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Evaluation of Computational Thinking Using Four Educational Robots with Primary School Students in Peru

Evaluación del pensamiento computacional utilizando cuatro robots educativos con estudiantes de primaria en Perú

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ABSTRACT

The Development of Computational Thinking skills in elementary school students can be done through different activities, with or without the use of computers or technological devices. In this sense, the use of programmable robots brings many of the advantages of educational robotics for teaching fundamental aspects of computing. This paper describes an educational intervention that evaluates the use of four educational robot models to improve Computational Thinking with primary school students in the Huancavelica region in Peru, South America. This Peruvian region is known for its low human development rates, where the population still faces some important barriers regarding access to education and technology. The study was conducted with 6 to 13 years-old children for four weeks. Computational Thinking was evaluated using computational concepts like sequences, cycles, events, parallelism, conditionals, operators, and data manipulation. The evaluation results showed that children preferred robots that have more interaction, connectivity, and programming features, and they could contribute significantly to the development of Computational Thinking skills.

Palabras clave:
Robótica educativa,
Programación,
Pensamiento computacional,
Conceptos de computación

RESUMEN

El desarrollo de habilidades de pensamiento computacional en estudiantes de primaria puede llevarse a cabo a través de distintas actividades, con o sin el uso de computadoras o aparatos tecnológicos. En ese sentido, la utilización de robots programables trae consigo muchas de las ventajas de la robótica educativa para el contexto de la enseñanza de aspectos fundamentales de la computación. Este artículo describe una intervención educativa que evalúa el uso de cuatro modelos de robots educativos para mejorar el pensamiento computacional con estudiantes de primaria en la región de Huancavelica en Perú, Sudamérica. Esta región peruana es conocida por sus bajas tasas de desarrollo humano, donde la población aún enfrenta importantes barreras de acceso a la educación y a la tecnología. El estudio se desarrolló con un grupo de estudiantes de 6 a 13 años, durante un período de cuatro semanas. La evaluación del pensamiento computacional se realizó utilizando conceptos computacionales como secuencias, ciclos, eventos, paralelismo, condicionales, operadores y manipulación de datos. Los resultados de la evaluación mostraron que los niños preferían los robots que tienen más interacción, conectividad y características de programación, y que podrían contribuir significativamente al desarrollo de sus habilidades del pensamiento computacional.

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1. Introduction

In recent years, Educational Robotics (ER) has grown as a technological resource in primary education to provide pedagogical strategies in the teaching and learning processes. Educational robotics (García et al., 2016) arises with the theories of Seymour Papert (1980) and Marvin Minsky (1968) at the Artificial Intelligence Laboratory of the Massachusetts Institute of Technology (MIT). In 1967 the first version of Logo, the children's programming software, known as "turtle language," was created; in which the turtle robot located on the ground was connected to a computer; so, children could program the movements of the turtle robot.

At the beginning of 1980, these devices became popular. They were included in educational activities through projects that allowed the development of mathematics, informatics, electronics, and mechanics skills, combining fun and games in the students to propose solutions to specific problems. Currently, robotics has been introduced in all fields of science; for example, research in robotics is not only led by the United States, Europe, and Japan. Nevertheless, also, in recent years, it has been incorporated with great emphasis in South Korea and China (Yoo, 2015). Meanwhile, in Latin America, its incorporation is very incipient (D'Abreu & Villalba-Condori, 2017). Brazil took its first steps in the 1980s (Almeida, 2014); Chile, in November 2017, the JUNAEB incorporates educational robotics for children in schools called new Local Education Services through the "I Connect to Learn" Program in Barrancas and Puerto Cordillera (Coquimbo-Andacollo) (Maximiliano, 2017). Likewise, there are initiatives in Costa Rica, Mexico, Colombia, Ecuador, and Peru.

1.1. Context

Peru is a developing country in South America, with an HDI of 0.75 – considered high, but suffers from an unequal distribution of incomes – the Gini index is 0.35. According to Castillo (2020), "all but two political regions (Loreto and Madre de Dios) and all geographical regions in Peru experienced a reduction in inequality between 2007 and 2017 as measured by the Gini coefficient, but the equality gains are highly heterogeneous and seem to have slowed down since 2012" (p. 1). The focus of this study is the Peruvian region of Huancavelica.

Occupying an area of 4.215.56 km^2, the Huancavelica region has 365.317 inhabitants, according to the national estimate for 2020. This region has a very low nominal GDP (3.028 USD compared to the capital city, with a GDP of 199.869 USD). It is subdivided into 7 provinces and 19 districts. The region's economy is mainly concentrated on mining –mainly copper, plumb, silver, and gold–. There is a presence of agricultural activity in the region, with potatoes, some herds-related business, mainly bovine and swine, and local alpacas and llamas.

A robust migrant movement of workers characterizes the region: they come and go according to the availability of work. Despite this floating population, there are 2.501 public and private schools in the regions, most of them not providing secondary education – only 290 do that –. These schools suffer from poor access to the Internet just 15.1% of primary education schools were connected in 2014, and 29.7% of secondary schools. These numbers are lower than the Peruvian average, 27.9% in primary schools and 52% in secondary schools. These data reveal the precarious situation of the Huancavelica region regarding connectivity if compared to the rest of the country.

In Huancavelica, most educational institutions are located in social exclusion and poverty areas, with limited or no access to technological resources, especially educational robotics. Students residing in these areas do not have technological devices in their homes; there is a digital gap for students in urban areas, which generates inequality in the teaching and learning process results. Added to these, other extracurricular factors, such as social, cultural, and economic environment, negatively impact student performance, resulting in low levels of learning. Even though primary education reached 94.9% of potential students in 2014 – and 80.3% at secondary level in the same year – the last available census, the quality of the educational experience suffers from the lack of support, especially regarding essential aspects in XXI century, as digital literacy and problem-solving skills.

To help to mitigate these problems, one possibility is to rely on educational robotics as a technological resource to develop Computational Thinking (CT) in students (Wing, 2006). In this way, the objective is to increase their skills with repercussions on their academic training and future decisions for personal, familiar, and social benefit.

Educational robotics in Peru had its beginnings in 1994 with the implementation of LEGO at *Colegio Alejandro Deustua* (Lima, Peru's capital city) with the support of the Wernher Von Braun Institute. At the Ministry of Education (MINEDU) level, it began with INFOESCUELA in 1996, through a Pilot Project for 12 schools. After two years, it extended to 130 schools throughout Peru. In 2008, the MINEDU requested the Inter-American Development Bank (IDB) funds. Once approved, the "IDB - MINEDU - LEGO" project is executed in the most vulnerable populations in Peru (Linares, 2015). In 2010, MINEDU acquired modules containing 128.000 WeDo educational robotics kits and 20.000 licenses for them.

Since 2011, MINEDU has distributed robotic kits to 20.732 educational institutions. 65% of these are rural multi-grade poly-teaching (two or more sections under the responsibility of a teacher) and one teacher (one teacher per classroom). In this project, not all teachers have had the opportunity to receive training. It should be noted that the PeruEduca initiative, in 2018, distributed approximately 42.848 robotics kits to 19.344 educational institutions, benefiting a total of 2.500.000 elementary school students.

In this sense, the article assesses the preferences of Huancavelica children in choosing among four models of educational robots: Zowi robot, Jimu robot, mBot robot, and Lego Wedo, by using them in different educational situations. In order to evaluate them, CT concepts such as sequences, cycles, events, parallelism, conditionals, operators, and data were developed with the children during robotic-based activities.

This educational intervention was developed with twenty children (from 6 to 13) in an educational robotics extracurricular course as an initial experience for the region.

2. Educational Robotics and Computational Thinking

2.1. Educational Robotics

The integration of ER in the teaching and learning processes can be developed through various approaches. The first implies that the contents focus on the construction or assembly of robots and the second on robot programming; while the third approach is the most important because ER is used in the classroom as a support tool in learning other disciplines of the school curriculum (Moreno et al., 2012).

In recent years, the use of ER in the school stage has become a frequent topic of education research because they offer a wide range of challenges and opportunities for students to develop disruptive thoughts, innovative ideas, and other skills necessary for learning inside and outside of the classroom (Moreno et al., 2012; Catlin & Woolard, 2014). Many researchers have shown that students can process information faster when using ER; likewise, ER activities are usually well accepted by boys and girls. Furthermore, they feel interested and motivated to continue learning ER topics compared to other disciplines (Witherspoon et al., 2016); allowing to reach a broad audience since robots typically stimulate the interests of students (Catlin & Woollard, 2014), comprising the entire range of motivation components (attention, relevance, confidence, attitude, and satisfaction) (Sarmento et al., 2015). Also, to capture students' attention, ER integrates several areas, such as Programming, Mathematics, Mechanics, and Electronics, for instance. This way, ER creates a robust environment to foster computational practices and perspectives, such as connecting with other participants and expressing their ideas into a team.

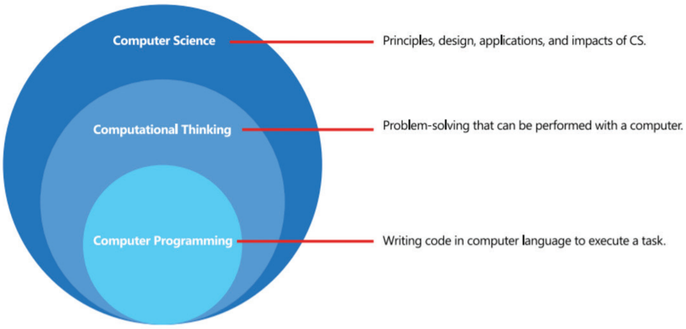
Programming is considered an ER stage when systematically organized under four keywords: Imagine, Design, Build, and Program. This forms a conglomerate of actions and activities that promote non-compartmentalized learning (García, 2015). ER enables the design, construction, and development of learning environments through which participants can achieve a correct appropriation of knowledge, from the abstract to the tangible (Caballero-González & García-Valcárcel, 2020). The use of educational robotics is considered first-order computational manipulators, focused on the aspects of the CT offered by the design of the materials, including sequencing, reasoning, problem-solving, and understanding of systems (Sullivan & Heffernan, 2016). ER must improve the curricular, syllabus-based subjects, and social skills; teachers are a fundamental part of implementing these new practices to reach this goal. Because of it, they are supposed to receive proper training and continuous motivation (Rosinvale et al., 2019).

2.2. Computational Thinking

The definition of Computational Thinking (CT) begins indirectly with the work of Seymour Papert in the Logo programming language, with the philosophy that children could build knowledge by manipulating and interacting with a computer, which would allow them to develop procedural thinking through programming, among other skills (Papert, 1980) – nonetheless, Papert did not explicitly define CT. In 2006, Jeannett Wing (2006) defined CT in the following way: "Computational thinking involves solving problems, designing systems, and understanding human behavior, by drawing on the concepts fundamental to computer science" (p. 33). From this, it follows that the core of CT is to think like a computer scientist when it comes to solving a real-life problem. Furthermore, it is manifested in that same paragraph "To reading, writing, and arithmetic; we should add computational thinking to every child's analytical ability" (p. 33). However, it is essential to point out that the manipulation of computers is not a required activity to develop many CT skills – which is usually called "unplugged CT" as used by Zapata-Ros (2019) and Brackman et al. (2017), among others.

The cornerstone of CT (Grover & Pea, 2013) is the value of abstraction concerning other thoughts; thus, we consider that CT is the process of thought involved in the formulation of problems so that its solutions can be represented as steps and computational algorithms (Aho, 2012; García-Peñalvo, 2018; García-Peñalvo & Mendes, 2018). However, CT cannot be reduced to developing programming skills or competencies for understanding and proposing algorithms – these are important parts of CT but could not be assumed as CT itself. The relationship between CT and programming and Computer Science itself is synthesized by Jara and Hepp (2016) in Figure 1.

Figure 1. Relationships among CT, Computer Science and Computer Programming.



Source: Jara & Hepp, 2016

There is a mutual influence between CT and Computer Programming, which is no clear-cut barrier among them (Bocconi et al., 2016) – for instance, (Alves et al., 2019) presents a comprehensive review of approaches to assess CT in K-12 education from code analysis. Computer Programming itself depends clearly on the ability of understanding algorithms, which is one of CT pillars, as mentioned by (Brackmann et al., 2016), which points out the four primary techniques (or pillars) of CT:

- Decomposition.
- Pattern Recognition.
- Abstraction.
- Algorithms.

In another recent definition of CT (Weintrop et al., 2016), it is stated that it is characterized by skills and develops competencies in people. The competencies generated by CT are the ability to deal with open problems, persistence in working through severe issues, and confidence in dealing with complexity. In this sense, CT is a crucial skill in solving unstructured problems, understanding, and interpreting data, and communicating information to others using computers or other agents (Lee et al., 2014). Regarding childhood education, González-González (2019) and Álvarez-Herrero (2020) shows comprehensive analysis of CT activities, including robotics and coding, as exemplified by García-Peñalvo (2016).

It must be noted that there is a vast intersection between the fundamentals of Computational Thinking and Mathematical reasoning, as already noted by (Barcelos & Silveira, 2012; Barcelos et al., 2015; Barcelos et al., 2018) and also Natural Sciences (Rich et al., 2019). Mainly in Robotics, the Mathematical aspects and Scientific thinking required by problem-solving activities could be improved and better systematized by applying Computational Thinking principles.

The CT is being advocated as a critical competence of the 21st century that should allow students to be digitally literate and creators of computational artifacts. For this, the integration of CT in primary education is necessary, where students should be taught to use computational tools to "express themselves, solve problems, represent knowledge, and build models and simulations" (Bocconi et al., 2016, p. 36). Besides, the common usage of ER and CT could improve students' motivation, as shown by (Díaz-Lauzurica & Moreno-Salinas, 2019), especially when connected to STEAM (Sciences, Technology, Engineering, Arts and Math) initiatives. Camargo et al. (2021), Conde et al. (2021) and Ferrada-Ferrada et al. (2020) present comprehensive literature reviews about fostering STEAM through various activities, including robotics.

In the Peruvian context, (Gutiérrez & Sanders, 2009) points out the lack of adequate materials in several educational levels, as well as proper teacher training, as barriers to the teaching of Computer Science-related subjects, which reflects in curricular misconceptions in undergraduate curricula, which would also eventually affect the development of CT activities at other educational levels.

The evaluation of Computational Thinking is based on three dimensions as appear in (Brennan & Resnick, 2012; Curasma et al., 2019):

- Computational Concepts (concepts they interact with, such as cycles, iteration, parallelism, etc.).
- Computational Practices (they develop custom programming practices and interact with the concepts, such as debugging projects or redesigning the work of others).
- Computational Perspectives (how they see the world around them and about themselves).

Table 1 shows the computational concepts, which will be used as a basis of this study, to assess CT in children of the Huancavelica Region in Peru.

Table 1. Computational Concepts of CT.

Computational Concepts	
Sequences	It refers to a particular task or activity that is expressed as a series of steps or individual instructions that the computer can execute.
Cycles	They allow executing the same sequence of instructions on multiple occasions.
Events	Refer to "when something happens, then it causes something else to happen."
Parallelism	Refers to several sequences of instructions that are executed at the same time, simultaneously (in parallel).
Conditionals	It is the ability to make decisions to solve problems in your environment.
Operators	Refer to the inclusion of logical, mathematical, and string expressions in programs.
Data	Refers to the inclusion, storage, retrieval, and updating of values in a program.

3. Method

3.1. Research focus

The research methodology is based on the qualitative method that states that the facts are investigated after they have occurred, where data collection is carried out through observations and interviews by a group of children.

3.2. The participants and the research context

Workshops have been carried out with the four educational robots: Zowi BQ, Jimu robot, mBot robot, and Lego WeDo 1.0, with 20 children from schools of the Huancavelica Region. These four robots were chosen as the only ones available to the researchers in the aforementioned context. These children come from educational institutions in the public and private sectors; their ages range from 6 to 13 years old, among which 5 were girls, representing a convenience sample. The workshop was carried out as an extracurricular activity for 24 hours, spread through 4 weeks, 6 hours a week, 2 days per week, in a classroom located at the National University of Huancavelica. Figure 2 shows some pictures taken during the educational interventions, with the experiences developed by the children.

To know the preference of robots and with it, the evaluation of computational thinking based on computational concepts (Sequential, Cycles, Events, Conditionals, Operators, and Data), four groups consisting of 5 children each were formed; to develop activities with robots: Zowi, Jimu, mBot, and Lego WeDo.

The activities they carried out were: with the Zowi robot, they developed a program to determine the emotions of the robot's face (happy, annoyed, sad, and surprised); With Jimu robot, they developed a program that allows aerobic movements and dances of the robot from a Smartphone; Using a mBot robot, they developed a program that will enable them to interact with the ultrasound sensor to light an LED at a certain distance and show color; With a Lego WeDo robot, a crocodile was built and they created a program using the sensor to close and open the crocodile's mouth.

Figure 2. Experience of children with educative robots.

3.3. Instrument

The instrument used to collect data are observations and semi-structured interviews with children (Grover, 2011), where they have adapted for activities with the four robots. Observations and interviews are related to robot preferences and questions about computational concepts: sequences, cycles, events, parallelism, conditionals, operators, and data.

Table 2 shows examples of questions asked to the groups of children. The questions had to be simplified and/or repurposed according to each group's different levels of language understanding and expression capacity. The variables and elements collected through this questionnaire were related to children's acceptance and satisfaction with the experiences, identifying preferences among the four robots, and children's self-awareness regarding the learning perception of basic CT concepts.

Table 2. Questions for groups of children.

Category	**Technical Topics**	**Question Types**
Robot Preference	The graphic interface on computers and smartphones, interactive games, Movements.	• From which interface would you like to control the robot? • Are you happy when interacting with the robot? • The entertainment is greater with a robot that has more movement?
Computational Concepts	Sequences, cycles, events, parallelism, conditionals, operators, and data.	• Is the learning of computational concepts related to the preference of the robot? • What concepts do you develop more with the preferred robot?

4. Results

According to the views in the classroom, robots create an expectation in children concerning their technical characteristics and functionalities.

Table 3 describes the observations of the children's experience with robots and the evaluation regarding the development of Computational Thinking based on CT concepts (Le & Wartschinski, 2018) and the responses to interviews.

5. Conclusions

During the development of the workshops with the four educational robots, it was observed that children prefer to interact with the Jimu robot, due to its characteristic of mobility and aerobic control from a mobile phone, since they feel motivated and with the desire to learn to program in a fun and playful way.

Regarding the development of Computational Thinking, according to the evaluations carried out, the four robots were allowed to develop computational concepts: sequential, cycles, and events. While with the Jimu robot, they also developed parallelism, conditionals, operators, and data; this is due to the preference by boys and girls compared to other robots. In the case of the mBot robot, they also developed parallelism and conditionals; the other computational concepts were not developed due to the complexity of the robot for this age group.

Table 3. Assessment of CT in children.

Robot	Activities Observation with robots	CT observations
Zowi Robot	This robot aroused the interest of all children alike for its graphic interfaces on computers and smartphones by having interactive games. Also called attention the gesture option "Pinta Bocas" (LED matrix) of the robot when programming it a face (happy, sad, surprised, etc.), the child drew the same face in a time of 5 seconds.	With the Zowi robot, the children developed a large part of computational concepts (sequential, cycles, parallelism, events, and conditionals). They also generate an attitude of continuing to program the robots, wanting to control all the functionalities.
Robot Jimu	C Compared to other robots with the Jimu robot, all the children were more motivated and interested in interacting due to its aerobic movements and dances. The children interacted with the robot from the smartphone through a mobile application where it was observed that children prefer the control of the robot from a cell phone than from a fixed computer.	With the Jimu robot, the children developed all the computational concepts (sequential, cycles, parallelism, events and conditionals, operators, and data) due to multiple characteristics of the robot, such as aerobic movements, control from the smartphone, and physical appearance. Also, they demonstrated an attitude of continuing to learn and, consequently, the development of more CT skills.
Zowi Robot	This robot aroused the interest of all children alike for its graphic interfaces on computers and smartphones by having interactive games. Also called attention the gesture option "Pinta Bocas" (LED matrix) of the robot when programming it a face (happy, sad, surprised, etc.), the child drew the same face in a time of 5 seconds.	With the Zowi robot, the children developed a large part of computational concepts (sequential, cycles, parallelism, events, and conditionals). They also generate an attitude of continuing to program the robots, wanting to control all the functionalities.
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mBot Robot	Compared to other robots, with the mBot robot, all the children were more motivated and interested in interacting due to its aerobic movements and dances. The children interacted with the robot from the smartphone through a mobile application where it was observed that children prefer the control of the robot from a cell phone than from a fixed computer.	With the mBot robot, children developed specific skills of computational concepts (sequential, cycles, parallelism, events, and conditionals). The robot did not generate an expectation, less in the girls; therefore, the development level of CT was lower compared to other robots.
Lego WeDo	Due to the ease of assembling parts, this robotic Kit motivated little interest in the building and programming programs in Lego WeDo. However, the reaction was the opposite for older children, as it did not have a diversity of components; they decreased their interest compared to other robots.	With the Wedo robot, children developed few skills in computational concepts (sequential, cycles, and events). It was also observed that they did not generate attitudes to continue programming due to the few technical functionalities of the robot.

Concerning the mBot robot, it allows the development of different projects in the field of education because it has a variety of sensors that easily integrates with the Scratch software, which helps put into practice all the computational concepts (del Rey et al., 2020). With this robot, it is recommended to work with children between 9 and 13 years old due to its complexity in programming. While for children from 6 to 8 years old, the use of Jimu and Zowi robots is recommended, due to their characteristic of aerobic mobility and control from a mobile device, because these characteristics attract the attention of children of that age (D'Abreu & Villalba-Condori, 2017). For children between 6 and 8 years old, the study shows that it would be more recommendable to work with the Lego Wedo robot because it has a greater diversity of parts and easy assembly.

Some risks to the validity are important to be mentioned, as the adoption of only four types of robots; the type of activity used which each robot since they could have introduced biases in the results; and the reduced number and gender imbalance of students involved in this study. The educational gender gap is a complex reality in some Latin America regions – Duryea et al. (2007) studied girls and boys between 6 and 18 years, in four countries of this regions (including Peru): noticeable gender differences favoring boys appeared, especially those children of the lowest income quintiles and indigenous ethnicity.

One important finding is that it is advisable to have specific educational robots for each age range; this will generate CT skills without losing interest in using robots by children. Also, it is recommended to purchase a robot with functionalities of different aerobic movements, programming, and control interface from a Smartphone. These characteristics substantially impact children's feeling of motivation, stimulate teamwork, and have a positive attitude to develop projects and challenges. By adopting these recommendations, there will be more significant achievements in developing CT skills by using ER.

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