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The Acquisition of Computational Thinking through Mentoring: An Exploratory Study

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Abstract: Educational robotics are commonly present in kindergarten and primary school classrooms, particularly Bee-bot. Its ease of use allows the introduction of computer programming to young children in educational contexts from a science, technology, engineering, arts, and mathematics (STEAM) perspective. Despite this rise, there are still few investigations that collect evidence on the effectiveness of robotic interventions. Although mentoring experiences with robotics had been carried out in educational contexts, this work explores their effect on the acquisition of computational thinking skills through mentoring. Participants from the second grade, aged seven through eight years, were exposed to two sessions of robotics with Bee-bot in order to promote hands-on experimentation. The sessions were conducted by nine students of the fourth grade (the mentors), aged 10 to 11 years. A descriptive case-study methodology was employed for the analysis of the mentoring intervention. The effect of the mentoring experience was assessed in terms of motivation and computational thinking skills. Mixed quantitative and qualitative results show two important findings: (i) Mentoring is a powerful tool to be considered for improvement of the motivation and cooperation of students in their teaching–learning process, and (ii) computational thinking skills can be acquired by second-grade students through a mentoring process.

Keywords: educational robotics; bee-bot; mentoring; computational thinking; STEAM model

1. Introduction

In the recent years, STEAM-related fields (science, technology, engineering, arts, and mathematics) have become a source of innovation in the processes related with teaching and learning. Specifically, K–12 education (from kindergarten to 12th grade) has incorporated modern technologies to develop interest and learning in the STEAM subjects. In particular, early-age students are being engaged with robotics and computer-based games. These new technological environments enable young students to promote skills related to mathematical problem solving through activities typical of the computer sciences.

Computational thinking (CT), as a universally applicable attitude and skill [1], is beginning to be accepted as one of the fundamental 21st century abilities for everyone [1,2]. Curricula and environments including CT or digital competences are being developed for different age groups, from kindergarten to university, in several countries [2,3]. The programming tasks are especially relevant because several contents and skills could be developed out of mathematics and science concepts for social and arts education. Coding allows teachers to graduate the difficulty depending on the level shown by the student. Nowadays, there exist different languages for coding which could be used in

learning activities. Most of them are visual programming languages based on drag-and-drop code blocks, with Scratch as the main example [4]. In addition, some robotics have been designed in order to implement coding tasks at early ages, which are useful tools due to their simplicity for both students and teachers (see [5,6] for a specification of different robotic toys).

However, sometimes, the number of pupils is too high to change the methodology and to use robotics with sufficient quality. Mentoring experiences have been applied with success in several areas, such as in medicine and sciences (see, e.g., [7–11], and the references therein). Among the several features that this type of mentoring program presents, we stress two: Firstly, the mentee experiences an extra motivation because one partner takes part in their learning; secondly, the mentor is a model for the rest of students, with special characteristics and abilities as their responsibility. Thus, it becomes interesting to check the effects of implementing a complete program of mentoring to introduce robotics in early ages correctly.

In this paper, we describe a mentoring experience using the robot Bee-bot with 7–8 year old participants. We start with section on the background of robotics and CT, as well as a brief review of mentoring programs. In Section 1.3, we specify the aim of the paper. The materials and methods employed to perform our experiments are presented in Section 2. Finally, some results and discussion are shown; we emphasize the impact of the mentoring experience and the positive assessment reported by the participants. We also make some remarks and indicate future research directions. This is an incipient study for using mentoring in early-age robotics activities.

1.1. Robotics and Computational Thinking: The STEAM Approach

In 2017, the Horizon Report [12] described the rise of experiences based on the STEAM learning model as one of the short-term trend adoptions for the next one to two years in K–12 education. These days, the STEAM approach is successfully implemented at different levels, integrating a common framework for the learning and teaching of the implied subjects [13–19].

In addition, in recent years, the so-called educational robotics (ER) seems to permeate the field of education [5,20]. The ER approach is present from teacher training courses to extracurricular activities for students of very young ages [20]. In the case of schools, within the STEAM paradigm, ER is becoming a powerful resource for integrating mathematics and science content with aspects of technology, engineering, or arts through coding and technology in the classroom [21,22]. Concerning the early years of education, very little of the ER trend takes place in kindergarten or first-grade classrooms [21,23,24]. To some extent, this issue can be due to the lack of teacher training and the lack of resources, since the cost of the necessary technological instruments is not always assumable.

On the other hand, ER through tangible environments, like physical robots, engages young children in CT, as it enables the integration of relevant concepts and abilities from other areas of the early-childhood curriculum [25]. Although the CT has been defined from different perspectives [3], we understand CT as a broad set of thought processes and skills used for problem solving and logical thinking, not just in the way that humans program computers, but in ways that humans think [1,26]. In this work, as recent and classic studies have revealed, we consider CT practices linked to mathematical problem solving [27–31]. In this sense, CT activities require skills, such as decomposition, abstraction, iteration, and generalization, which are also required in mathematical performances. Concerning the early-childhood education, CT has been introduced in teaching proposals through the STEAM approach using ER to connect coding activities with mathematics and science concepts [21]. Commonly, this approach suggests activities designed to engage children in solving structured puzzle-like challenges, such as navigating mazes using instructional commands [2]. Finally, it should be noted that this pedagogical approach based on the characteristics of programming and the use of technological tools is not new. In the 1970s, and much more substantially in the 1980s, proposals and research based on the use of programming and its relationship with problem solving, algebraic reasoning, and abstraction processes typical of mathematics education were made [32].

Although this trend did not survive the 1990s due to the limitations and availability of the technology of the time [33], its legacy has survived to this day.

1.2. Mentoring

The use of ER constitutes an important advance in science and programming learning. However, one of the principal limitations that the community of teachers could find is the time and the human resources necessary to transfer the basicsnotions of the functioning of the robot correctly. In order to avoid these difficulties, mentoring programs are a possible solution due to their flexibility. In [7], the authors review the use of the mentoring experiences in several scientific and social areas. They mention that, in science, they are developed to promote participation and as a strategy to increase the understanding of science of certain students, citing [7–11], among others. In pedagogic research on mentoring, the role of the mentor and the benefits induced by the mentoring process have been studied [7]. In [34] (p. 35), citing [35], Wallace points out the following advantages: "(1) A firm foundation of relevant skills and knowledge; (2) appreciation for expertise; (3) confidence in abilities; (4) how to be responsible; and (5) an understanding that learning lasts a lifetime." Furthermore, mentoring has been treated as part of communities of practice [7].

1.3. Aims

In this work, we intend to explore these two aims:

- Are second-grade students able to learn CT skills through a mentoring process?
- What elements of the teaching–learning process are enhanced in a mentoring experience between fourth- and second-grade students?

2. Materials and Methods

The mentoring intervention was conducted during the last semester of the academic year 2018–2019 in the second grade of primary school (7–8 years old) of a public school in Spain. The experience consisted of a quasi-experimental study because the participants were not selected randomly [36]. Hence, the sample was configured by the individuals pertaining to the natural second-grade classroom. As we will describe, the second-grade classroom was mentored by 9 fourth-grade students who taught about the use and coding of the educational robot Bee-bot. In this sense, we designed a one-group post-test-only study configured as a pre-experimental design [37]. These kinds of studies involve a low-incidence population of students, and the interventions are usually carried out in natural classrooms. Although these studies present a lack of a comparison group, they are particularly common in educational research where changes in educational outcomes derive from modifications of the learning process. Moreover, as with much research conducted in school contexts, the ethics prevented us from configuring a control group in which children would be deprived of this mentoring experience.

In order to address the research questions, we had configured a mixed quantitative–qualitative approach. Quantitative data will be obtained to measure the CT skills deployed during the mentoring intervention. In Section 2.2.3, we will precisely describe the instrument devoted to this purpose. Concerning the qualitative data, they will be obtained from the interactions of each mentor with their students and from the motivation perceived by the researchers during the intervention.

This section begins with the description of the participants. In Section 2.2, we describe the materials used to carry out the mentoring experience and the instrument used in order to assess the CT skills after the experience. Finally, in Sections 2.3 and 2.4, we describe the design of the mentoring experience and a brief overview of the implementation.

2.1. Participants

As stated, the mentoring experience with Bee-bot was carried out in a second-grade classroom formed by 24 students. The ages of the students ranged between 7 years 1 month and 8 years 1 month (*M* = 7 years 6 months, *SD* = 10 months). The mentors in charge of the experience were 9 students from the fourth primary grade selected by the teacher. It is important to mention that all the students of fourth grade completed a robotics-based instruction on Bee-bot prior to this experience. This fourth-grade robotic instruction consisted in a one-week program (45 min per day) based on coding Bee-bot to complete paths similar to those shown in Figure 1 with the coding box [38]. The selection criterion for these mentors was based on their grade qualifications in this one-week robotics-based instruction.
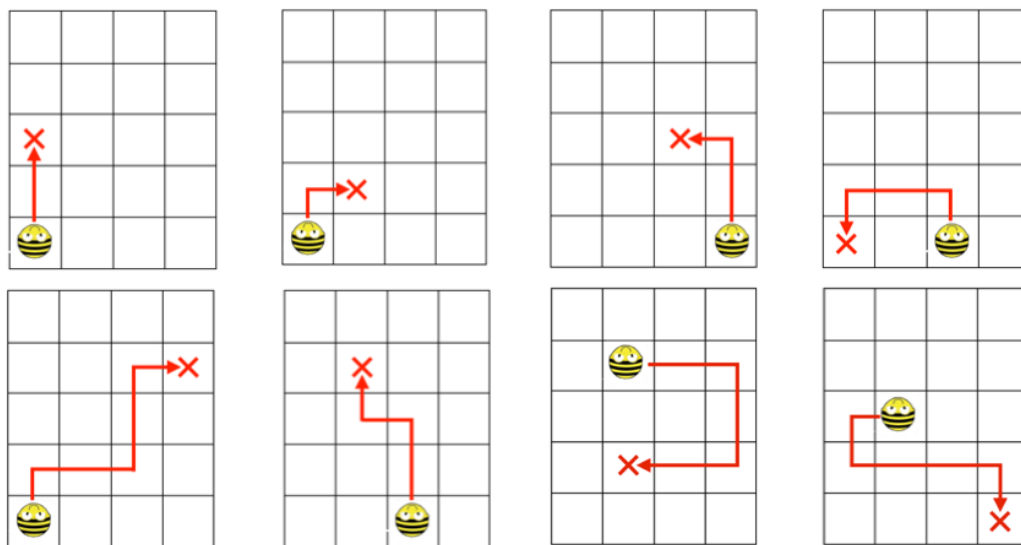

Figure 1. Paths to be completed with Bee-bot during the one-week robotics instruction carried out by fourth-grade students.

2.2. Materials

2.2.1. Bee-Bot

Bee-bot (Figure 2) is a commercial robot adapted to be child-used, and has been classified as a *Tangible User Interface* in the taxonomy of Strawhacker and Bers [39]. Bee-bot allows children to initiate their coding skills through visual instruction blocks presented as buttons on the top of the robot. Usually, the use of Bee-bot in education is intended to develop the coding skills and visuospatial abilities in early-years students (see [40–42], for example).

Figure 2. Bee-bot robot (**left**); coding instructions available (**center**); Bee-bot activity board (**right**).

As seen in the center panel of Figure 2, Bee-bot presents different coding instructions that allow us to communicate with the robot. All the movement actions are relative to the reference system of the robot itself. Summarizing, these are the available options:

- Two *turn instructions* (right or left): Make the robot turn 90 degrees (clockwise or anti-clockwise) over itself.
- *Forward* and *Reverse*: Correspond to straight-line movements of the robot of 15 cm; the robot does not change its orientation.
- *GO*: Executes the instructions introduced up to that moment.
- *PAUSE*: Executes a one-second stop between the instructions where this instruction is located.
- *CLEAR*: Clears all sequenced instructions.

Due to the particular movement characteristics mentioned above, the usual tasks presented to be completed with Bee-bot consist of board panels with a 15 cm grid (Figure 2, right). The grid gives the student a better conceptualization of the space that surrounds the robot [41]. This fact translates into an aid when the student thinks about the coding instructions that have to be programmed to move the robot to a determined point.

2.2.2. The Coding Box and the Path Tasks

In order to present coding situations in the sense of computer science, we have implemented a physical card system, called the *coding box* in the following [43,44]. Each card represents a block to be sequenced in order to make the robot complete a path on a grid board. In our case, we use the cards shown in Figure 3. These cards are intended to be sequenced in the board shown in the right panel of Figure 4, similarly to how a program is created to be read and executed in any visual block programming language.

Figure 3. Cards used as coding instructions on Bee-bot.

Figure 4. (**Left**) Example paths used in the first session. (**Right**) Hands-on coding of Bee-bot.

In this mentoring experience, we focused on special kinds of tasks to be completed with Bee-bot, the so-called *path tasks*. These tasks consisted of coding Bee-bot to go across a marked path on a grid board, similar to those shown in Figure 1. Several boards were prepared to speed up the process of

presenting the path tasks, one per task. For completing each path task, participants were invited to prepare the movement instructions on the coding box with the cards. Once it was done, they could transfer the instructions to Bee-bot, as seen in the right panel of Figure 4.

2.2.3. CT Assessment Instrument

In order to measure the CT acquisition, we adapted the validated test developed by Román-González et al. [45], which evaluates different dimensions of CT. Since the original test was proposed for students ranging from 5th to 10th grade, we adapted for second-grade students only the items related with the following components: Basic directions and sequences (four items), loops—repeated times (four items) and loops—repeated until (three items). At the end, the test consisted of 11 items that were evaluated as correct or incorrect. The test was completed by the students two days after the mentoring intervention with the Plickers webtool (https://get.plickers.com/).

2.3. Mentoring Experience Design

The mentoring proposal was designed with a two-fold aim: (i) To observe the coding knowledge achieved by the fourth-grade mentors during the previous one-week instruction (this issue is not addressed in this work), and (ii) to serve as an opportunity to interact, in a cooperative way, between fourth-grade mentors and second-grade mentee students.

The duration of the mentoring experience was intentionally designed to be short: Two sessions of 45 m each. This duration was chosen in order to be realistic according to the time usually devoted to robotics-based activities in a second-grade class. The mentors selected the contents and the development of the two sessions for the second-grade students. These sessions were modeled by the mentors after the one-week Bee-bot instruction that they received previously. The teachers of each classroom and the researchers supervised the design and selected the path tasks to be completed by the mentored students. The first session was devoted to an introduction to Bee-bot conducted by the mentors; the second session was intended to promote the second-grade students' acquisition of CT skills without the intervention of the teacher. Table 1 depicts the detailed scheme of each session.

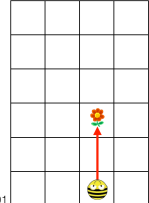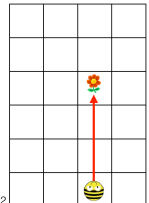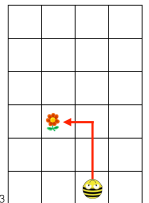**Table 1.** Contents addressed during the mentoring experience conducted by fourth-grade students.
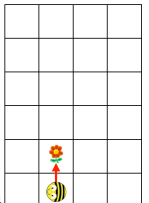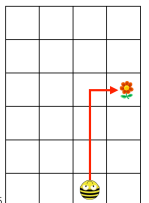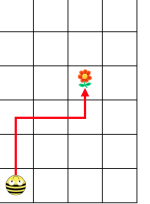
Session 1. Introduction about robots: What does coding mean?   What is Bee-bot? Buttons and movements   Coding with Bee-bot: Use of the coding box   Completing a path task with Bee-bot
Session 2. Brief reminder about the use of Bee-bot   Path task resolution with Bee-bot and the coding box

2.4. Mentoring Experience Implementation

The 24 students of the second-grade classroom were divided into nine groups; each mentor was in charge of one group. In particular, six groups were formed by three students, and three groups were formed by two students. As described in Table 1, the first session opened with an introduction to robotics and coding. To better understand what coding means, the buttons and movements of Bee-bot were examined and described using the coding box with simple paths (described in Figure 4).

The second session began with a brief overview on the fundamentals of coding with Bee-bot. Each mentor presented to their group a set of path tasks to be completed during the remaining time of the session with the help of the coding box. At that time, the mentors adopted a guiding role. If they found that their students were not doing the task correctly, then the mentors interceded in order to re-explain the coding basics. In Table 2, we show the path tasks presented to the mentored groups, extracted from the work of Pérez and Diago [38].

Table 2. Path tasks presented to each second-grade group during session 2 of the mentoring experience.

3. Results and Discussion

As no pre-test was administered previously to the intervention, the data obtained were analyzed using an exploratory approach. We present the results with a descriptive case-study methodology, focusing on the effects of the mentoring experience on the second-grade students' motivation and CT skills as a *contemporary phenomenon in a real-life context* [46] (p. 73). Two kinds of data were collected: (i) Qualitative data from the observations of the interactions of each mentor with their students, and (ii) quantitative data from the CT test completed by the second-grade students.

Overall, from observational data collected by the researchers, the mentoring experience went better than expected in terms of motivation. To this end, researchers completed a three-point scale concerning students' participation during each one of the sessions (very participatory, not very participatory, not participatory). From these data, 80% of the students were motivated during the sessions and showed a positive attitude. Despite the collaborative environment of the mentoring experience, 15% of the students were not very participatory. Those students corresponded to students who did not work normally in the regular classes. The other 5% of the students were students who did not attend one of the sessions.

3.1. Impact of the Mentoring Experience

As said briefly in the previous paragraph, during the mentoring experience, the excitement of the students could not be avoided. Although no categorical analysis was carried out, we present here the perceptions observed and written down during the mentoring experience in terms of the students' excitement. From a comparison to the standard class routine, the reason for the positive reception was obvious: The two-fold innovative practice. On one hand, it was the methodology; the mentoring approach gave an opportunity to work differently from the regular-class methodology and with the accompaniment of the mentors. On the other hand, it was the contents; STEAM contents, robotics in particular, resulted in attractive and new content for all students. Especially during the path tasks (session 2), each student in every group contributed with different ideas, trying to resolve together the problems presented. There was no time for negative behavior or contempt for any contributions of their classmates. When someone disagreed, they spoke in a reasoned way. In general, the acceptance of the experience was very positive. Despite the young age of the second-grade students, they attended to their mentors with great expectation and attention, listening carefully to all the explanations that were provided by the mentors. These observations are aligned with other mentoring experiences encompassing robotics, as the observed impact on the second-grade mentees points towards a positive effect on the attitudes regarding STEAM contents, a better critical thinking, and an improvement of teamwork skills [47–49]. The attractiveness of robotics-based activities could be a plausible explanation for these improvements, but the rationale is not clear. These interpretations need to be tested in further research due to the exploratory character of this study.

Concerning the performances of the students, although the separation into groups was totally random for both the groups and mentors, we observed qualitative differences between groups. In particular, we observed dissimilar ways of internally compiling the information provided, both in

the explanations (session 1) and in the path task performances (session 2). This fact was probably due to the maturity of students, which is very unalike at these ages.

3.2. CT Assessment

As described in the materials section, the acquisition of CT abilities was evaluated through a selection of 11 items of the validated CT test developed by Román-González et al. [45]. The test was filled out two days after the last of the sessions by all the students through the Plickers platform. Figure 5 shows the percentages of correct answers for the CT test. Out of a total of 11 questions, almost all the students (95%) answered more than five items on the CT test correctly. Only one student answered less than 45% of the questions related to CT skills. The rest of the students, despite the lack of previous knowledge on coding or sequencing instructions, solved more than 50% of the CT test items correctly.
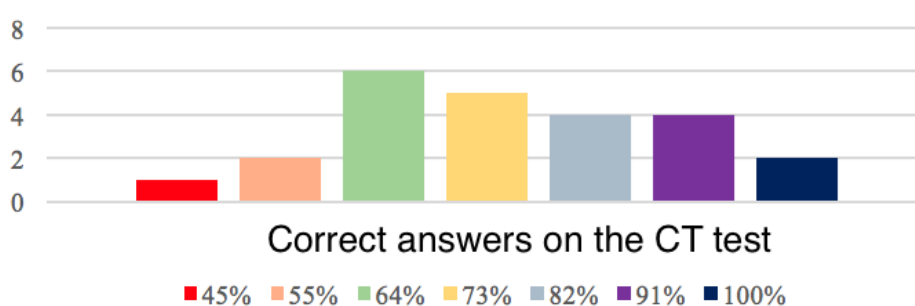

Figure 5. Percentages of correct answers for the computational thinking (CT) test completed by the second-grade students.

The results obtained in the evaluation test led us to conclude that second-grade students are able to learn CT skills through a mentoring process. We are aware that only some of the validated test items were used, but this part evaluates elemental CT skills and concepts: Basic directions and sequences, and the "repeat times" and "repeat until" sentences concerning loops. A more detailed study will be needed to assess other CT dimensions, such as design process or debugging. In general, our results led us to conclude that the second-grade mentee students had been able to understand the essential notion of what algorithms are in terms of developing a plan to solve a problem. They were capable of creating simple programs through the Bee-bot environment by making use of the coding box as a first approximation of conventional coding languages. Moreover, their knowledge on patterns and sequenced instructions was promoted through this mentoring experience.

4. Final Remarks

Although this exploratory study is susceptible to some limitations, it addresses an educational intervention in a real classroom situation based on a mentoring experience. In particular, through this research, we have been able to explore variables and factors to be addressed in future research works related to the acquisition of CT through mentoring.

The present study provides evidence on mentoring as an effective way to learn basic CT skills. In particular, we have proof that the second-grade mentee students were able to acquire the basics of coding through the Bee-bot robot and the coding box tool. Concerning the teaching–learning process involved in this mentoring experience, we observed that the use of robotics through mentoring supposes a very positive contribution to the autonomous work of both the second- and fourth-grade students. We emphasize the use of basic ER, such as Bee-bot, as an initiation environment to develop coding skills in early-years students. These technological environments allow teachers to present basic coding skills to young students, such as implementing a plan/algorithm, debugging, and testing.

Finally, this mentoring experience became an opportunity to promote cooperative work, not only between students of the same age. On one hand, the second-grade mentees experienced an extra motivation, since the students learned by playing, investigating, observing, and cooperating. On the other hand, the fourth-grade mentors showed their skills in robotics and coding by guiding the second-grade students to complete the coding activities. In general, we can say that this mentoring project was awarded a very positive reception. It is true that some of the students did not engage 100% with the experience, but for the majority, it was an opportunity to be creative and responsible for their own work.

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