Effects of the Use of Robots on Algorithmization, Decentration and Locating in the Plane Skills

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Abstract. Now that computer science (CS) has entered the curriculum, two questions regularly emerge: on the one hand, teachers wonder in which time slot to teach CS and, on the other hand, they wonder about the equipment to be used and thus the methods of implementing the activities (plugged or unplugged). Without a time slot in the schedule, CS activities are widely used in mathematical activities, especially for planar orientation. In this context, we question the effect of the use of a robot by 10 to 12-year-old students on their abilities to create an algorithm, decenter, and coordinate in the plane. An experimental method was conducted with thirty-six students divided into two experimental groups (with and without robots). Four critical skills were assessed in a pre- and post-test: algorithmization, decentration, absolute location, and relative location abilities. The results show that the students who programmed the robots made more progress overall than those who performed paper-based tasks only. The algorithmization performance of both groups improved significantly, showing that this skill can be trained in both plugged and unplugged activities. The contribution of this research is twofold as it shows the effect of the use of educational robots on students' ability to decenter and, assures teachers that they can use both plugged and unplugged modalities for computer science activities during planar orientation activities in mathematics.

Keywords: teacher education · computer science education · disciplinary course

1 Introduction & Context

Computer Science (CS) entered the compulsory school curriculum in the French-speaking part of Switzerland in 2021. Since no time slot is dedicated to its teaching in the K-8 timetable, this new discipline has largely found its place in mathematical activities, particularly in those of locating in the plane. Indeed, the design of a route is a recurrent task in geometry and it can be materialized by educational robots (ER) which execute programs to move from point A to point B. As computer science is not a subject that is being thought on its own, it needs to be integrated into other subjects. Therefore we often see the use of robots in mathematics, but it is also used during language courses. The use

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of ER then allows "placing the student at the heart of the conscious learning process, which sees him/her involved as an actor of his/her own learning tools" [7] (p. 35). Beyond this pedagogical added value, it remains relevant to study the contributions of ER to the construction of knowledge in both CS and mathematics. In the context of the route task, each of these two disciplines mobilizes the notion of algorithmization as knowledge to be constructed, while relying, as a prerequisite, on the students' ability to locate in the plane. However, the literature indicates that this prerequisite is often underestimated and that the ability to locate in the plane often poses difficulties for students [2] insofar as it implies, upstream, the ability to decenter [13] and thus to locate in space. Faced with such a nesting of abilities, it is clear that the route task is not so easy. However, the literature also shows that the use of ER, such as the Blue-bot robot (TTS Group Ltd, Hucknall, Nottinghamshire, United Kingdom), allows precisely the training of students' ability to decenter [8,3]. Therefore, our research question is the following: **if ER allows students to develop their ability to program and to decenter, does it have also a positive effect on their ability to locate themselves in the plane?** As a result, the objective of the present study is to measure the effect of the use of ER on formulating an algorithm, decentration, and locating in the plane abilities of 10 to 12-year-old students. Our research hypotheses are as follows: 1) Students who performed the route task by programming a robot (test group) will improve their ability to decenter (thus to locate in space) significantly, while this will not be the case for students who only performed the same task on paper (control group). 2) The students who performed the route task by programming a robot (test group) will significantly improve their ability to locate on the plane, as a result of the development of their decentration skills, while the students who only performed the same task on paper (control group) will not.

This paper has the following structure: in Section 2, we mention analyses of similar initiatives or approaches to CS education of future teachers. Subsequently, we talk about the source of the data we collected to answer our research question in Section 3 and analyze it in Section 4. We conclude finally in Section 6.

2 Related Work

2.1 Locating in the Plane

According to Piaget [12], knowledge related to locating in space develops in childhood when the child is in the operative stage (between the ages of 7 and 12). At this stage, children can adopt different points of view from their own, in particular, to distinguish between what is in front of them and what is behind them, but they still have some difficulty distinguishing between left and right. Moreover, knowledge related to planar location is developed around 11-12 years old, when the child moves into the formal operative stage. Euclidean space (coordinate space) then appears, which corresponds to "global knowledge of an environment independent of the individual's point of view" ([10], p. 25). Furthermore, three types of cues can be distinguished according to Charnay and Douaire [4]: 1) The subjective cue that takes into account the observer's point of view i.e., the cue is placed on the subject, and the directions are determined according to the subject's frame of reference; 2) The objective reference point which is independent of the observer's point of view i.e., the chosen objects are used as temporary reference points and the directions are defined independently of the observer's point of view; 3) The absolute reference point i.e., reference points defined by a reference point (origin) and directions and orientations (graduated axes). Based on this state-of-the-art, in-plane locating tasks often consider, on one hand, the relative cues and, on the other hand, the absolute cues.

Moreover, while manipulating objects, 2 spaces should be considered: the micro-environment considers the space between the student and the plane while the meso-environment considers the space between the student and the robot which moves both in the plane and in the space. The use of robots thus adds complexity to the task of locating objects in the plane.

2.2 Decentration and Robots

Locating in space requires the ability to decenter, i.e. to adopt points of view other than one's own. According to Piaget[12], during the decentration process, the subject moves from the spatio-temporal stage to the logical-mathematical stage. As soon as students start using an object (such as a robot), they need to know how to decenter from it, so as to be able to locate in the plane and space. In this regard, a study [14] tested students' ability to distinguish left and right through a paper-based activity versus an activity with a robot. This study was carried out in Quebec with 22 students aged 6 and 7. The results were similar between the pre-test (60% success rate before the activity with the robot) and the post-test (62% success rate after the activity with the robot), which does not, at this stage, allow us to attribute an effect of the use of a robot on the decentration activity. Nevertheless, according to the researchers, we should continue to explore the effects of paper-based activities aimed at decentration awareness, and the effects of activities with educational robots that mobilize cognitive strategies on decentralized movement planning. Our study thus allows us to continue exploring this avenue, albeit with older children (aged 10 to 12).

2.3 The Route Task and the Skills of Algorithmization and Programming

While the route task is aimed at the ability to locate in the plane, it is also often implemented to develop the ability to anticipate what is needed for problem-solving. It is in this context that the notions of algorithmization and programming take their place in both mathematics and CS. Learning to program, using educational robots is a relatively recent pedagogical approach [11]. The task of moving from point A to point B (referred to here as the route task) offers an affordable programming opportunity, insofar as the problem-solving posed by this task is common. Programming involves writing computer code to create a program to be executed by a machine (in this case, a robot). This program tells the robot what to do and how to do it. As a result, the problem-solver (here, the student) needs to think before programming in order to be able to solve the problem [6] behind the route task. As these previous authors demonstrate, educational robots are tangible, offering students the chance to put their thoughts into practice by manipulating them. Like puppets, students move them (for example) to embody the solution to the problem posed. It is at this point that students verbalize a solution, i.e. formulate in their own words the behavior of the robot to be programmed. The next step is to transpose this behavior, formulated in the student's language, into a programming language (the robot's). In the context of our study, it is pertinent to delineate between the proficiencies of algorithmization and programming, considering that not all students engage in robot programming. Algorithmization, herein, pertains to the procedure involving the conceptualization, formulation, and construction of algorithms. In our pedagogical approach, students are tasked with the creation of a comprehensive set of sequential directives, transcribed onto paper, aimed at strategizing a navigational course from point A to point B. The act of programming itself involves a whole range of actions and thoughts, and when it comes to programming robots, it also involves the physical dimension and spatial location (not just in the plane). In fact, according to [7], the specific features of robots compared to other digital tools, such as computers, are on the one hand that "the robot is distinguished by its nature as a real and systemic object", which contrasts with the virtual character of computer-based educational software [9], and secondly that the robot can "combine learning from robotics and learning by robotics".

3 Data Collection & Methodology

3.1 Population

In order to address our research question, we conducted a quantitative quasi-experiment involving two classes from primary schools in Switzerland's Canton of Vaud. A total of 36 primary students aged 10 to 12 participated in the study, which lasted three weeks. In order to create two equivalent groups, the overall score on a pre-test, which measured all four skills (decentration, algorithmization, relative location, and absolute location) was assessed (Table. 1). The research was conducted in accordance with the stipulations set forth in the 190 decision of the education department of the canton of Vaud (Switzerland), which required anonymization of data, consent from school principals, and voluntary participation with written consent from legal representatives of the participants. The study was conducted by two pre-service teachers from HEP Vaud with the assistance of two qualified primary teachers. One researcher was present per class to oversee the experimental groups and only intervened if there was an issue with the robots. The other qualified teacher oversaw the control group and intervened only to correct exercises when they were finished. Most students never programmed a robot before and never had a computer science course as it is not implemented in the curricula. However, all students knew how to use a tablet and received a short 30-minute introduction to the Blue-bot robot.

	Experimental group	Control group	Total
Number of girls	11	10	21
Number of boys	7	8	15
Total	18	18	36
Grades x<60	7	8	15
Grades 60<x<80	4	5	9
Grades x>80	7	5	12

Table 1. Distribution of participants in both groups.

3.2 Design of the Study

The experimental group received a 90-minute math course dedicated to the coordinate plane and locating objects in space, during which they programmed a Blue-bot robot using the Blue-bot application on a tablet. Each group was provided with one robot, a gridded floor mat, a tablet, and an exercise worksheet (Appendix. 8). The control group performed a paper-based activity in pairs, completing traditional mathematical exercises (Appendix. 8). Both groups received similar feedback: the control group was informed if an exercise was correct or incorrect, while the experimental group received feedback from the tablet or the robot. All the exercises used in the study were sourced directly from Swiss exercise books or were modified to align with the robot-based activities. The 90-minute session required students to create an algorithm to guide a robot from point A to point B. While students working on paper wrote down the algorithm (which they embodied in a programming language made of arrows), students working with the robots programmed the path on a tablet (Table. 2). As the paper-based activity was routine, students were expected to complete it more quickly. On the other hand, students working with the robot were expected to take more time by programming the robot to accomplish the task.

Pre-test	Introduction to robotics	Robots and Paper activity	Post-test	Exchange groups
All students 30 minutes	All students 60 minutes	Gp 1 with robots Gp 2 on paper 90 minutes	All students 30 minutes	Gp 1 on paper Gp 2 with robots 60 minutes

Table 2. Design of the experiment

It was known beforehand that the precision of the movements of the Blue-bot would pose a challenge for students in the experimental group. Due to the robot's tendency to move 15cm and turn 90°, it was anticipated that the robot may not always end up in the precise location intended. The students were advised of this issue and were instructed to replace the robot when necessary. Furthermore, it was anticipated that programming exercises would be relatively more manageable for students working with the robot, while more conventional coordinate plane exercises would prove more difficult with the robot. Conversely, it was also anticipated that students working on paper would experience greater difficulty with the algorithmization, but would face less difficulty with the coordinate plane exercises. While creating the exercises, we presumed that students might encounter challenges in transferring their learning from the robotics-based activities to the paper-based post-test.

3.3 Data Collection & Data Analysis

The experiment tested a two-modality experimental condition: with a robot and without a robot (on paper). To measure the learning of decentration and locating in the plane, we created a paper-based pre- and post-test, which measured four skills: decentration, algorithmization, relative location, and absolute location. These skills were broken down into measurable indicators (Appendix. 6). The pre- and post-test were given before and after the paper-based activity and the robot activity. The dataset utilized in this study consisted of points, each representing a continuous variable. The study quantitatively evaluates the dimensions of decentration and algorithmization. For each instance where the student is required to decenter themselves, one point is awarded if the spatial rotation is executed accurately. Similarly, one point is awarded for the correct execution of a series of steps to evaluate the dimension of algorithmization. The dimensions of absolute and relative locating are evaluated qualitatively based on four weighted criteria, each with a weightage of two points: coordinate order, coordinate sign, origin accuracy, and precision. Scores were assigned based on a total of 16 to 27 points and were weighted to reflect the students' competencies as closely as possible. The pre-test in decentering provided a baseline score and ensured that the control and experimental groups were equivalent. The present study employed a statistical analysis using the Wilcoxon signed-rank test. Excel and XLSTAT software were used for data analysis and visualization. Due to a limited sample size of 18 students per group, the Wilcoxon test was utilized as it is well-suited for assessing significant differences in small paired samples.

4 Findings

The mean scores of students' pre- and post-tests were compiled in a table that can be found in Appendix. 7. The mean scores for the experimental group and control group were compared to assess the effectiveness of the robot intervention. A statistically significant improvement ($p < 0.05$) in all mean scores was observed for both experimental and control groups, with the exception of the absolute locating skill within the control group.

4.1 General Achievement in the Tests

The test revealed a significant difference between the pre- and post-test scores for the experimental group, with a Wilcoxon signed-rank test statistic of $T = 2.50$ ($p = 0.000$). The test also revealed a significant difference between the pre- and post-test scores for the control group, with T = 31.50 ($p = 0.009$). This indicates a statistically significant improvement in performance regardless of the group to which they were assigned. The findings of this study indicate that the choice between paper-based and robot-based instruction does not significantly influence the overall grades of the students. However, it is important to conduct a detailed analysis of each specific skill to determine if there are any significant differences between the two instructional methods.

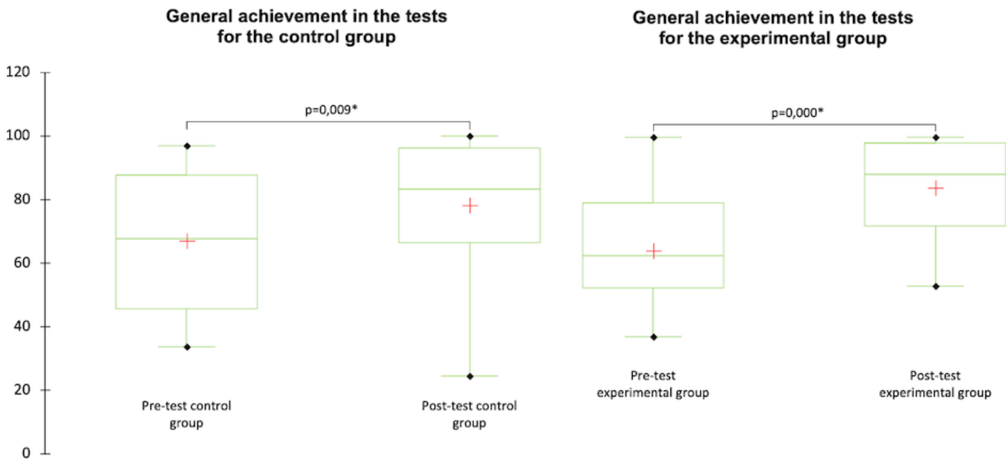

Fig. 1. Graph of general achievement of both groups in the tests.

4.2 Achievement in decentration

The results of the study revealed a significant difference between the pre- and post-test scores for the experimental group, with T = 25.5 ($p = 0.014$). Upon conducting a detailed analysis, it was found that the skill of decentering exhibited a significantly greater improvement in the group assigned to manipulate robots compared to the paper group.

4.3 Achievement in Algorithmization

Our study findings indicate that participants' algorithmization skills significantly improved, regardless of whether they completed the exercises on paper or by using a Blue-bot robot. Both the experimental group and control group demonstrated substantial performance gains in their algorithmization abilities. The Wilcoxon signed-rank test statistics were T = 12 ($p = 0.003$) for the control group and T = 2 ($p = 0.000$) for the experimental group, indicating that the intervention effectively enhanced this skill regardless of the mode of delivery.

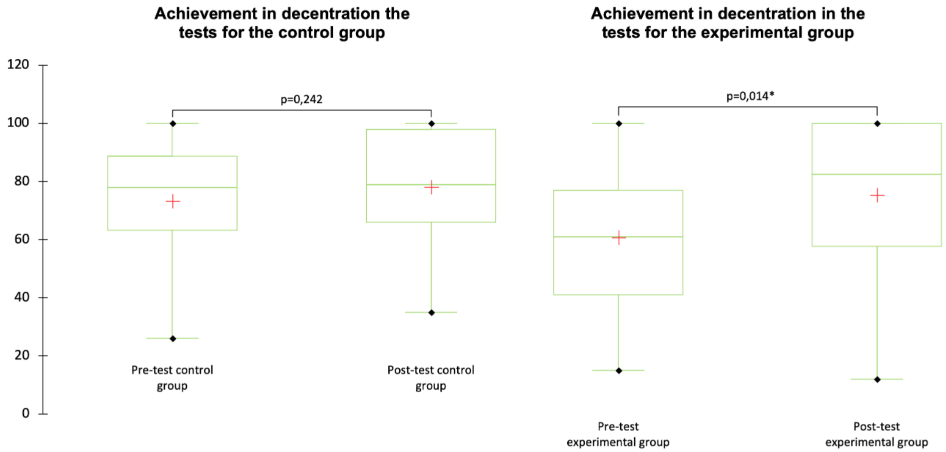

Fig. 2. Graph of achievement in decentration for both groups in the tests.

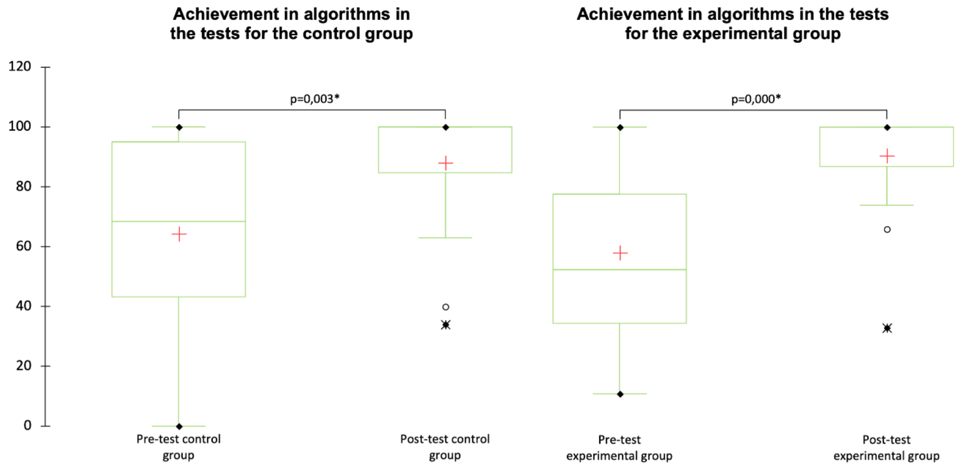

Fig. 3. Graph of achievement in algorithmization for both groups in the tests.

4.4 Achievement in Relative Location

The results of our study also demonstrate that all participants significantly improved their relative location skills, irrespective of their group allocation. The Wilcoxon signed-rank test statistics were $T = 9$ ($p = 0.020$) for the control group and $T = 13$ ($p = 0.026$) for the experimental group, indicating that the intervention effectively enhanced this skill regardless of the mode of delivery.

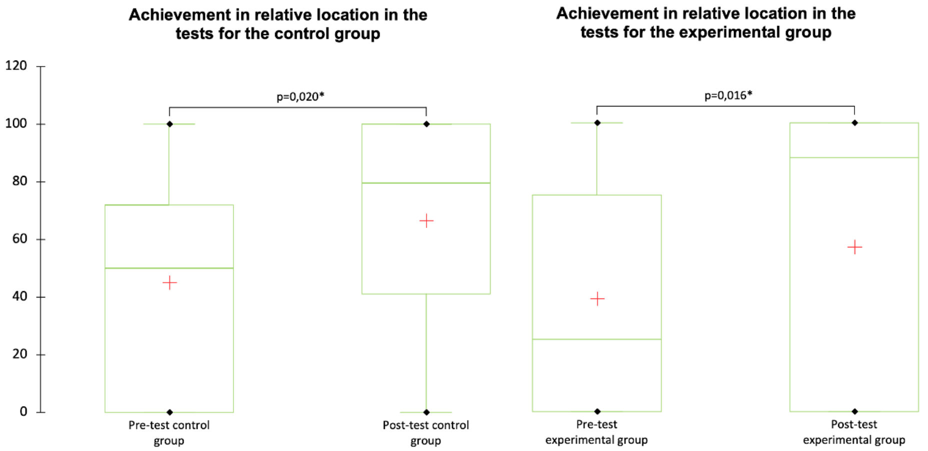

Fig. 4. Graph of achievement in relative location for both groups in the tests.

4.5 Achievement in Absolute Location

The results of the study revealed a significant difference between the pre- and post-test scores for the experimental group, with T = 10.5 (p = 0.040). The findings suggest that the robot-assisted intervention used in the study was particularly effective in enhancing the absolute location ability of the participants.

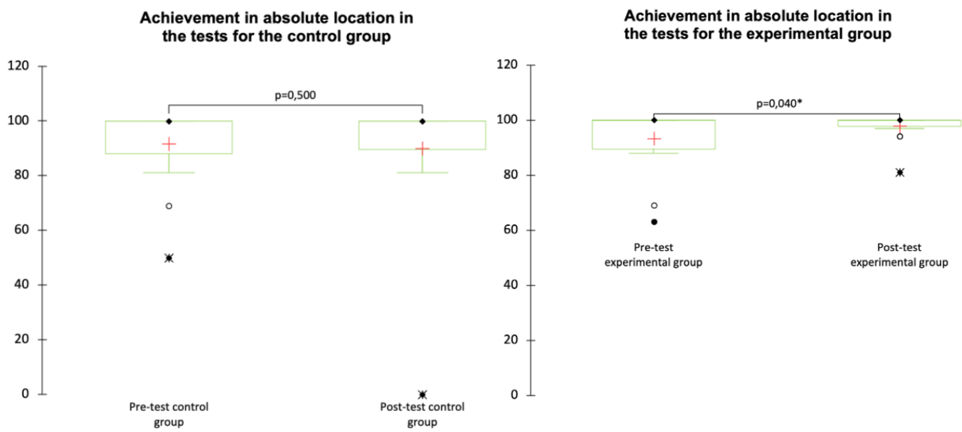

Fig. 5. Graph of achievement in absolute location for both groups in the tests.

5 Discussion

The purpose of this study was to explore the potential benefits of manipulating and programming robots in order to develop decentration and spatial location skills.

Our first hypothesis proposed that students who programmed a robot would significantly improve their ability to decenter. Our findings support this hypothesis. The engagement with robot programming seemed to facilitate a deeper understanding of spatial relationships and improved spatial navigation. Our research findings support existing literature, affirming that programming enhances decentration skills. The Blue-bot application facilitated decentration and anticipation, which are essential components of the learning process [8]. Furthermore, the provision of immediate feedback by the Blue-bot robot reinforced the positive effects on decentration. By promptly recognizing errors and limitations in decentration, students became aware of the challenges involved and demonstrated self-regulatory behaviors. Immediate feedback is particularly beneficial for procedural learning [15], and since decentration is a procedural skill, it requires timely feedback for effective acquisition. In contrast, the control group, which did not receive immediate feedback, experienced greater difficulty in recognizing their own limitations in decentration. Therefore, the disparity in results regarding decentration skills can be attributed to the more direct and tangible approach utilized in the experimental group, involving the robot, as well as the provision of immediate feedback, which facilitates the regulation and learning process associated with decentration.

Our second hypothesis suggested that the experimental group, who engaged in robot programming, would demonstrate a significant enhancement in their spatial skills compared to the control group. Our findings provide further support for this hypothesis, as they reveal that students who engaged in robot programming exhibited notable advancements in their absolute locating abilities. The development of decentration appeared to play a pivotal role in the participants' enhanced capacity to mentally manipulate objects within a plane and comprehend spatial relationships more proficiently. These results have been shared with the teachers of both classes and will be taken into account in further mathematics and computer science courses. Students who solely worked with paper materials remained confined within a limited micro-environment, lacking the stimulus to explore beyond their immediate paper sheet. In contrast, students manipulating robots transcended this micro-environment and transitioned to a broader meso-environment by constantly walking around the Blue-bot grid. We postulate that the size of the resources utilized may have influenced the students' engagement with the environment.

While the absolute locating skill was improved only by the experimental group, the relative locating skill was significantly improved by both groups. Decentration is useful for relative location [4], which explains why the robot group was able to improve this ability. However, a valid question arises as to why the control group also exhibited significant advancements (p-value $= 0.003$) despite the absence of notable improvements in decentration skills. We posit that this occurrence may be attributed to the delayed feedback they received, which fostered a more comprehensive understanding of the concepts at hand [5].

Lastly, our findings in the algorithmization skill showed that both groups improved significantly. Research indicates that algorithmization can be effectively taught through both plugged and unplugged approaches [1]. Thus, both groups in our study were provided with opportunities to engage with this concept, either by directly programming robots or by manually constructing algorithms on paper. The cognitive processes involved in the creation of algorithms were highly similar across both groups. Notably, students in the experimental group received immediate feedback, enabling them to self-regulate. In contrast, the control group received delayed feedback, as their exercises were corrected by the teacher once all tasks were completed. Nonetheless, substantial progress in algorithmization skills was observed in both groups. It can be postulated that immediate feedback facilitates task completion, whereas delayed feedback encourages the development of problem-solving strategies. These findings align with previous research, which demonstrates that delayed feedback stimulates the cultivation of anticipation processes and the formulation of more refined behavioral instructions for programming the robot [5].

It is important to acknowledge that further research is needed to validate these findings across larger and more diverse samples, as well as explore the use of robots with more complex tasks and prevent students from getting immediate feedback. Such investigations would contribute to a more comprehensive understanding of the benefits and implications of integrating robot programming into educational practices.

6 Conclusion

This research aimed to investigate the impact of manipulating robots on decentration skills and performance in locating in the plane among 10 to 12-year-old students. The study included two experimental groups, one using robots and one without robots, with a total of 36 participants. Pre- and post-tests assessed four key skills: decentration, algorithmization, absolute locating, and relative locating. The results indicated that students who programmed the robots showed a greater overall improvement, particularly in the skill of decentering, which had a positive effect on location in the plane.

Students who did not manipulate robots demonstrated an understanding of algorithms, as a result of delayed feedback. Both groups made significant progress in algorithmization skills, highlighting the effectiveness of both plugged-in and unplugged approaches.

However, it is important to note that these results are limited by the small sample size of the study. Future research should aim to replicate these findings on a larger scale to further investigate the effects of educational robots on decentration and location skills. Overall, educational robotics has the potential to contribute to both mathematical and computer science education, which proves that ER has its place in primary schools. We strongly believe that computer science supports mathematics and vice versa. A programmer needs to know basic mathematics to understand algorithmization, but computer science also supports mathematics by enabling students to manipulate abstract concepts.

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Appendix

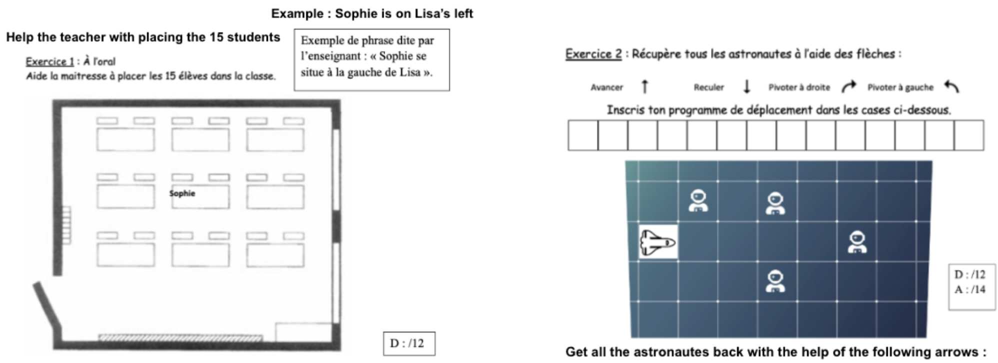

Fig. 6. Example of tasks in Pre- and post-tests. Original instructions in French with English translation.

General achievement	Observations	Minimum	Maximum	Median	Mean	SD
Pre-test control group	18	34	97	68	67	21
Post-test control group	18	25	100	83	78	22
Pre-test experimental group	18	37	100	63	64	18
Post-test experimental group	18	53	100	88	84	15
Decentration achievement	**Observations**	**Minimum**	**Maximum**	**Median**	**Mean**	**SD**
Pre-test control group	18	26	100	78	73	23
Post-test control group	18	35	100	79	78	19
Pre-test experimental group	18	15	100	61	61	25
Post-test experimental group	18	12	100	82	75	27
Algorithm achievement	**Observations**	**Minimum**	**Maximum**	**Median**	**Mean**	**SD**
Pre-test control group	18	0	100	69	64	33
Post-test control group	18	34	100	100	88	21
Pre-test experimental group	18	11	100	53	58	31
Post-test experimental group	18	33	100	100	91	18
Relative location achievement	**Observations**	**Minimum**	**Maximum**	**Median**	**Mean**	**SD**
Pre-test control group	18	0	100	25	39	42
Post-test control group	18	0	100	88	57	47
Pre-test experimental group	18	0	100	50	45	39
Post-test experimental group	18	0	100	80	67	41
Absolute location achievement	**Observations**	**Minimum**	**Maximum**	**Median**	**Mean**	**SD**
Pre-test control group	18	50	100	100	92	14
Post-test control group	18	0	100	100	90	23
Pre-test experimental group	18	63	100	100	93	11
Post-test experimental group	18	81	100	100	98	5

Fig. 7. Table of descriptive statistics

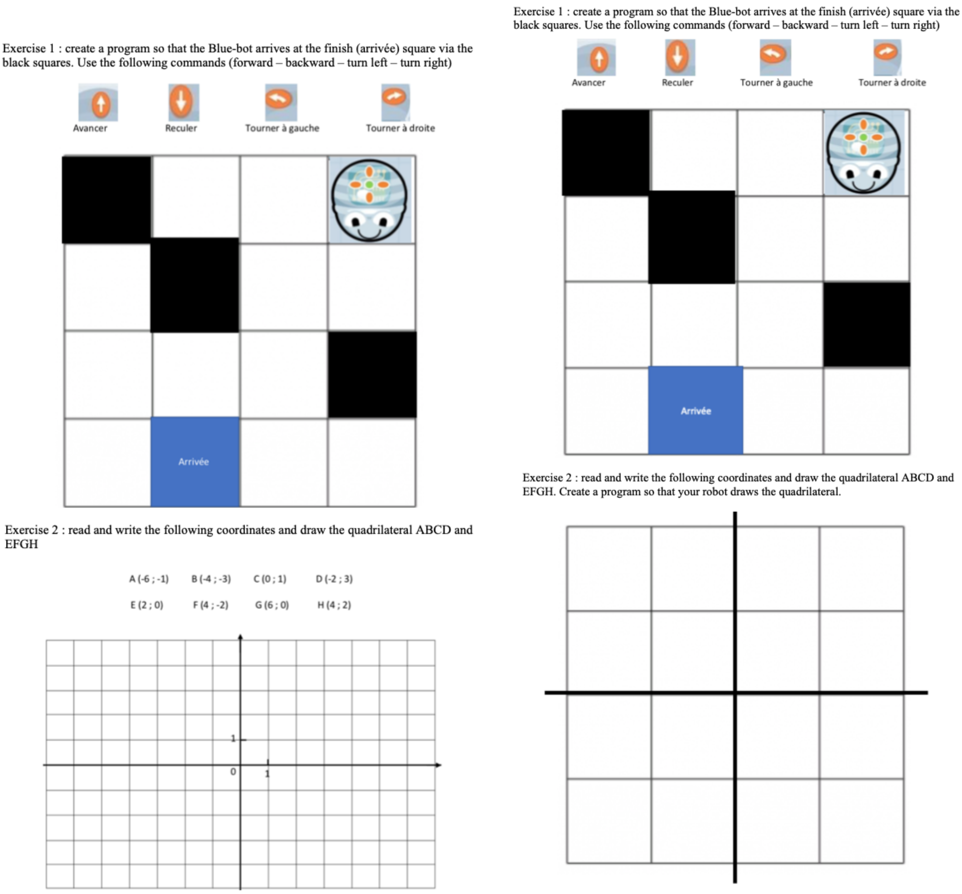

Fig. 8. Left : Paper tasks. Right : Robot tasks. Original instructions in French with English translation.