Methodology and results on teaching Maths using mobile robots

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Abstract. In 58 Italian Public Comprehensive Institutes (Istituti Comprensivi), that include Primary and Elementary schools, 2911 students experimented the use of a mobile robot, Sapientino Doc by Clementoni, to learn curricula matters such as Mathematics, Geometry and Geography (MGG). The project "*A scuola di coding con Sapientino*" was developed during the 2016/2017 regular school year for about 3 months (April-June 2017). The schools were distributed throughout Italy and involved 2911 students from 5 to 8 years old, 155 classes, and 163 teachers. The aim of the research is to demonstrate a learning gain in Mathematics, Geometry and Geography, after the students use a mobile robot during regular lessons held by their own teachers in their classrooms. In this paper, we present the methodology used to develop the project and the results of data analysis.

1 Introduction

A survey on the use of robots in educational field was made by Benitti [2], who reviewed the international literature on Educational Robotic (ER) published over 10 years listing robots, students age and obtained results, and by Mubin[8] who gives an overview on robot kits, robot roles and robot usage domains. About robot kits, a recent study was conducted by Garcia [10] by listing characteristics of robot kits and apps, currently available on the market for teachers of 4-14 age students, and costs, that for Mondada[7] is one of the obstacles to the massive use of robots in the schools. From the literature analysis, it emerges that many of ER activities are extra-curricular, during summer camps or workshops. Few studies show quantitative data, using statistical methods, or a controlled group to compare the results of the test group, or a random choice of the users belonging to each group. Few empirical data are available on the use of low cost robots since in 90% Lego® robots are used. Few studies analyze the use of robots to teach subjects different from computer science or mechatronics. Moreover, the use of robots in a class is not the only favorable condition for learning, but also: the presence of the teacher, the spaces suitable to do the activities with the robot, the availability of one kit for each team of 2-3 students, short theory lessons and tutorials to link theory and practice, realistic but affordable tasks linked with curricular subjects, teachers at ease with the robot, etc. So ER researchers and teachers need to choose the more suitable robot kit for their students, and carefully design where and how to use it and with which role. The analysis of the interviews to 85 students by Shin[11] highlighted that young students prefer a robot that acts as a peer during the learning process. In the ER research field, studies with students 5-12 years old have been conducted using different robot kits. For example, Bee-Bot was used by many authors, including: Highfield[5] with 33 children aged 3-5 years in a Primary school in a 12 weeks project for 2 hours each lesson; Eck [4] with 4-5 years old children, 1 hour a week for 6 weeks; Di Lieto[3], on a sample of 12 children aged 5-6 years, 75 minutes twice a week for 6 weeks. Lego® WeDo was used by Kazakoff, Sullivan and Bers[6] during a 10 hours intensive course in the robotic week with 29 children. Lego® Mindstorms was used by Barker and Ansorge[1], in a post school program with 32 students aged 9-11 years, 1 hour twice a week for 6 weeks, and by Zygouris[13] to teach geometry concepts to 12 years old. Thymio was used by Friebroon and Ben-Ari [12] with thirty 7-8 years old students of Elementary school, while Nulli and Di Stasio[9] used Cubetto with 5-6 years old kids of Primary School during a school year. Our research was conducted using the mobile robot Doc, during the project "*A scuola di coding con Sapientino*", with almost 3,000 5-8 years old students, during the regular school lessons.

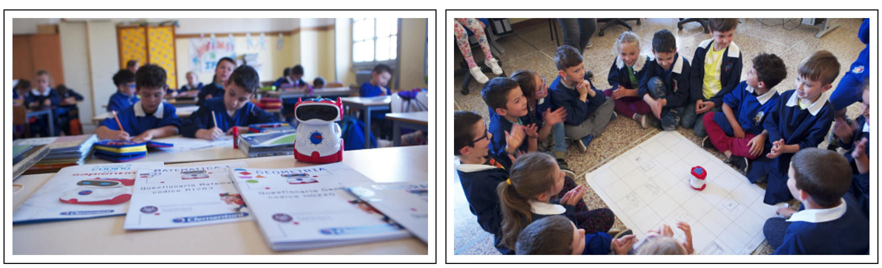

Fig. 1: Educational activity organization: *left*) filling the questionnaire, *right*) learning with robot Doc.

The project "*A scuola di coding con Sapientino*"[3] was promoted by three different subjects: Clementoni, an Italian company leader in educational toys (the Sapientino DOC inventor), DIAG Dept. (Department of Computer, Control, and Management Engineering) at Sapienza University of Rome, and MIUR (The Italian Ministry of Education, University and Research). The project was born with the main shared purpose to bring in the classrooms an easy-to-use and fun tool (the robot Sapientino Doc[4] by Clementoni) to introduce the basic concepts of programming and robotics. The educational activities with the robot (see Figure 1 *right*) were designed to learn main concepts of Maths, Ge-

[3] Web site of the project with additional information, material and results: https://sites.google.com/a/dis.uniroma1.it/doc-scuola/attivita

[4] http://www.clementoni.com/en/61323-doc-educational-smart-robot/.

ometry, Geography (MGG) measuring the learning gain through questionnaires (see Figure 1 *left*).

2 Methodology

The methodology that we used for this project is illustrated below:

1. identify a robot that fits Primary and Elementary schools needs
2. identify the curricula subjects in which we want to analyze the learning gain after using the robot
3. write the educational activities within a scenario
4. write the initial and final evaluation questionnaires to be distributed to students for the assessment of the learning gain
5. Phase A: test the educational sessions and the teaching materials in few sample schools and refine the material before the national distribution
6. Phase B: run the educational sessions on a large distribution of Italian Public Comprehensive Schools and collect the evaluation questionnaires data through an on-line web system
7. analyze data and publish the results

Due to time and project constraints, we could not arrange a controlled experiment to do a comparison with another method of teaching MGG. This further experimental modality is planned as future work.

Number of students	2911
Where	intra-curricular activity inside the classroom, during the regular lesson time
Robot role	tool to engage the students to learn
Teacher role	transfer base knowledge
Subjects	Maths, Geometry, Geography (MGG)
Background knowledge required	none for students; provided teaching material for teachers
Robot cost	low cost product, affordable for public schools

Table 1: Parameters of our experiment.

Table 1 summarizes the characteristic of the project in terms of number of participants, teacher role, robot role and cost, domain and location of the learning activities, that are fundamental parameters to describe the experiment, as underlined by [8].

2.1 Mobile robot Doc

Our research was conducted using the mobile robot Doc, even if the methodology can be adopted using mobile robots with the same characteristics of Doc. Doc is an easy programmable mobile robot. It is tall 12 cm and it looks like an astronaut with a visor, see Figure 2 *left*). When Doc is switched on, 2 circles illuminate the visor for simulating the eyes, so one can easily identify the front of the robot. It is equipped with 2 driving wheels about 8 cm apart, with no odometers and sensors, it has a step of 13 cm and it moves at a speed of about 11.5 cm/sec.

Fig. 2: *Left*: Robot Doc with its keyboard and modes selector. *Right*: Educational activity: commutative properties of the sum on the line of numbers.

Doc can move linearly or turn itself, on the spot, by 90 degrees. It does not have movable arms or manipulators. The keyboard for its programming is placed on its head and is composed by 7 touch buttons through which it is possible to program Doc to move a step forward or backward, to turn 90 degrees to the right or left, to reproduce a fun sound effect, to cancel the moves entered so far from robot's memory, and to make Doc undertake the command sequence just entered (see Figure 2 *left* bottom). There are three playing modes: Free, Game and Edu, that can be selected by moving the selector behind robot head (see Figure 2 *left* top). In particular, using the Free mode, the robot is free to move around, either on its puzzle mat or on any other clean and smooth surface. The strong quality of the product is that the user can enter a sequence of commands and execute it with one touch. The robot can interact with the user through a set of predefined sentences at the beginning of the activity, with an introductory message to invite the user to start or at the end, to give feedback, or in the meanwhile, in case of lack of activity, to catch the user's attention, before to eventually freeze. Its energy is supplied by 3 batteries 1.5 V AA alkaline, which guarantees continuous use of the robot for 5-7 hours. The Sapientino Doc product box contains also rectangular double face puzzle mat of dimensions 91cm x 65cm, that recreates a grid with boxes that adapt to Doc's paces (13cm). The analysis of the product has highlighted several educational strengths among which the teaching of mathematics, geography (orientation, points of view, directions) and geometry (open and closed lines, geometric shapes) concepts. Scenarios and educational activities were therefore designed according to these basic concepts, using the robot in Free mode. We also designed an evaluation questionnaire for each scenario, to analyze the student improvements after using the robot, and a feedback questionnaire for the teacher to evaluate the student experience in terms of interest, motivation, active participation, fun, cooperation, frustration, rule respect, anxiety, self-organization.

2.2 Experimental design

The hypothesis we want to test with our research is that using a mobile robot enables a learning gain in MGG with additional benefits of being an amusement experience and of facing and learning a new technology. We measure the learning gain by evaluating the score of the initial and the final evaluation questionnaires, that consist in eight questions about MGG. The experimental method adopted a within-subject design (repeated measures). In fact, each student executed the questionnaires under two different conditions: before using the robot (initial questionnaire), after using the robot (final questionnaire). The null hypothesis is that there is no difference in the questionnaire scores.

2.3 Test of the teaching material (Phase A)

Five classes were selected for phase A of the project. Each class received 4 boxes of Sapientino Doc, i.e. 4 robots, batteries, a grid board with white squares and a first version of the teaching material, which included the description of the didactic activities (scenarios) and the evaluation questionnaires for the students. During phase A, teachers were trained by Sapienza and Clementoni researchers, through a meeting at school, without the students, at a time immediately before the activities, and they chose two scenarios to be executed in the classroom. After, the teachers, supported by the researchers, administered the initial evaluation questionnaire, managed the educational activities and administered the final evaluation questionnaire. During these educational sessions the researchers could test each scenario, train the teachers, receive their comments and suggestions on scenarios, questionnaires and designed acquisition tools. Researchers also measured the time that took to do an educational session, that consists in the execution of two scenarios. It takes 30 min. to fill the initial evaluation questionnaires, about 2h to execute the activity with the robot and 30 min. to fill the final evaluation questionnaire. At the end of phase A, we improved the teaching material and created the project website for teachers' on-line training, with video demonstration of educational activities, a community, a contacts section and a frequent asked questions page. We also added the Edu and Game scenarios for Primary schools, we created one more scenario and questionnaire for the first Elementary classes and added a feedback questionnaire for the teachers. Finally, the proposed scenarios and the questionnaires associated with them are shown in Table 2. In order to improve the questionnaire aesthetics and the compilation experience, their final version was done by Clementoni's graphic staff and colored printed. All this material (in Italian) is available in the already reference project web site.

	Questionnaires				
Scenarios	**Mathematics 1**	**Mathematics 2**	**Geography**	**Geometry**	**Primary**
Mathematics 1	X				X
Mathematics 2		X			
Geography			X		X
Geometry				X	X
Storytelling	X		X		X
Edu	X		X		X
Game	X	X	X		

Table 2: Scenarios and questionnaires for Primary and Elementary. The X value indicate the association between them.

2.4 Run of the educational sessions at National level (Phase B)

As already mentioned, a total of 58 Italian Public Comprehensive Institutes (Istituti Comprensivi), including 155 Primary and Elementary classes, adhered to the project on a voluntary basis (see Table 3). The schools were distributed throughout Italy, involving 60% of Italian regions (see Figure 3), 2,911 students from 5 to 8 years old, 163 teachers and about 600 robots.

Fig. 3: Geographic distribution of schools participating to the project.

As in Phase A, each class received 4 boxes of Sapientino Doc, i.e. 4 robots, batteries, a grid board with white squares and the final version of the teaching material, which included the description of the scenarios and the evaluation questionnaires for the students. During Phase B, teachers were trained on-line. They chose two scenarios and executed their activities autonomously (i.e., without physical presence of Clementoni or Sapienza researchers). Finally, they collected the evaluation questionnaire data and filled in their on-line feedback questionnaire, through the website.

Number of	Total	Primary 5y.o.	I Elem. 6y.o.	II Elem. 7y.o.	III Elem. 8y.o.
classes	155	38	58	52	7
questionnaires	4926	677	1938	2056	255

Table 3: Number of classes and questionnaires involved in the project, divided by school grade.

2.5 Questionnaires: evaluation and feedback

We created three sets of questionnaires: two paper evaluation questionnaires for students and one on-line feedback questionnaire for teachers. An initial evaluation questionnaire is filled by the students before the execution of the activities with the robot, and a final one is filled after the activities with the robot. Both are supposed to be filled by the students in the classroom, just before and after the activities with the robot. Teachers could read the questions to the Primary and first Elementary students, if needed. The questions in the final questionnaire are slightly different from the ones in the initial, but the difficulty level is the same. In fact, during Phase A, we observed that with a final questionnaire equal to the initial one, the students took less time to fill the final questionnaire because they wrote automatically the same answer of the initial one, without any cognitive effort on the question. The questionnaires regard Mathematics, Geometry or Geography subjects and aim at evaluating students capacity to answer eight questions for each scenario. For Primary school students, that cannot neither read nor write, we created ad-hoc questionnaires with three questions, where students have to color their answers. The protagonist of the initial questionnaire is a frog, Zap, while in the final one there is a robot, Doc, in order to create a cognitive link with the performed activities. We collate together the initial and the final questionnaires because we want to be sure that they refer to the same student, in order to relate individual performance before and after the teaching activity. The student can use pencil, rubber and must fill with the appropriate answer a red box near the question.

For example, in the Mathematics 1 questionnaire, the first two questions ask how many steps will do Zap/Doc to reach a flag, being the step equal to one unit in Question 1 and two units in Question 2; Question 3 asks how many steps will do Zap/Doc to reach the pool goggles, Question 4 to reach the swimming pool and Question 5 asks for the total number of steps done. To complete Questions 6 and 7, the student must read a short story and fill the gaps with appropriate given numbers. Finally, in Question 8, s/he must write which is the longest route made by Zap/Doc to reach its home.

The on-line feedback questionnaire for the teachers have multiple goals: 1) collect the student answers to the evaluation questionnaires; 2) collect the feeling of the teachers about the student experience using the robot, in terms of interest, motivation, active participation, fun, cooperation, frustration, rule respect, anxiety, self-organization; 3) collect the teachers feedback about coding tools.

2.6 Educational Activity organization: Teachers and Teams

The teacher was free to decide which scenarios to execute during the educational session, depending on his/her didactic objective. We asked to run 2 scenarios in the same day, in order to minimize the bias effect of the evaluation questionnaires and the loss of data due to the absence of students. Moreover, we suggested to the teachers to spend some time, in the days before the educational session and without the students, to become familiar with the robot keyboard, modes and actions. As already mentioned, at the beginning, the students filled in the initial evaluation questionnaire associated with the chosen scenario (see Figure 1 *left*), then they were divided in teams of 4-5 students, in order to execute the activities of the scenarios, using the robot (see Figure 1 *right*). Each team could use one robot and a billboard (the white one or the colored one). At the completion of the activities, the students filled in the final evaluation questionnaire. The teacher could fill in the feedback questionnaire in a different day.

2.7 Scenarios

The design of educational scenarios took place alongside the analysis of robot Doc and analyzing similar activities that took place in similar domains (Thymio[5], Bee-Bot[6], MARRtino Sapienza mobile robot[7]). At the beginning, we wrote the following 4 different scenarios and the related evaluation questionnaires: 1) Mathematics, 2) Geography, 3) Geometry, 4) Storytelling.

After Phase A, we introduced a simplified Mathematics scenario for first elementary classes, splitting Mathematics in two scenarios: Mathematics 1 and Mathematics 2. Moreover, we introduced Edu and Game scenarios to address the needs of Primary students.

Mathematics 1 scenario includes a number of didactic activities related to the baseline calculation on the line of numbers. The activities take place with the Doc robot set on a grid board with numbers. Students have to program linear opened routes. The didactic objective is the verification on the line of numbers of simple math operations such as sum, subtraction and multiplication. The methodology includes students programming the robot to move on the line of numbers and checking the results of the maths operations. Figure 2 *right*) shows an example of an activity to teach the commutative property of the sum: i) put the robot on the blank mat at the initial position (number 0); ii) program robot A to move forward for 2 steps, turn on the right to watch the reached number, turn on the left and move forward for 3 steps, turn on the right to watch the final number position (number 5): students must record the robot A final number position; iii) program robot B to first move forward 3 steps and then 2 steps: students must record the final number position of robot B and compare it with the final number position of robot A.

Mathematics 2 scenario differs from the previous one in the methodology. In fact, in this scenario the robot is used as a tool to verify the results of operations mentally calculated previously by the students. Example of activity: students record on their notebook the result of *2+3* and *3+2* sums. Then they program the robot to verify the correctness of their results.

Geometry scenario includes a number of tasks related to geometry concepts that take place with the Doc robot on a grid board with white boxes and other graphical elements. The didactic objectives is the verification of the knowledge of simple flat geometric figures (square, rectangle and circumference) and the introduction to the perimeter's calculation. The methodology include students programming the robot to move by making a route with a geometric shape. For example, program the robot to move along a square route.

[5] https://www.thymio.org/en:thymio
[6] https://www.bee-bot.us/
[7] http://tinyurl.com/marrtino

Geography scenario includes a series of activities related to geography concepts that take place with the Doc robot set on a grid board with white boxes and other graphical elements. The didactic objective is the verification of basic elements of geography such as different points of view and reference systems. The methodology include students placing the robot on the grid board in an initial position and orientation and then programming it to reach a final position and orientation being at different relative orientations with respect to the robot. For example, the robot is placed in the left corner of the grid, watching the students team and they must program it to reach the opposite corner.

Storytelling scenario explore the ability to set and move the robot in scenes or stories represented on the puzzle mat. It includes a series of activities related to a story chosen by the teacher. It could be a story that the class has already developed in recent months (for example going at the theater). It can be implemented with the white grid board, enriched with the characters of the history (protagonist, antagonist, aides, obstacles, etc.), or the boards provided by the product.

Edu and *Game* scenarios are the ones described in the instruction manual of the product.

3 Data Analysis

Table 4 summarizes the number of classes that executed the questionnaires, divided by school grade. In this paper we focus on the results of the Mathematics 1 questionnaire (Maths). The results of Primary, Geometry, Geography and Mathematics 2 questionnaires are published on the project website mentioned above.

	Questionnaires				
Number of classes	**Mathematics 1**	**Mathematics 2**	**Geography**	**Geometry**	**Primary**
Primary	0	0	0	0	52
I Elementary	44	2	28	32	0
II Elementary	3	37	36	34	0
III Elementary	1	5	3	5	0
Total	48	44	67	71	52

Table 4: Number of classes that executed the questionnaires, divided by school grade.

By comparing the initial and the final evaluation questionnaires, using statistical methods, we want to measure if there were improvements in the score obtained by the students on each question. Maths questionnaires were executed by 48 classes involving a total of 886 students (445 female and 441 male).

Global statistics The first analysis presented here considers the score to each question by all the students. The results are presented in Table 5 showing the percentage of correct answers given in each question before and after the educational activity with the robot, the difference, and the corresponding p-value of the two distributions. As shown in the table, most of the results are extremely significant, two results are very significant (Questions 4 and 7), one is significant (Question 7) and one is not significant (Question 8).

Question	Before act.	After act.	Difference	p-value	Significance
1	**60.9 %**	**68.5 %**	**7.6 %**	**8.56e-04**	***
2	**53.6 %**	**66.3 %**	**12.7 %**	**5.08e-08**	****
3	**57.1 %**	**65.5 %**	**8.4 %**	**3.03e-04**	***
4	54.0 %	60.3 %	6.3 %	7.17e-03	**
5	**35.0 %**	**43.6 %**	**8.6 %**	**2.14e-04**	***
6	73.9 %	80.4 %	6.5 %	1.25e-03	**
7	71.4 %	76.5 %	5.1 %	1.48e-02	*
8	89.7 %	88.1 %	-1.6 %	2.89e-01	-

Table 5: Percentage of correct answers in 886 Math questionnaires before and after the educational activity with the robot and p-value of the distribution.

From this analysis, it is possible to conclude that the educational activities with the robot has a very significant impact in the increase of score of the Math questionnaire. The same results are shown in a graphical format in Figure 4). In the rest of the paper, we present other analysis only in a graphical format for better readability. Note that, being the low number of II and III Elementary classes using this questionnaire, Figure 4 *left*) represents basically I Elementary results.

By looking more specifically at the score of each student, we found some general positive trend after using the robot: 47% of students got a better score in the final evaluation questionnaire and 26% of them got the same score; the percentage of students who achieved the maximum score (i.e., all correct answers) increased from 19% to 25%; only a few students did not answer to the questions, but for Questions 4 and 5 the number of blank answers decreased, while it remained equal for Questions 2, 6 and 7; all the questions, except Question 5, got more than 50% of correct answers before the activity, confirmed that the questionnaire is well calibrated on the students level and this was possible mostly thanks to the teachers feedback collected during Phase A; the general downward trend of score during questionnaire time, is probably due to students effort in doing eight Maths questions. In particular, the last question, Question 8, albeit with low significance, kept a negative difference for all the schools levels. Breaks should be foreseen during questionnaire time.

We would like to show in Figure 4 *right*), the data related to III Elementary students only. While these data are not statistically relevant (only 1 class), we can observe a highest percentage of correct answers (89% on average), with respect to the I Elementary students (65% on average) due to the fact that the Mathematics questionnaire was written for I Elementary students principally, and the high number of questions with negative difference (-6% means 1 student) are probably due to loss of motivation in doing for the second time a trivial questionnaire for them. Here the lesson learned is that the improvement of the

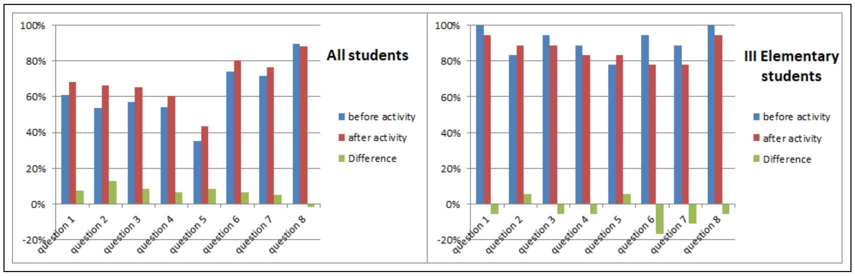

Fig. 4: Percentage of students who gave correct answers to the questions. *Left*: a comparison of the results before and after the activity with the robot, for all the students. *Right*: the comparison for III Elementary students only.

score is also affected by the way in which the activities to be performed with the robot are designed, not only the robot itself.

Teacher's feedback Analyzing the feedback questionnaires, we can distinguish three types of teachers involved in the project:the *neophytes*, or beginners, not expert in coding; the *apprentices*, teachers who attended coding courses but hadn't experience in classroom; the *experts*, teachers who had a medium or strong experience in coding and robotics in classroom. Overall, they all commented that Doc is used by children with joy and fun, without fear to make mistakes. Most of them underlined how all the students were active and interested, also the ones assessed as usually not motivated.

4 Conclusions

In this paper we presented our methodology to teach Mathematics using mobile robots and the results of data analysis, collected from 2,911 students of 58 Italian Public schools, Primary (5 years old) and Elementary (from 6 to 8 years old). Using a eight questions evaluation questionnaire on Maths, we found the improvements in the score obtained by the students on most of the questions and this learning gain is very significantly correlated with the use of the robot. Overall, we found general positive trend in the increase of better and maximum scores and the decrease of blank answers. The lessons learned are to reduce the number of questions and calibrate the questions with the level of the class. About teachers, all their feedbacks have reported a good level of satisfaction about the experience. They discovered a new cheap and practical tool for educational robotics and noticed high involvement and enthusiasm of their students.

As future work we are planning a controlled experiment to compare our methodology with the traditional one and schedule a didactic competition associated with the project activities between classes and schools.

5 Acknowledgements

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