



THE DEVELOPMENT OF COMPUTATIONAL THINKING IN STUDENT TEACHERS THROUGH AN INTERVENTION WITH EDUCATIONAL ROBOTICS

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ABSTRACT

Aim/Purpose	This research aims to describe and demonstrate the results of an intervention through educational robotics to improve the computational thinking of student teachers.
Background	Educational robotics has been increasing in school classrooms for the development of computational thinking and digital competence. However, there is a lack of research on how to prepare future teachers of Kindergarten and Elementary School in the didactic use of computational thinking, as part of their necessary digital teaching competence.
Methodology	Following the Design-Based Research methodology, we designed an intervention with educational robots that includes unplugged, playing, making and remixing activities. Participating in this study were 114 Spanish university students of education.
Contribution	This research helps to improve the initial training of student teachers, especially in the field of educational robotics.

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Findings	The student teachers consider themselves digital competent, especially in the dimensions related to social and multimedia aspects, and to a lesser extent in the technological dimension. The results obtained also confirm the effectiveness of the intervention through educational robotics in the development of computational thinking of these students, especially among male students.
Recommendations for Practitioners	Teacher trainers could introduce robotics following these steps: (1) initiation and unplugged activities, (2) gamified activities of initiation to the programming and test of the robots, (3) initiation activities to Scratch, and (4) design and resolution of a challenge.
Recommendation for Researchers	Researchers could examine how interventions with educational robots helps to improve the computational thinking of student teachers, and thoroughly analyze gender-differences.
Impact on Society	Computational thinking and robotics are one of the emerging educational trends. Despite the rise of this issue, there are still few investigations that systematize and collect evidence in this regard. This study allows to visualize an educational intervention that favors the development of the computational thinking of student teachers.
Future Research	Researchers could evaluate not only the computational thinking of student teachers, but also their didactics, their ability to teach or create didactic activities to develop computational thinking in their future students.
Keywords	computational thinking, educational robotics, digital competence, student teachers

INTRODUCTION

Digital competence is one of the eight basic competences of the European Reference Framework of key competences for lifelong learning (European Communities, 2007). In the last decade, digital competence has been integrated into the curriculum of obligatory education in many countries of the European Union and in the initial teacher training. Student teachers must not only have such competence as educated adults, but also, as part of their professional preparation, they must be able, among other aspects, to design, develop and evaluate didactic activities in which digital technologies are used as teaching tools in the teaching/learning processes of all the subjects of the curriculum including activities aimed at students to develop their own digital competence. In recent years, the development of these technologies and the accelerated process of society transformation has made the need for such competition more evident and, at the same time, has given rise to several extended redefinitions that, in turn, include more dimensions or sub-competences.

One of the emerging educational trends that is either integrated into or parallel to digital competence is computational thinking and robotics. The number of schools that introduce, either the ordinary curriculum or through extracurricular subjects, activities related to robotics and computational thinking (Bustillo & Garaizar, 2014; Valverde, Fernández, & Garrido, 2015) has been increasing. This trend is also getting into the university classrooms (Adell, Esteve, Llopis, & Valdeolivas, 2017; Yadav, Greter, Good, & McLean, 2017) where, in the training of student teachers, they begin to introduce useful activities both to update their training in digital competence as to familiarize them with specific pedagogical resources of computational thinking that allow them to transfer these skills to their practices in the classroom.

Despite the relevance and topicality of this subject, there is a lack of research on how to prepare student teachers of Kindergarten and Elementary School in the didactic use of computational thinking, as part of their necessary digital teaching competence (Adell et al., 2017; Yadav et al., 2017).

This article presents the results of an intervention through educational robotics for the development of computational thinking (understanding it as part of the teaching digital competence), of student teachers. This intervention was designed as part of a broader training process following a Design-Based Research methodology (van den Akker, Gravemeijer, McKenney, & Nieveen, 2006). The rest of the article describes the educational intervention carried out; the evaluation instruments used; and the results obtained.

LITERATURE REVIEW

DIGITAL COMPETENCE AND COMPUTATIONAL THINKING

Martin (2005) defined digital competence as the awareness, attitude and capacity of people to properly use digital tools to identify, access, integrate, manage or evaluate digital resources, build new knowledge, express themselves through different media and communicate. In a similar line, Ferrari (2012) characterized it as the set of knowledge, attitudes, and skills required when using information and communication technologies (ICT) to perform different tasks (managing information, communicating, solving problems, creating or share content), in an effective, efficient, appropriate, flexible or critical way. Based on an extensive analysis of the literature, Larraz (2013) frames it in four dimensions or divisions (informational, technological, multimedia and communicative) and proposes an evaluation model, which we will take as reference in this investigation. Similarly, the Joint Research Center (JRC) of the European Commission determines, in the DigComp 2.0 framework (Vuorikari, Punie, Carretero, & van den Brande, 2016), the following dimensions: (1) information literacy, (2) communication and collaboration, (3) creation of digital content, (4) security, and (5) problem solving.

The latest trends consider that digital competence must go beyond mere digital literacy. Hall, Atkins and Fraser (2014) affirm that, in the case of teachers, digital competence also implies having skills, attitudes and knowledge to promote true learning on their students in a context enriched by technology. Computational thinking and some of the concepts related to it (coding, programming, and algorithms) have been conceptualized as a new digital literacy, fundamental for the XXI century (European Commission, 2018). Indeed, as stated by Juškevičienė and Dagienė (2018), digital competence and computational thinking have a lot in common. According to *the Common Framework of Digital Teacher Competence* published by the INTEF (2017), of the Ministry of Education, Culture and Sport of Spain, programming is a part of this teaching competence, within the area of "Digital Content Creation", so, the universities must rethink what training actions have to carry out to properly work this competence during initial teacher training.

The *International Society for Technology in Education & Computer Science Teachers Association* (ISTE & CSTA, 2011) define computational thinking as a process of problem solving that includes the following characteristics: (1) formulate problems in a way that allows us to use a computer or similar to help solve them; (2) logically organize and analyze the data; (3) represent the data through abstractions such as models and simulations; (4) automate solutions through algorithmic thinking; (5) identify, analyze and implement possible solutions more effective; and (6) generalize and transfer this process to a wide variety of problems. In this way, computational thinking may be a motivator to pursue computer science and other STEM-related majors (Shute, Sun, & Asbell-Clarke, 2017). Likewise, in terms of learning, computational thinking also contributes to promote many aspects of 21st century competencies, such as creativity, innovation, critical thinking and problem solving (Lye & Koh, 2014; Mishra & Yadav, 2013).

However, there is still no agreement among the experts on the important aspects of computational thinking, starting with its definition, the reasons for including it in the curriculum, its key elements and its pedagogical approach (Adell, Llopis, Esteve, & Valdeolivas, 2019). Regarding the introduction of computational thinking in education, controversies have arisen in this topic, among which the terminological debate stands out. There are two main positions when defining the term. The first one emphasizes computer aspects and is closely related to programming. In this direction, for example, would be the first definition of Jeanette Wing (2006) and also this would be the interpretation of Great Britain when introducing in 2013 the subject of programming in the curriculum (Kotsopoulos et al., 2017). However, the very same Wing (2008) reformulated the concept to place greater emphasis on cognitive processes, the formulation of problems and the search for effective solutions as elements that would be part of computational thinking.

Corradini, Lodi and Nardelli, (2017) consider that, in education, it's necessary to approach the definitions that promote the transmission of a series of principles and methods, above those that emphasize systems and tools. In their work, they collect four categories that would define computational thinking. On the one hand, the mental processes involved in problem solving; on the other, the methods or operational approaches used in computer science; thirdly, the practices used to search for solutions based on computer logic and, finally, the transversal skills related to general ways of operating in the world that can be improved by computer scientific thinking.

EDUCATIONAL ROBOTICS

One of the emerging resources to develop computer thinking, as well as students' own digital competence is educational robotics. A robot is a tangible object, with which you can interact with the environment through programmed instructions, also useful in Kindergarten, as a tool for the development of cognitive skills, through play, creativity or the resolution of challenges (Da Silva & González, 2017). From the European project, *Educational Robotics for STEM* (ER4STEM) educational robotics has been defined as a field of study whose objective is "to improve the learning experience of people through the creation, implementation, improvement and validation of pedagogical activities, tools (for example, guidelines and templates) and technologies, in which robots play an active role, and pedagogical methods inform every decision." (Angel-Fernandez & Vincze, 2018, p 41).

Recent reviews of the literature on educational robotics in the mandatory stages (eg, Bascou & Menekse, 2016; Benitti, 2012; Kubilinskiene, Zilinskiene, Dagiene, & Sinkevičius, 2017; Mubin, Stevens, Shahid, Al Mahmud, & Dong, 2013; Toh, Causo, Tzuo, Chen, & Yeo, 2016; Xia & Zhong, 2018) highlight its potential for the development of computational thinking and the understanding of concepts and processes related to STEM areas. The use of robots is not only a motivator in the classroom, but for its technological features, allows the design of activities that promote both computational thinking, and skills related to scientific and mathematical skills such as social skills, collaborative and teamwork (Benitti, 2012).

Technically, the use of a robot can involve aspects of design, construction and programming (Mikropoulos & Bellou, 2013), usually following the this sequence of steps: (1) the construction of the robot itself, using the imagination of the students; (2) the development of the program, using a visual programming environment; (3) the download of the program in the robot itself; and (4) the execution of the program. There are different types of robots. For Chang, Lee, Chao, Wang, and Chen (2010), the most common characteristics of robots are usually: (a) constant repetition, an attribute that allows the student to practice certain tasks or mechanical actions; (b) flexibility, which allows the teacher to design and adjust tasks; (c) the digitalization, the technological possibilities of communication and interaction from Bluetooth or Wi-Fi connections; (d) the physical appearance, whether humanoid or not, arouses the curiosity and fantasy of the students; (e) the movements, which not only awaken interest but can help or guide the student; and (f) the interaction, the robot's ability to interact with people, from sensors or from speech recognition itself.

In a study in different schools in Sweden and Austria, Kandlhofer and Steinbauer (2016) found a significant effect of the use of educational robotics, both in competences related to scientific skills and mathematics, as in cross-disciplines such as teamwork and social skills. Similar results are those contributed by Chin, Hong and Chen (2014). However, as pointed Benitti (2012), there are still few empirical studies that show the impact of robotics on student's learning, especially in the first cycles of Elementary School.

In this work, three methodological frameworks commonly used in this type of research are identified. The first of these is the one proposed by Resnick (2007), consisting of a method of spiraling work that includes, in a successive way, the processes of imagining, creating, playing, sharing, reflecting and, re-imagining. On the other hand, Angeli et al. (2016), carried out an adaptation of the TPACK model and the computational thinking (CT) concept. The model TPACK_{CT} was defined as one that is able to identify creative and authentic CT projects, potential technologies to implement the CT, and use such possibilities to transform content through understandable representations. Finally, Kotsopoulos et al. (2017) propose a pedagogical framework based on the principles of constructionism and social constructivism, including pedagogical experiences (1) unplugged, (2) playing, (3) making or building, and (4) to remix. The latter is the framework that has been taken as reference in the investigation.

PURPOSE OF STUDY

The purpose of this study is to explore the potential of an intervention through educational robotics to develop the computational thinking of future teachers. The following research questions guided this article: (1) What is the level of digital competence of student teachers? (2) To what extent does this intervention with educational robotics improve computational thinking of future teachers? (3) Does gender affect the development of computational thinking of future teachers?

METHOD

The methodology selected for the development of this project, for its suitability and convenience, is the methodology based on educational design, a variant of the well-known research methodology based on design (Design-Based Research, DBR), applied to the educational world (Plomp & Nieveen, 2009). It is a methodology that follows a systematic and cyclical process of analysis, design, development and evaluation of an educational experience or intervention, as a solution to an educational problem (McKenney & Reeves, 2012).

In line with DBR methodology, the research process was structured in three main phases (Plomp & Nieveen, 2009). In a first phase, we analyzed the literature with regard digital competence and computational thinking of student teachers, and we also explored the perception student teachers have of their own digital competence. In a second phase, we conducted the iterative process for the design and refinement of the intervention with educational robots. Finally, the effectiveness of the intervention in the development of computational thinking was evaluated.

THE INTERVENTION

Based on the aforementioned methodological approaches, and the analysis of the context (professionals and students), the following educational intervention has been designed (see Table 1).

Table 1: Pedagogical framework of the intervention

ACTIVITIES	DURATION	DESCRIPTION
1. Unplugged	1 week	Initiation activities, with printable material that can be cut, puzzles, cards, etc., and design of a board game.
2. Playing	1 week	Gamified activities of initiation to the programming (hour of code, Doodle of Google), and test of the robots (MakeyMakey, Bee-Bots, and mBots).
3. Making	2 weeks	Initiation activities to Scratch: individual task of designing a greeting card, and / or group to create a video game with Scratch
4. Remixing	3 weeks	Resolution of a challenge (<i>line-following</i> and obstacles) with mBot, through programming with mBlock (based on Scratch), and design of a didactic activity to work the CT in a Primary Education classroom.

All activities were performed in group setting, and to develop the activities under the proposed methodological framework, different elements related to robotics and programming have been used.

In the first place, student teachers played with unplugged initiation activities with puzzles, crayons, and printable material, like grids, arrows, and binary cards with numbers and letters, from CS Unplugged, an online collection of free teaching material. In addition, student teachers had to design their own unplugged game using that material.

For playing activities, Makey-Makey was used, an Arduino board that through circuits, crocodile cables and a USB interface connected to the computer, allows to turn everyday objects into keyboards, video game controls and buttons to press. Through this activity the students examined the operation of an Arduino board. Also, in this phase were used Bee-Bots, educational robots in the shape of a bee designed especially for children in their early educational stages. These robots can be programmed in a simple and intuitive way, to follow a simple sequence of instructions (move forward, backward or make turns). To use the Bee-Bots, were used themes related to the curriculum. Likewise, the mBots robots were used in toy mode, allowing to familiarize the students with these robots in an entertaining way. This robot also has an Arduino board that can be programmed so it was later used in the remixing phase in a more complex way, in order to integrate what was learned previously.

In the stage dedicated to making or building, they experimented with the Scratch, free programming language. This language is based on blocks of colors with different functions that are assembled together and allows to start in a simple and visual way to the world of computing and mathematics, as well as problem solving and collaboration (Olabe, Basogain, Olabe, Maiz, & Castaño, 2011). In this activity, student teachers had to design an interactive greeting card with Scratch, using different characters, scenarios, sounds and including clickable elements and a full credits list.

Finally, in the remixing phase, student teachers had to program their mBots to follow a black line drawn on the ground, and overcome obstacles above the line, using the line-following and proximity sensors. As indicated above, the mBots were programmed from the mBlock programming language, based on Scratch, to execute the different actions set as challenges.

CONTEXT

This investigation was carried out in a medium-sized Spanish university during the year 2018, and it was integrated as a specific activity in the instructional schedule. The activity consisted of the didactic proposal explained in Table 1, and the students had 7 weeks to develop it.

In total, 114 students from a medium-sized Spanish university participated (36% males and 64% females, with an average age of 20 years); of the bachelor's degree in Primary Education. During the moment of the intervention, they all took the subject of New Technologies Applied to Education.

INSTRUMENTS

INCOTIC. The Inventory of Competencies in Information and Communication Technologies (INCOTIC) is a questionnaire of self-perception of the digital competence of university students. In addition to a series of items on biodata and on the availability of ICT resources, it has a digital competence section, with 20 items distributed from the 4 literacies - informational, technological, multimedia and communicative, and a Likert scale of 1 to 5 (González-Martínez, Esteve-Mon, Larraz Rada, Espuny Vidal, & Gisbert Cervera, 2017). The items were phrased in terms of “can do”, and examples of items include: “I believe I have the capability to scan a b/w document at 300 dpi resolution”, or “I believe I have the capability to mark my content with a Creative Commons license”.

CTt. Computational Thinking test (CTt) is composed of 32 questions independent of previous knowledge of a programming language, and it can be administered in 45 min session. Each item addresses one or more of the 7 following computational concepts: Basic directions, “repeat”, “repeat until”, “if”, “if/else”, “while”, and simple functions. According to the authors, these concepts are aligned with CSTA standards for science education (Román-González, Pérez-González, Moreno-León, & Robles, 2018). Some examples of items are presented here. Example 1: “Which instructions lead ‘Pac-Man’ to the ghost along the path marked out?” (Item with loops-repeat times). Example 2: “The instructions should take ‘Pac-Man’ to the ghost by the path marked out. In which step of the instructions is there a mistake?” (Item with loops-repeat until + if/else conditional). The scale was recalculated to a range of 1-5 to compare results between both instruments.

ANALYSIS DESIGN

INCOTIC was administrated before starting the intervention with the purpose of knowing the general level of digital competence of student teachers.

Computational thinking was evaluated through CT test, before (pre-test) and after (post-test) of the educational intervention, in order to check its evolution. Based on students' scores in the pre-test and post-test, gain scores and normalized learning gains were calculated. Gain scores were calculated as the mean score in the post-test subtracted by the mean score in the pre-test. Normalized learning gains were calculated as Hake (1998).

The students' direct answers to the INCOTIC and CTt were stored in Google Drive databases linked with the instruments, which were downloaded as an Excel file and subsequently analyzed with the SPSS software.

RESULTS

First, we present the results based on the description of digital competence, comparing the dimensions or literacies of the competence (Table 2). We also present descriptive results of computational thinking (Table 3) and the learning gain between the Pre-test to post-test by gender (Figure 2).

LEVEL OF DIGITAL COMPETENCE OF STUDENT TEACHERS

In Table 2 we can see the descriptive results of the digital competence and the different literacies that compose it, based on the self-perception of the education students.

Table 2: Descriptive results of digital competence (N=114)

	TOTAL M (SD)	MALES M (SD)	FEMALES M (SD)
Digital competence	3.5 (.59)	3.5 (.65)	3.5 (.56)
Information literacy	3.6 (.69)	3.5 (.77)	3.6 (.65)
Technological literacy	3.2 (.87)	3.4 (.84)	3.1 (.88)
Media literacy	3.7 (.62)	3.7 (.69)	3.6 (.59)
Communicative literacy	3.6 (.85)	3.5 (.98)	3.6 (.79)

In general, students are considered digital competent (M = 3.5, out of 5). In Figure 1 we can also observe that the literacy that obtains a higher score is multimedia (M = 3.7, SD = .62), while the lowest is the technological one (M = 3.2, SD = .87).

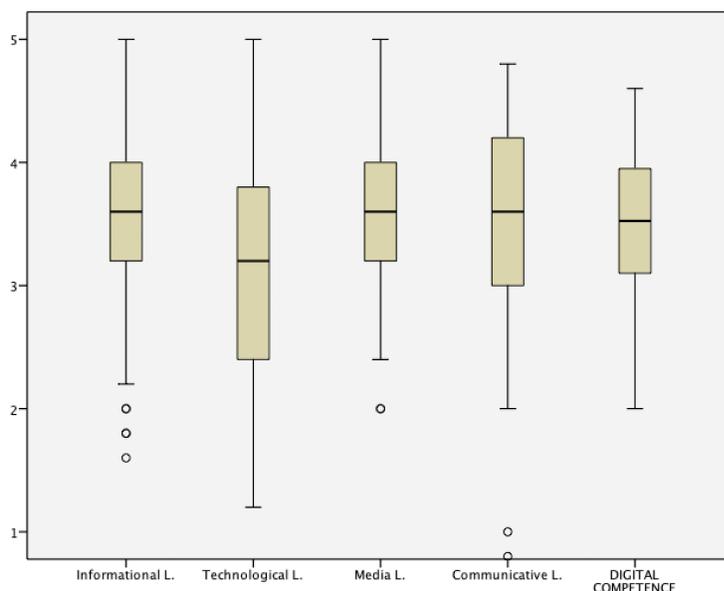


Figure 1: Box plot of the distribution of digital competence and its literacies

If we analyze the differences by gender (Table 2), both males and females obtain the same general score, observing a slight difference -not significant- in technological literacy with a higher score in the case of males (3.4 vs 3.1).

LEVEL OF COMPUTATIONAL THINKING AND LEARNING GAIN

The mean scores and standard deviations of the pre-test (n=112) and post-test (n=103) of computational thinking were also obtained. As we can see in Table 3, the average score of all students increased from 3.29 (SD=.65) to 3.77 (SD=.63), which implies a gain of .48 and a normalized learning increase of 28%.

Table 3: Descriptive results of computational thinking

	PRE-TEST M (SD)	POST-TEST M (SD)	GAIN SCORE	NORMALIZED LEARNING GAIN
Computational thinking	3.29 (.65)	3.77 (.63)	.48	28.0%
Males	3.48 (.57)	3.99 (.51)	.51	33.5%
Females	3.20 (.68)	3.66 (.65)	.46	25.5%

Likewise, in Table 3 we can also observe that males obtained higher average scores, both in the pre-test (3.48 vs. 3.20) and in the post-test (3.99 vs. 3.66), the standardized learning gain being also higher (33.5% vs. 25.5%). In Figure 2 we can clearly observe these changes in the average scores.

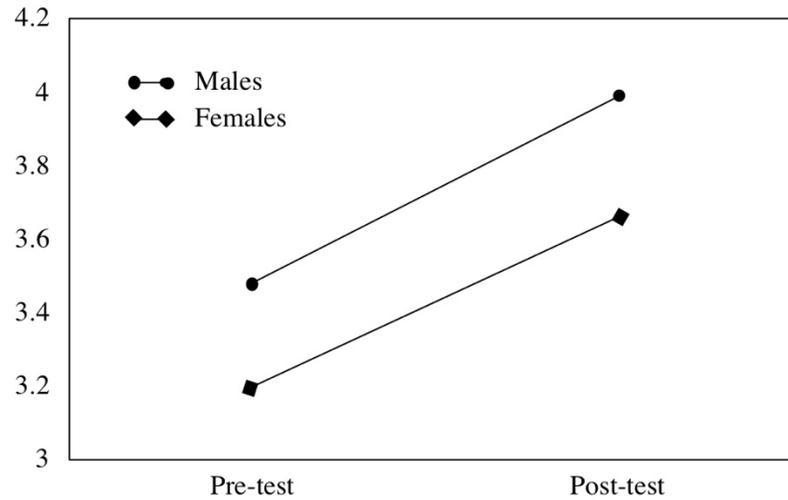


Figure 2: Difference between the Pre-test to Post-test by gender

CONCLUSION

The present investigation, developed following the methodology of DBR, has allowed to describe and to demonstrate the results of an intervention with educational robots for the improvement of the computational thinking of the student teachers. An intervention that, following the pedagogical framework proposed by Kotsopoulos et al. (2017) includes unplugged experiences, play, make or build and remixing.

The first results to discuss are the levels of the digital competence of student teachers. At a general level, the students of the degrees of education are considered digital competent, especially in the dimensions most related to the social and multimedia aspects, results that go in the line of similar investigations (Guzmán-Simón, García-Jiménez, & López-Cobo, 2018; Kennedy et al., 2009; Valtonen et al., 2011). Social and media aspects are perceived as simple, while student teachers find the highest difficulties in the technical aspects (Prendes, Castañeda, & Gutiérrez 2010). In this sense, the technological dimension, related to the use of software, the use of hardware or the resolution of computer problems, and that possibly has a greater relationship with educational robots, is the area in which they consider themselves less capable. This score is slightly higher in the case of males, data that are in line of other studies (Tømte & Hatlevik, 2011) and that according to Antonio and Tuffley (2014), evidence the social inequalities that still exist in certain countries.

With regard to the second research question, the results obtained also confirm the effectiveness of the intervention through educational robotics in the development of the computational thinking of these students. As we mentioned in the introduction, there is a lack of research on how to prepare student teachers in the didactic use of educational robots and computer thinking (Adell et al., 2017; Yadav et al., 2017). Our results, as well as those presented recently by Alimisis (2019), in their RO-BOESL European Project, and Negrini (2019), with the PReSO Project, contribute to filling that gap, providing innovative robotics-based training and learning activities.

The third question involved gender differences in the cultivation of computational thinking. Females obtain a significantly lower score than males with respect to their computational thinking. These results are in the same direction as those of Gui and Argentin (2011) and Kaarakainen, Kivinen, and Kaarakainen (2017). However, both in the case of males and females, there was a substantial increase after the development of the intervention with educational robots, being slightly higher among the

male participants, data that differ from similar research (Espino & González, 2015), who did not find gender differences in skills related to programming and computer learning.

We are aware of the limitations of this study, intrinsic to any research process, and especially in educational contexts. On the one hand, it would be appropriate to have a greater number of participants, as well as a control group that allows us to ensure the effectiveness of this intervention. On the other hand, and in the face of future lines of research, it would be advisable not only to evaluate the computational thinking of student teachers, but also their didactics. That is, the ability of these education students to teach or create didactic activities to develop computational thinking in their future students.

As pointed out in the introduction, educational robotics seems to be one of the most frequently used tools in school classrooms for the development of computational thinking and digital competence. This study has made it possible to visualize an educational intervention that, through the use of this technology, favors the development of the computational thinking of student teachers. Despite the rise of this issue, there are still few investigations that, in an empirical way, systematize and collect evidence in this regard, a trend that, very probably, has already begun to change.

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