–La Mancha. The population is somewhat higher than the 50,000 students (36,973 + 16,828) who are sixth-grade students at public schools in both regions. The sample is non-probabilistic and intentional, so we opted for a quasi-experimental design. Regarding the gender of the experimental group, 45.2% were female and 54.8% male. There was an experimental mortality of 16 students. For dimensions 1 and 2, there was a control group of 36 students from two classes in the Madrid region, of which 47.2% were female and 52.8% were male. The experimental and control group worked on the same

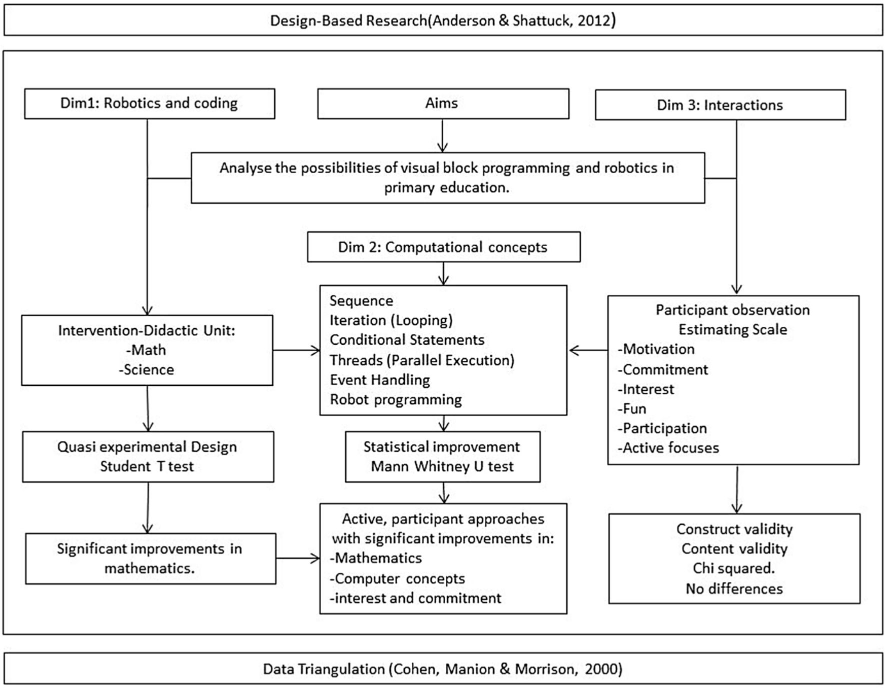


Fig. 2 Research design, elements and structure

unit and learning program, there were differences regarding learning resources (described in this study). Control group worked mainly with textbook, lecturing and notebooks. The students in the experimental group and control group worked the exact same contents and they did the same exams/test, the only difference was the technological resources in the experimental group.

According to data from the contingency analysis, Pearson's Chi square test showed there were no significant differences with regard to gender, nor for the educational centers in the different variables analyzed. The sample size and the Kolmogorov–Smirnov test values meant that normality was assumed.

Application or intervention

We detail a series of activities and practices that were integrated into the curricular area of mathematics (didactic unit 3, 'whole numbers'), and in natural sciences (unit 8, 'electricity and magnetism'). In both the math and science, we integrated the elements of motion and ultrasonic sensor, as well as providing a curricular proposal. We apply this intervention in the experimental group.

Motion

The first example observed in Fig. 3 shows the blocks that give orders to the robot's engines. The speed can be 50 (slow), 100 (intermediate) or 255 (fast). The example sets

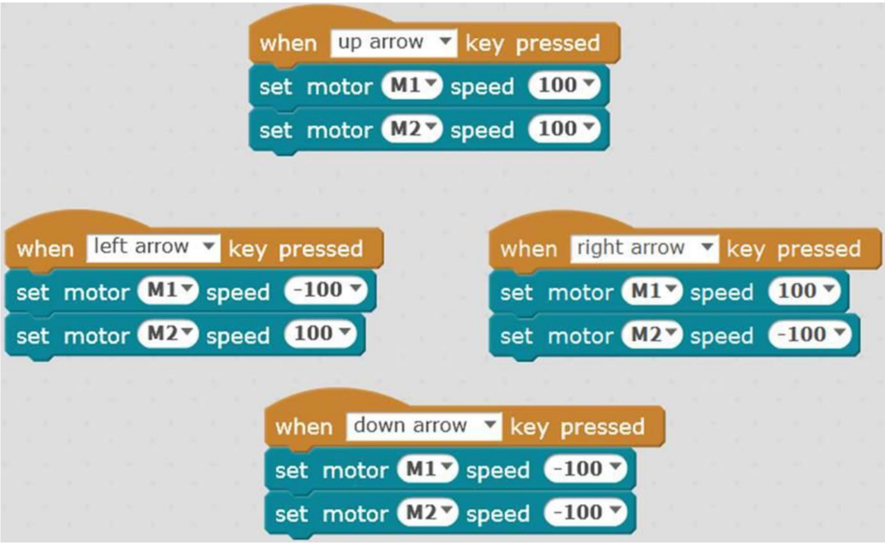


Fig. 3 Blocks for mBot engines

the speed at 100. Four events are set in motion by pressing the arrow on the keyboard up, down, left and right (Fig. 3).

By pressing the 'up' arrow, both engines spin the wheels forward (100), and by pressing the 'down' arrow, both motors turn in the opposite direction (− 100). By pressing the left arrow, motor 1 (M1) to the left of the robot rotates the wheel backwards (− 100) while the right wheel in motor 2 (M2) rotates forward (100). On the other hand, by pressing the right arrow on the keyboard, motor 1 (M1) to the left of the robot rotates the wheel forward (100) while the right wheel on motor 2 (M2) rotates backwards (− 100).

In this way, the robot is perfectly controlled by the arrows on the computer keyboard. Users have to take into account the speed, for if we change 100 for 255 in all squares, the robot will go faster, while reducing it to 50 will obviously slow down all its movements. The robot's mode of rotation is entirely on itself as both wheels rotate simultaneously. The activity enables problem solving, encouragement and fun; students were interested in the response of the robot, so they showed motivation, interest and active participation.

Ultrasonic sensor

It is necessary to understand how block programming functions in order to enable the mBot to avoid obstacles by means of the ultrasonic distance sensor. The device can be programmed into the activity so that when the space bar is pressed, the robot advances. On the other hand, if the ultrasonic sensor detects that it is near an obstacle (less than 10 cm), the robot can be maneuvered to avoid contact. When you release the space bar, the robot stops (Figs. 4, 5).

In short, these activities are planned for sixth-grade primary education students and integrated transversally in sciences and mathematics; they allow students to understand the codes that move the robot through the engines. This also helps them understand the

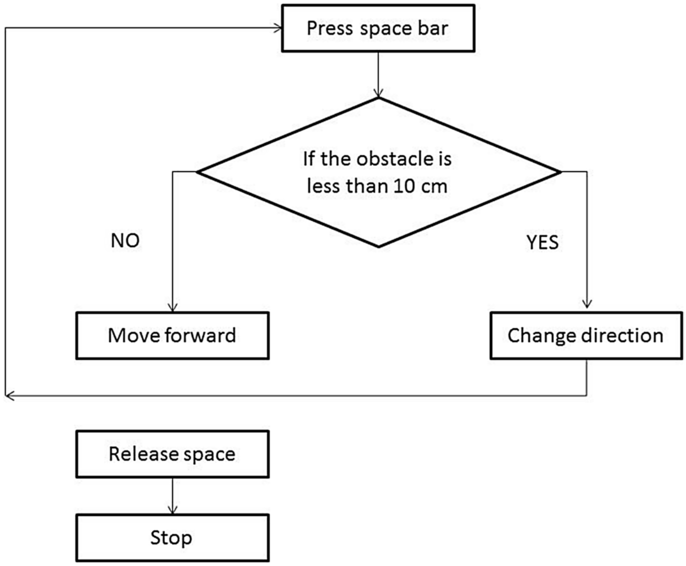


Fig. 4 Process and structure. Ultrasonic sensor

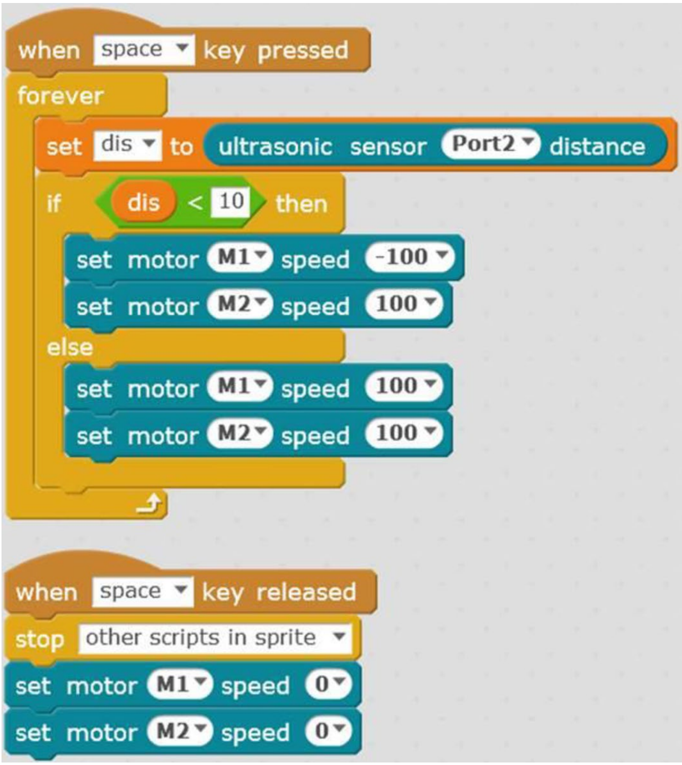


Fig. 5 mBlock details. Code to rotate when an object is detected

creation of a variable that depends on the distance registered by the ultrasonic sensor, and makes the robot rotate if there is an obstacle nearby; it works through a conditional. It facilitates the understanding of integers by inserting a loop that allows the instructions to work at all times when the key is pressed.

These programming concepts, sequences, loops and conditionals allowed students to develop competencies related to mathematics, science and technology, fostering an interdisciplinary approach. Students were interested in the response of the sensor, showing motivation, interest and encouragement in all the process.

A curricular proposal

Starting from the theoretical references of the ISTE and CSTA K-12 (Computer Science) standards, the main context and design relates to the Spanish educational system, within the regulatory framework of the Organic Law for the improvement of educational quality (LOMCE) 2013. As the competences for education in Spain are decentralized across the various autonomous communities, each community can develop and approve its own curricula. As an example, we highlight the curriculum authorized in Castilla–La Mancha, Decree 54/2014, 10/07/2014, for primary education students in that autonomous community.

According to the different curricular areas, there are blocks of content, evaluation criteria and learning standards that act as reference points in the evaluation process. The content and practices related to programming and computational thinking can be integrated in an interdisciplinary way, more coherently in natural sciences and mathematics through project methods or in didactic units. Some examples are indicated for the sixth grade (Decree 54/2014):

Natural sciences:

- CN1.4.1. They make adequate use of information and communication technologies as a leisure resource.
- CN5.1. They identify the sources of energy with which the machines operate.
- CN5.3.1. They use simple resources provided by information technologies to communicate and collaborate.

Mathematics:

- MA1.9.3. Resolution of challenges and problems with the precision, care and interest appropriate to the educational level and the difficulty of the situation.
- MA1.10.1. Decision making in problem-solving processes by assessing the consequences of problems and their suitability, for the simplicity and utility of the tools.
- MA1.12.1. Use of simple technological tools for performing numerical calculations, for learning and solving problems.
- MA2.2.4. Use of negative numbers in real contexts.

In short, it is a question of providing a design in which mathematical- and science-related content is integrated in line with an interdisciplinary perspective, with the aim of gaining the advantages that arise from manipulation and experimentation in these types of activities; such benefits include developing logical thinking, in algorithms, sequences and different computational concepts. The advantages deriving from motivation, enthusiasm, commitment and fun greatly benefit the student and are clear to see in the approaches that focus on the active teaching of coding and experimenting with educational robots.

Instruments and reliability

Mixed methods are applied by using a variety of tools and techniques in interventions in different dimensions: 'It is perfectly logical for researchers to select and use different methods, selecting them as they see the need, applying their findings to a reality that is both plural and unknown' (Maxcy 2003, p. 59). The intervention, or fieldwork, in this study was developed in academic year 2016–2017. The students belonging to the experimental group worked on a didactic unit in mathematics and another in sciences, in which programming and robotics were integrated in the content and activities, including managing the mBot.

The first dimension measured the results of the math test (unit 3) and the science test (unit 8) through a quasi-experimental method. The construct validity was tested by exploratory factor analysis, using the criterion of extraction of eigenvalues > 1 and the varimax rotation method. Exploratory factor analysis is a statistical technique that is used to reduce data to a smaller set of summary variables and to explore the underlying theoretical structure of the phenomena. It is a method of data reduction which infers presence of latent factors which are responsible for the shared variance in a set of observed items. It is exploratory because the user does not specify a structure, and assumes each item could be related to each latent factor. Varimax rotation is used to simplify the column of the factor matrix so that the factor extracts are clearly associated and there should be some separation among the variables. In addition, a Cronbach's alpha value of 7.18 gave an acceptable level of reliability (Hair et al. 1998). Cronbach's alpha is a measure of internal consistency, which is considered to be a measure of scale reliability.

The second dimension analyzed the values obtained from an estimation scale derived from the participant observation technique; the 24 items were organized for sequence, iteration, conditional statements, parallel execution, event handling and robot programming. We analyzed the learning processes and the work with computational concepts in the intervention. This type of research aims to describe the individual experience in particular environments. Due to the presence of ordinal data in dimension 2, we opted to apply a non-parametric test (Mann–Whitney U). The qualitative validation of the content by seven experts provided an Aiken V value ($V = S/[n(c-1)]$) greater than 0.7 in all items. Content validity refers to the extent to which a measure represents all facets of a given social construct. The generally accepted quantitative index for content is the Aiken's V index. This index will be used to quantify the ratings of panel experts constituted for evaluating the items in the instrument (Aiken 1980). Therefore, the relevance and adequacy of the instrument in the qualitative validation were deemed acceptable. The construct validity was examined by exploratory factor analysis, taking the extraction value of eigenvalues > 1 and the varimax rotation method. The Cronbach's alpha value of 7.31 certified its reliability.

In the third dimension, participant observation consisted of obtaining data on an estimation scale from the fieldwork. Here the emphasis was on a methodological and data triangulation on data and techniques in the three dimensions, thereby obtaining data from different sources, techniques and instruments to strengthen validity. It is advisable to use more than one method in order to improve the validation process.

Results

Dimension 1: robotics and programming in sciences and mathematics

Dimension 1 applied a quasi-experimental design in which the means were compared using a Student's *t*-test, through statistical inference. Differences in the pretest and posttest were analyzed with a paired sample test. We also analyzed differences between the control and experimental groups.

The results from the Student's *t*-test showed significant improvements in the math test results, demonstrating that the program implemented improved students' ability to understand coordinates, integers and negative numbers. The posttest values provided the data once the intervention was complete, and they revealed the statistically significant differences previously mentioned (0.000) at a significance level of 99% between paired samples (Table 3). The values for the unit 3 mathematics test on 'whole numbers' underlined the advantage of an educational design that includes visual programming language and robotics in order to understand mathematical elements.

As for the comparison of means between the control group and the experimental group, the mean in the math test seems to improve appreciably (7.45), while in the science test it remains close to 6.7 points, with no apparent differences (Table 4).

Comparing the control group and the experimental group, we verified the homogeneity of variances through Levene's test, assuming homoscedasticity in the math test (0.899), although it was not assumed in the science test according Levene (Table 5).

From these values, the *p* value was checked in the math test with a significance of (0.00) at a significance level of 99% (Table 5). Therefore, the research hypothesis is confirmed and the null hypothesis rejected; there are statistically significant improvements

Table 3 Paired differences

	Mean	Std. Deviation	Std. Error Mean	Upper α = 99%	Lower α = 99%	T	df	Sig
Math: pretest–posttest	− 1.204	1.315	.136	− 1.563	− .846	− 8.831	92	**.000**
Science: pretest–posttest	− .129	1.689	.175	− .590	.332	− .737	92	.463

Related samples. Student's *t* test

Table 4 Group statistics

	N	Mean	SD	SE mean
Math: posttest				
Experimental group	93	7.45	1.256	.130
Control group	36	6.39	1.225	.204
Science: posttest				
Experimental group	93	6.77	1.360	.141
Control group	36	6.69	.980	.163

Control and experimental group

Table 5 Paired samples

	Levene's test for equality of variances		*t*-test for equality of means		
	F	Sig.	t	Df	Sig. (2-tailed)
Math: posttest					
Equal variances assumed	.016	.899	4.341	127	**.000**
Science: posttest					
Equal variances not assumed	5.607	.019	.369	88.017	.713

Student's *t* test. Independent sample testing

in the curricular area of mathematics in the elements measured in this quasi-experimental design. Therefore, it can be highlighted that there is an improvement in mathematics when using these resources and activities.

In the results of the science test, the statistical values show that there is no significant improvement in this curricular area whose content addressed electronic devices, motors, electricity and circuits. Statistically significant improvements were not observed in the pretest and posttest, with a value of 0.463 (Table 3), nor in the comparison of means in the control and experimental groups, with a significance of 0.713 (Table 5). In short, the null hypothesis is accepted; there are no statistically significant improvements in the sciences. Therefore, it can be highlighted that there is not an improvement in sciences when using these resources and activities.

Dimension 2: computational concepts and practices

In dimension 2, we detailed the computational concepts integrated in the intervention. The values that the frequencies contributed from the scores of the estimation scale are highly positive in all the units of analysis, especially in robot programming, since more than 60% of the evaluations are good or excellent (2.6). There were also very positive results in the work involving sequences and conditionals (2.1 and 2.3), with values superior to 50% that amounted to good or excellent. Loops and parallel execution have positive, but more modest values (2.2 and 2.5).

It is worth noting that there were statistically significant improvements in the integration of computational concepts in the unit applied. There was an improvement over the control group in the understanding of sequences, loops, conditionals, parallel execution, events and robotic use, as shown by the Mann–Whitney *U* test (Fig. 6 and Tables 6, 7 and 8). Therefore, an improvement in the computational concepts is perceived when using these resources.

Dimension 3, 'robotics and interactions in the classroom' (Table 6 and Fig. 7), assessed elements related to participation, interactions and learning processes. Values above 60% were obtained, and deemed to be 'good' or 'excellent', which was particularly positive with regard to the elements of fun, commitment, participation, interest and motivation for the students participating in the intervention (3.5, 3.6, 3.7 and 3.8). With valuations close to 55%, the application of active teaching–learning methods and problem solving (3.1 and 3.4) were outstanding. Critical thinking skills showed positive but modest values (3.3).

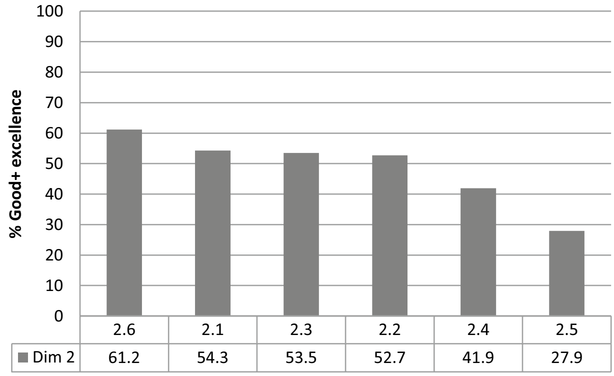


Fig. 6 Dimension 2. Computational concepts. Percentage (good + excellence)

Table 6 Dimension 2 scales

Items	%					Mann–Whitney *U*
	1	2	3	4	5	
Dimension 2: computational concepts						
2.1. Sequence	3.9	15.5	26.4	34.9	19.4	0.00*
2.2. Iteration (looping)	2.3	20.9	24.0	39.5	13.2	0.00*
2.3. Conditional statements	7.0	13.2	26.4	42.6	10.9	0.00*
2.4. Parallel execution	3.9	20.9	33.3	29.5	12.4	0.00*
2.5. Event handling	9.3	28.7	34.1	27.1	0.80	0.00*
2.6. Robot programming	10.9	14.7	13.2	40.3	20.9	0.00*
Dimension 3: participation and interactions						
3.1. Active methods	4.7	12.4	29.5	45.7	7.80	
3.2. Motivation	7.8	9.30	19.4	25.6	38.0	
3.3. Critical thinking skills	2.3	18.6	49.6	26.4	3.10	
3.4. Problem solving	0.8	2.30	39.5	51.2	6.20	
3.5. Interest in the subject	3.1	8.50	17.8	33.3	37.2	
3.6. Participation	2.3	9.30	14.0	31.0	43.3	
3.7. Encouragement	0.8	14.0	9.3	31.0	45.0	
3.8. Fun	0.0	11.6	10.1	29.5	48.8	

Participant observation values. Scale of estimation (1 = poor, 2 = passed, 3 = acceptable, 4 = good, 5 = excellence)

*$p < .01$

Conclusions and discussion

In this case study we have analyzed 93 primary school students as they worked on content in mathematics and sciences with robotics and a visual block programming language. Using various techniques and instruments of analysis, we have detailed the implementation of programming and robotics, and emphasized the benefits acquired in mathematics, computational concepts and interactions in the classroom. From the analysis of the data, this research concludes:

Table 7 Ranks according to Mann–Whitney *U* test

Experimental group-control group	N	Mean rank	Sum of ranks
2.1. Sequence			
Experimental group	93	79.49	7393.00
Control group	36	27.56	992.00
Total	129		
2.2. Iteration (looping)			
Experimental group	93	80.38	7475.00
Control group	36	25.28	910.00
Total	129		
2.3. Conditional statements			
Experimental group	93	80.68	7503.50
Control group	36	24.49	881.50
Total	129		
2.4. Parallel execution			
Experimental group	93	81.29	7560.00
Control group	36	22.92	825.00
Total	129		
2.5. Event handling			
Experimental group	93	79.16	7361.50
Control group	36	28.43	1023.50
Total	129		
2.6. Robot programming			
Experimental group	93	82.58	7680.00
Control group	36	19.58	705.00
Total	129		

1. There were statistically significant improvements in the mathematics curriculum area with the integration of programming and robotics. On the other hand, there were no statistically significant improvements in sciences (Dimension 1, Student's *t*-test, Tables 3, 4, 5).
2. Particularly positive results were obtained in robot programming, working with sequences and conditionals (Dimension 2, Table 6 and Fig. 6).
3. The work on computational concepts when programming improved significantly with the implementation of the unit. There were statistically significant improvements in sequences, loops, conditionals, parallels, events and robotics (Dimension 2, Tables 6, 7, 8).
4. In these practices, motivation, commitment, fun, participation and interest in the subject matter increased (Dimension 3, Table 6 and Fig. 7).
5. Active methods and problem solving were considered to have had a significant presence in the intervention. The use of critical thinking skills showed positive, but more modest, results (Dimension 3, Table 6 and Fig. 7).

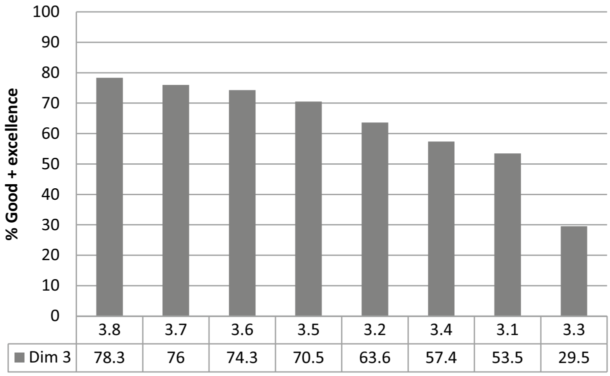
This study clearly demonstrates that there can be an improvement in understanding computational concepts, working with robotics and in performance in mathematics when using approaches that focus on active methods, and where students actively participate and

Table 8 Contrast of statistics

	2.1. Sequence	2.2. Iteration (looping)	2.3. Conditional statements	2.4. Parallel execution	2.5. Event handling	2.6. Robot programming
Mann–Whitney U	326.000	244.000	215.500	159.000	357.500	39.000
Z	−7.347	−7.859	−8.071	−8.265	− 7.223	− 8.957
Asymp. sig (2-tailed)	.000	.000	.000	.000	.000	.000

Grouping variable: control group-experimental group

Fig. 7 Dimension 3. Participation and interactions. Percentage (good + excellence)



show motivation, commitment, interest and have fun while involved in the process. These conclusions lead us to recommend that the educational authorities include robotics and programming in the educational context of sixth-grade students in the area of mathematics. The motivation, fun, commitment and enthusiasm showed by the students through this pedagogical approach indicate the relevance and adequacy of the practices detailed here. Students are totally in favor of this pedagogical design, which highlights the usefulness of, and active learning provided by, this approach. This research coincides with recent studies regarding the benefits of robotics and programming in elementary education (Chen et al. 2017; Kucuk and Sisman 2017; Mazzoni and Benvenuti 2015; Spolaôr and Vavassori-Benitti 2017).

The review of the literature shows several studies that promoted the inclusion of programming and robotics in schools, describing their benefits in terms of motivation, commitment and problem solving. Research also reveals problems in implementing robotics and programming in schools, as their application in the area of sciences in this present investigation has shown. Future research should analyze these obstacles, which could be related to attitudes, teacher training or logistical problems in the schools.

Similar works and earlier studies (Maya et al. 2015; Sáez-López et al. 2016) focused on the advantages of coding in primary school, highlighting benefits related to problem solving (Kafai and Burke 2014), science (Sengupta et al. 2013) and computer concepts (Baytak and Land 2011; Kwon et al. 2012). This research coincides with Oddie et al. (2010) on the advantages of programming robots in educational environments. We also agree with other researchers (Kanda et al. 2004; Rogers and Portsmore 2004) regarding significant improvements in students' performance, as we have detailed in dimensions 1 and 2. In line with previous research in this field, the contribution of this study is that we have confirmed the pedagogical advantages of applying programming and coding using robots in primary schools, especially in math. These activities enabled students to learn about computational concepts from an active learning perspective. This type of intervention was motivational and fun for the students, who felt encouraged and actively participated in solving the problems presented to them.

This research coincides with Ishii et al. (2007), whose findings showed a significant increase in the ability of students to construct computational algorithms. We also agree with Barak and Zadok (2009) who cite the benefits of robotics in science and technology, and in the acquisition of problem-solving skills. This research provides further implications for practitioners and educational designers; they should consider integrating programming and robotics in curricula. There are many advantages to teaching computational concepts, coordinates, values and integer numbers as motivation for the student to learn how to operate the robot. The immediate feedback and response of the robot when operating with numbers is a powerful and highly motivational tool for students.

There are also implications to researchers working in the field of instructional technology, who should consider the integration of coding and robotics in k-12 case studies, starting from basic computational concepts such as sequences and loops, and progressing to work with intuitive robots such as Bee bot, Ozobot and mBot from the fifth grade in primary school. From the aforementioned studies and the results of the present investigation, we recommend the integration of robotics in the pedagogical design for primary education. We believe it is essential to integrate robotics with visual block programs such as Scratch, Blockly or mBlock, because it is the only way to enable students at this level to work and program intuitively.

From the data obtained, we recommend the integration of educational robotics with visual block programming in mathematics, especially in the subjects or didactic units related to coordinates and integers. In this way, the students put into practice the mathematical concepts they learn, and receive immediate feedback when inserting coordinates or numbers in the robot. Further research could focus on the analysis of other robots or resources that use visual block programs, such as Sphero SPRK, Lego Wedo 2.0 or Lego Mind storms EV3. Their integration and application in mathematics would be of interest to researchers in this field.

The advantages of the educational approaches that apply robotics are consistent with the theoretical framework presented here. These resources allow students to manipulate computational concepts and practices in the real world in order to solve all kinds of situations and problems. Their application implies the development of a new literacy in the use of technologies; the visual block code in this case enables students to acquire greater competence in mathematics. In addition to an active methodological approach, their experience is considerably enriched and made proactive with problem-based learning, project method and collaborative initiatives. The algorithms and programs are based on logical and mathematical concepts, which are learned with greater motivation and enthusiasm with these resources. In the intervention presented with integers and coordinates, we can see the outstanding improvements achieved with the implementation of computational concepts from an active and participatory perspective.

Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

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