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Exploring the educational potential of robotics in schools: A systematic review

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ABSTRACT

This study reviews recently published scientific literature on the use of robotics in schools, in order to: (a) identify the potential contribution of the incorporation of robotics as educational tool in schools, (b) present a synthesis of the available empirical evidence on the educational effectiveness of robotics as an educational tool in schools, and (c) define future research perspectives concerning educational robotics. After systematically searching online bibliographic databases, ten relevant articles were located and included in the study. For each article, we analyze the purpose of the study, the content to be taught with the aid of robotics, the type of robot used, the research method used, and the sample characteristics (sample size, age range of students and/or level of education) and the results observed. The articles reviewed suggest that educational robotics usually acts as an element that enhances learning, however, this is not always the case, as there are studies that have reported situations in which there was no improvement in learning. The outcomes of the literature review are discussed in terms of their implications for future research, and can provide useful guidance for educators, practitioners and researchers in the area.

1. Introduction

Popular interest in robotics has increased astonishingly in the last few years. Robotics is seen by many as offering major new benefits in education at all levels (Johnson, 2003). The commercial educational robotics market is also growing. Research by the Japan Robotics Association (JPA), the United Nations Economic Commission (UNEC), and the International Federation of Robotics (IFR), indicates that the market growth for personal robots, including those used for entertainment and educational purposes, has been tremendous and this trend may continue over the coming decades (Kara, 2004).

Educational theorists such as Papert (1993) believe that robotics activities have tremendous potential to improve classroom teaching. However, Williams, Ma, Prejean, Lai, and Ford (2007) affirm that there is limited empirical evidence to prove the impact of robotics on the k-12 curriculum. Educators have started to generate ideas and develop activities to incorporate robotics into the teaching of various subjects, including math, science, and engineering. However, without research evidence to support their direct impact on students' academic performance, robotics activities may be just a "fashion" (challenge presented by Johnson, 2003). Researchers highlight that most of the literature on the use of robotics in education is descriptive in nature, based on reports of teachers achieving positive outcomes with individual initiatives (Caci, Cardaci, & Lund, 2003; Petre & Price, 2004; Williams et al., 2007).

Another aspect observed in the literature is that until now, most of the applications of robotic technology in education have mainly focused on supporting the teaching of subjects that are closely related to the Robotics field, such as robot programming, robot construction, or mechatronics. Moreover, most of the applications have used the robot as an end or a passive tool in the learning activity, where the robot has been constructed or programmed (Mitnik, Nussbaum, & Soto, 2008). Rusk, Resnick, Berg, and Pezalla-Granlund (2008) agree that the way robotics is currently introduced in educational settings is unnecessarily narrow. Exploring a wider range of possible applications has the potential to engage young people with a wider range of interests. Young people who are not interested in traditional approaches to robotics become motivated when robotics activities are introduced as a way to tell a story (for example, creating a mechanical puppet show), or in connection with other disciplines and interest areas, such as music and art (Resnick, 1991; Rusk et al., 2008).

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Different students are attracted to different types of robotics activities (Resnick, 1991). Students interested in cars are likely to be motivated to create motorized vehicles, while students with interests in art or music are likely to be more motivated to create interactive sculptures. Rusk et al. (2008) examine strategies for introducing students to robotics technologies and concepts, and argues for the importance of providing multiple pathways into robotics, to ensure that there are entry points to engage young people with diverse interests and learning styles.

It seems that educational robots is a relevant tool for improving learning. However, this assertion needs to be further supported through the application of experiences and above all, through empirical evidence.

The central question that this study attempts to answer is whether educational robotics, used as a teaching tool in areas other than the teaching of subjects that are closely related to the field of Robotics itself, can improve students' performance in elementary, middle and high schools. The aim of the study is to carry out a literature review on the use of educational robotics, in order to:

(a) identify the potential benefits of incorporating robotics as an educational tool in different areas of knowledge,
(b) present a synthesis of the empirical evidence available thus far on the educational effectiveness of robotics,
(c) define future research perspectives concerning the educational use of robotics based on the literature reviewed.

2. Methods

A systematic review is a method that enables the evaluation and interpretation of all accessible research relevant to a research question, subject matter or event of interest (Kitchenham, 2004). To conduct this review, we followed a defined process for conducting systematic reviews based on Kitchenham (2004) and Khan et al. (2001), covering the following stages and activities:

Stage 1:Planning the review
- Activity 1.1: Identification of the need for a review
- Activity 1.2: Development of a review protocol

Stage 2: Conducting the review
- Activity 2.1: Identification of research
- Activity 2.2: Selection of primary studies
- Activity 2.3: Study quality assessment
- Activity 2.4: Data extraction and monitoring
- Activity 2.5: Data synthesis

Stage 3: Reporting the review
- Activity 3.1: Communicating the results

2.1. Planning and conducting the review (Stages 1 and 2)

Initially, we performed a search to identify the existence of systematic reviews involving robotics in education. No specific research on the subject was found, however, there are systematic reviews involving the use of technology for education, specifically the use of computers and video games in health and physical education (Papastergiou, 2009) and the use of ICT (Information and communications technology)for teaching activities in science lessons (Hogarth, Bennett, Lubben, Campbell, & Robinson, 2006).

Within the context of this paper we carried out a systematic literature review using the basic approach identified in Kitchenham (2004), in order to examine the state of research in educational robotics in schools, based on the following research questions:

Question 1: What topics (subjects) are taught <u>*through*</u> *robotics in schools?*
Question 2: How is student learning evaluated?
Question 3: Is robotics an effective tool for teaching? What do the studies show?

For the purposes of this study, a systematic review was undertaken in January and February 2010, in the following international online bibliographic databases:(a) IEEE XPLORE, (b) ACM Digital Library, (c) ScienceDirect, (d) SpringerLink, (e) ERIC (Educational Resources Information Center) and (f) Wilson Education. Searches were restricted to peer-reviewed articles, written in English, and published between 2000 and 2009 (research over the last ten years). The search string used was: ((teaching OR learning OR teach OR learn OR education OR educational) AND (robotic OR robotics OR robot OR robots OR Lego) AND (school OR k-12)). Table 1 shows the protocol executed for each database.

The following criteria were used to determine which papers would be included in the review:

1. The article reports the application of robotics as a teaching tool, in other words, the objective is not to teach robotics *per se* (such as in robotic courses, for example) but using robotics as an educational means.
2. The article presents educational robotics in an elementary, middle and high school context.
3. Articles were included only if they presented a quantitative evaluation of the learning, observing the guidelines proposed by Kirkpatrick and Kirkpatrick (2006), who recommend carrying out tests before and after the training, to evaluate the learning.
4. It should involve the use of physical robots.

Four criteria for exclusion (EC) articles were also identified:

EC1: Aimed at teaching of robotics, i.e. robotics is the subject of the learning and not a teaching tool.
EC2: Article does not provide a quantitative assessment of learning. If an article presented only interviews, observation and motivating analysis, then it was excluded.

Table 1
The specific protocol executed in each database.

Database	Protocol	Note
IEEE XPLORE	((((teaching or teach or learn or learning or education or educational) <in>ab) <and> ((robotic or robot or robotics or robots or lego)<in>ab)) <and> ((school or k-12)<in>ab)) <and> (pyr >= 2000 <and> pyr <= 2009)	- Search on the field "Abstract".
ACM Digital Library	(Abstract:((teaching OR learning OR teach OR learn OR education OR educational) AND (robotic OR robotics OR robot OR robots OR Lego) AND (school OR k12))) and (FtFlag:yes)	- Search on the field "Abstract". - Term k-12 replaced by k12 by restriction of the database - "FtFlag:yes" represents "Results must have Full Text"
ScienceDirect	pub-date > 1999 and title-abstr-key((teaching OR learning OR teach OR learn OR education OR educational) AND (robotic OR robotics OR robot OR robots OR Lego) AND (school OR k-12))	- Search on the fields "Abstract", "Title" and "Keywords".
SpringerLink	ab:((teaching or learning or education or educational) and (robotic or robot or robots or Lego) and (school or k12)) Content Type > Journal Articles Publication Date > Between Saturday, January 01, 2000 and Thursday, December 31, 2009	- Search on the field "Abstract". - Term k-12 replaced by k12 by restriction of the database. - Terms "teach" and "learn" suppressed by limiting the quantity of terms used to search the database. Variations to the terms removed were used, and can be identified that did not compromise the result.
ERIC	(Publication Date: 2000–2009) ((Keywords:teaching OR Keywords:teach OR Keywords:learn OR Keywords: learning OR Keywords:education OR Keywords:educational) and (Keywords: robotic OR Keywords:robot OR Keywords:robotics OR Keywords:robots OR Keywords:lego) and (Keywords:school OR Keywords:k-12)) and (Publication Type:"Journal Articles" OR Publication Type:"Collected Works Proceedings" OR Publication Type:"Dissertations Theses" OR Publication Type:"Dissertations Theses Doctoral Dissertations" OR Publication Type:"Dissertations Theses Masters Theses" OR Publication Type:"Dissertations Theses Practicum Papers") and Full-Text Available	- Search on the field "Keywords (all fields)".
Wilson Education	(teaching OR learning OR teach OR learn OR education OR educational) <in> Smart Search AND (robotic OR robotics OR robot OR robots OR Lego) <in> Smart Search AND (school OR k-12) <in> Smart Search AND Date: between 2000 and 2009 AND Limited to: PEER_REVIEWED In Education Full Text	- Search on the field "Smart Search".

EC3: It did not show the use of robots, involving automated equipment or simulation environments with robots.
EC4: The article was considered out of context, addressing undergraduate education (the focus of study is elementary, middle and high school), or it reports the design of robots, among other aspects.

The initial search yielded 197 papers. Normally, in the first stage, we quickly analyzed titles and abstracts with regard to the inclusion criteria. However, due to the specificities of the criteria, it was difficult to exclude articles based on the abstract alone. Therefore, we decided to seek the necessary information in the full text, basically reading the introduction and conclusion. Thus, it was possible to select the item or delete it (fitting into one of the criteria), as shown in Table 2.

As can be observed in Table 2, approximately 45% of articles were excluded because they are not in the context of research (EC4), as well as in the educational context (as for example, involving robotics in undergraduate education) as in technical aspects (as for example, the study focus on the design of robots). Considering only the 107 articles that approached teaching involving robotics for elementary, middle or high school, in 29% of the articles, robotics was the subject to be learned and not an instrument for teaching. Only five articles (2.5% of the total) were excluded because they did not involve the use of robots directly, but used simulation environments, for example. There were 60 articles excluded for not having a quantitative assessment of learning, 30% of the total or 85% of the articles that would be within the context of study, which we consider a big quantity.

Table 2
Summary of article selection.

Database	Articles resulting from the search	EC1	EC2	EC3	EC4	Selected
IEEE XPLORE	100	10	30	1	58	1
ACM Digital Library	15	1	6	1	7	0
ScienceDirect	10	3	2	0	4	1[a]
SpringerLink	10	4	2	2	1	1
ERIC	3	0	0	0	2	1
Wilson Education	59	13	20	1	18	7[a]
Total	**197**	**31**	**60**	**5**	**90**	**10[a]**

[a] One article repeated.

3. Results (Stage 3)

Initially, in order to gain confidence in the results, we classified and divided the studies into non-experimental (those that used no control group or other comparison to assess students' abilities) and quasi-experimental or experimental (those that included rigorous comparison with a control group). Therefore, the Table 3 presents the *Authors* in column 1, the *Article description* in column 2, including a brief description of the goal of the paper, and the *Study type* in column 3; this shows the classification the type of each of the studies, following common research designs used in evaluations in educational contexts, as shown in Table 4.

As an aid to the reader, Table 5 provides a summary of the overviewed research articles. For each article, Table 5 shows the following attributes: (a) column 1: reference of the paper, (b) column 2: *Age/Level* shows the age of the research participants and/or (as available in the article) the educational level in which the research was conducted, (c) column 3 *Topic(s)* presents the content that the researchers wanted to teach through robotics, (d) column 4 *Robot type* describes the robot used in the research, (e) column 5 *Sample* indicates the sample size, (f) column 6 *Details study type* shows data on how the study was conducted, focusing on the statistical method (as presented in the article), (g) column 7 *Major Findings* summarizes the principal results of the study.

4. Discussion

In this section we analyze the results of the systematic review, in an attempt to answer the three research questions elaborated in Section 2.1.

4.1. What topics (subjects) are taught through robotics in schools?

Mitnik et al. (2008) claim that "so far, most of the applications of robotic technology in education have focused on supporting the teaching of subjects that are closely related to the Robotics field, such as robot programming, robot construction, or mechatronics." The advancement of robotic technology has allowed new educational activities. Supported by sensors and actuators, robots are capable of exploring and interacting with the real world. Based on these capabilities, a series of educational activities can be developed to aid and foster the learning of relevant topics.

The results show that most of the studies (80%) explore topics related to the fields of physics and mathematics. The articles specifically report experiences with teaching Newton's Laws of Motion, distances, angles, kinematics, graph construction and interpretation, fractions, ratios and geospatial concepts. The articles also emphasize skills that can be developed or improved through robotics, emphasizing skills in problem solving, logic and scientific inquiry.

Table 3
Articles and study type.

Article	Article description	Study type
Hussain et al. (2006)	The purpose of this study is to investigate the effect of one year of regular "LEGO" training on pupils' performances in schools.	R O X O R O O
Lindh and Holgersson (2007)	The purpose of this study is to investigate the effect of a one-year regular robotic toys (Lego) training on school pupils' performance. This study differs from the previous one (Hussain et al., 2006) in the statistical method used and the sample size.	R O X O R O O
Barker and Ansorge (2007)	This paper reports on a pilot study that examined the use of a science and technology curriculum based on robotics to increase the achievement scores of young people aged 9–11 in an after-school program.	N O X O N O O
Whittier and Robinson (2007)	This article describes a teaching unit that used Lego Robotics to address state science standards for teaching basic principles of evolution in two middle-school life science classes	O X O
Williams et al. (2007)	The purposes of the study were to evaluate the impact of a robotics summer camp on students' physics content knowledge and scientific inquiry skills, and to explore various factors that might have contributed to the impact of the program.	O X O
Nugent et al. (2008)	This study investigated the use of educational robotics, paired with GPS and GIS geospatial technologies, as a context for learning selected concepts in science, technology, engineering and mathematics (STEM) within an informal learning environment.	O X O
Sullivan (2008)	The purpose of this paper is twofold: first, it provides a definition of science literacy that serves as a framework for analyzing the relationship of robotics activity to science literacy skills and knowledge; and second, it reports the results of a study focused on how academically advanced students used science literacy skills to solve robotics problems and the learning gains they achieved as a result of participation in the robotics course.	O X O
Owens et al. (2008)	The study reported evaluates the effectiveness of LEGO therapy and the SULP (Social Use of Language Programme) as low-intensity, easy to implement social skills groups for 6–11 year olds with HFA (High Functioning Autism) and AS (Asperger Syndrome) that contrast in their method of teaching (LEGO therapy uses a naturalistic collaborative play approach while SULP uses more direct teaching methods).	R O X O R O O
Mitnik et al. (2008)	This paper presents a novel application of robotic technology to primary and secondary school-level education. The application consists of an autonomous mobile robot that helps students to create abstract models of relevant concepts and properties of the real world by physically illustrating them.	N O X1 O N O X2 O
Nugent et al. (2009)	This paper describes a project aimed at middle-school youth, the program uses robotics and global positioning system (GPS) receivers and geographic information system (GIS) software to provide hands-on, self-directed learning experiences that promote personalized comprehension of science, technology, engineering, and math (STEM) concepts through experimentation. Results have focused on the project's impact on: a) youth learning of computer programming, mathematics, geospatial concepts, and engineering/robotics concepts and b) youth attitudes and motivation toward science, technology, engineering, and mathematics.	N O X O N O O

Table 4
Examples of common research designs (Trochim & Donnelly, 2006).

Study type	Design	Representation[a]
Non-experimental	One-shot posttest only	X O
	One-shot pretest–posttest	O X O
Quasi-experimental	Nonequivalent comparison group	N X O N O
	Nonequivalent group pretest–posttest	N O X O N O O
	Nonequivalent group pretest–posttest control group	N O X1 O N O X2 O
Experimental	Randomized posttest only	R X O R O
	Randomized pretest–posttest	R O X O R O O
	Randomized pretest–posttest control group	R O X1 O R O X2 O

[a] X = treatment; O = measures/evidence; R = random assignment.

However, two studies stand out for having distanced themselves from the area of exact sciences; one attempts to apply robotics to the teaching of basic principles of evolution (Whittier & Robinson, 2007), while the other develop social communication skills in individuals with autism (Owens, Granader, Humphrey, & Baron-Cohen, 2008).

Barak and Zadok (2009) attempt to answer the question "What type of knowledge the pupils address when working on robotics projects?" noting that the benefits of robotics are related to concepts in science, technology and problem-solving skills. Petre and Price (2004) observed that most of the approaches for educational activities (that include robotics) teach subjects that are closely related to the field of Robotics. The results of this systematic review reinforce this statement, because most of the studies found are concentrated in areas related to robotics.

It is important to note that in the scope of this review, only studies that presented a quantitative assessment of the benefits of robotics in learning were considered. Thus, it can be seen that there is a lack of research with quantitative assessment of learning, expanding the use of robotics to other areas of knowledge (i.e. areas not related to the exact sciences).

4.2. How is the learning of students evaluated?

To fully answer this question, it is necessary to investigate two aspects: (i) in what context are evaluations conducted? (types of robots used, information on participants, sample size and educational context), and (ii) what is the design of experiment used and how the results were obtained.

Analyzing the articles included in a systematic review, a predominance (90%) is observed of the use of Lego robots in educational activities, with a variation in the models used (NXT, RCX and Evobot). Only one article involves a quantitative assessment of robotics as a teaching tool using a robot developed by researchers themselves. Several research projects propose robots for educational purposes (Daidie et al., 2007; Hsiu, Richards, Bhave, Perez-Bergquist, & Nourbakhsh, 2003; Tiponut, Haraszy, & Ianchis, 2006), however, the assessment of learning through the application of robots (in fields other than robotics) was not observed in these works.

In relation to the research participants, despite the fact that protocol involved all grades of k-12, the studies included in the systematic review ranged from 5th grade through to 10th grade, with research participants aged between 6 and 16 years old. One possible explanation for the lack of quantitative studies using robotics in first grades may be the fact that the Lego robotics kit (the most commonly used in the studies, as noted earlier) is recommended for children aged 7 years old[1] and older. Furthermore, the analysis of this research data (age and school level) suggests a lack of quantitative studies on robotics as a teaching tool in 11th and 12th grades.

Most of the experiments involving robotics activities were not integrated into classroom activities, i.e., they occur as an after-school program or summer camp program. The exceptions were reported (i) by Hussain, Lindh, and Shukur (2006) and Lindh and Holgersson (2007) observing that in grade 8 teachers have been able to integrate their work in ordinary teaching, and (ii) Whittier and Robinson (2007) applied robotics in one of their classes.

Analyzing the studies, we can observe that the cases in which the robotics were applied as an extracurricular activity, always involved a "group of tutors". For example, in Barker and Ansorge (2007) the after-school program involved an adult volunteer or an after-school teacher to lead the activities of each group. Williams et al. (2007) reported that the robotics camp had 10 facilitators. In Sullivan (2008) the investigator and one other full-time instructor ministered the course. Owens et al. (2008) run every therapy group with help from one or two undergraduate volunteers. When the robotic activity occurred in the classroom, Hussain et al. (2006) and Lindh and Holgersson (2007) emphasize that "the participating teachers in the project have been taught how to handle the material, as pupils often ask highly intricate questions." These facts indicate the need for well-prepared teachers to use robotics in the classroom, as well as the possibility of group facilitators for the activities.

Based on the data summarized in Table 5, we observed that 70% of the studies involve a small sample (less than 100 participants) and comparing these data with those of Table 3, we can see that only two studies involve a random sample. Considering the guideline of Vockell

[1] Information available at http://www.lego.com/education/school/default.asp?locale=2057&pagename=ict_home&l2id=3_2.

Table 5
Context of the articles and major findings.

Article	Age/level	Topic(s)	Robot type	Sample	Detail study type	Major findings	
						Proved results	Non-proved results
Hussain et al. (2006)	193 Pupils in the fifth grade (12–13 years old) and 129 pupils in the ninth grade (15–16 years old).	Mathematics, problem-solving ability and attitude	Lego Dacta	322 Pupils	Quantitative and qualitative methods. The qualitative methods used in the project were observation, interview and inquiry. The quantitative methods involve a pretest/posttest with a control group. (regression model/ Generalized Linear Model (GLM)).	The results show better performances in mathematics for the trained group in grade 5. An interesting result of the study is that pupils with higher ability in mathematics tend to be more engaged. There is not a general positive attitude toward LEGO among the pupils. However, the authors observed in their study that for a certain category of pupils, i.e. high-performing pupils in mathematics in grade 5, they have a positive attitude toward the LEGO material.	When looking at achievements in mathematics for pupils in grade 9 before and after the training, the authors did not find any significant shifts in the mean with regards to mathematics. For the problem-solving skills, there is no significant improvement for grade 5 and 9. There is not a general positive attitude toward LEGO among the pupils.
Lindh and Holgersson (2007)	169 Pupils in the fifth grade (12–13 years old) and 205 in the ninth grade (15–16 years old)	Ability to solve mathematical and logical problems	Lego	374 Pupils	The qualitative methods used in the project were observation, interview and inquiry. The quantitative methods consisted of different tests in mathematics and problem solving – ANOVA test was performed (with a control group and an experimental group).	The first null hypothesis was not rejected and there is no statistical evidence that the average pupil gains ability to solve mathematical and logical problems from lego training. However, when the ANOVA test was performed on sub groups of students the null hypothesis was rejected in some cases, namely for the medium good pupils (pupils with medium scores (9–12p) do seem to have benefited from the lego robots). This indicates that lego training may indeed be useful for some groups of students.	In general manner, the mean values of the pupils test scores do not seem to differ between the lego and non-lego group with respect to the math test, and the same holds for the problem solution test.
Barker and Ansorge (2007)	9–11 Years old	Achievement in Science, Engineering, and Technology (SET)	Lego	32 students	A pre- and posttest quasi-experimental study with a control group	Only positive results were mentioned. The results of the study based on the increase of mean scores, from the pretest to the posttest for the experimental group, indicate that the robotics were effective at teaching youth about SET concepts like computer programming, robotics, mathematics, and engineering.	
Whittier and Robinson (2007)	Seventh and eighth grades	Teaching basic principles of evolution	Evobots (Lego)	29 Students	Pretest and posttest. Analysis made only by the average results.	Only positive results were mentioned. The authors reported that nearly all students showed significant gains in their individual conceptual understanding of the basic principles of evolution based on pre- and posttest scores. Though students did not master the concepts presented, “they did make notable gains in knowledge of evolutionary topics. More importantly, beyond the tests, students were able to both discuss and write about topics integral to a strong science foundation. Regular discussions of natural selection, adaptation, and niche specialization became commonplace among the students in these classes. Relevant vocabulary was not only explicitly discussed and emphasized, but also studied through contextual clues. New terms were integrated into teacher language and class discussions each period. For beginning level English Language Learners (ELLs) such conversations are no small feat considering the extensive vocabulary involved”.	
Williams et al. (2007)	Middle-school students (sixth to eighth grade)	Physics content knowledge (Newton’s Laws of	LEGO Mindstorms	21 Students	The participants was pretested, exposed to the summer camp program, and posttested to answer the research questions.	The article concluded that the activity had a statistically significant impact on students’ gains in physics content knowledge, involving the impact of	No statistically significant difference was found when comparing pretest and posttest scores from the scientific inquiry measure. Even though the

(*continued on next page*)

Table 5 (*continued*)

Article	Age/level	Topic(s)	Robot type	Sample	Detail study type	Major findings	
						Proved results	Non-proved results
		Motion) and scientific inquiry skills			A two tailed paired *t*-test was calculated to compare the pretest and posttest scores. An ethnographic study was also carried out to explain the quantitative data.	various variables on the movement of vehicles (the variables included the weight, the angle of the ramp, diameters of the wheels, the friction between the wheel and the surface, and the location of the weight) and energy flow (working with touch sensor).	scientific inquiry process was introduced to the students, they predominantly used the trial and error method to solve problems.
Nugent et al. (2008)	11–15 Years old	Learning in Science, Technology, Engineering, and Mathematics (STEM)	LEGO NXT Mindstorm kit +GPS	38 Students	The study used a pretest–posttest quasi-experimental design for the investigation, with the same assessment acting as both a pre- and posttest. The primary analysis was a repeated measures *t*-test for the combined group and by site.	The significant increase in student scores on the learning assessment provides evidence for the use of robotics and GIS/GPS technologies as a mean to promote STEM learning. Results support a conclusion that youth were able to increase test scores across four content areas including mathematics, geospatial concepts, computer programming, and engineering/ robotics. The largest increases were in the computer programming area, which is to be expected since youth had no previous experience with the programming concepts covered in the camp. What is especially encouraging, however, is the increase in the mathematics scores. The concepts identified within the mathematics-related questions were topics that are still traditionally difficult for students to learn within their formal education coursework, such as fractions, proportions, distance-related formulas, and geometry topics associated with degrees and circles.	The lack of significant improvement directly observed for the geospatial. Some of the geospatial activities relied on rather difficult concepts for the middle-school aged youth, such as the use of trigonometric ratios and coordinate distance formulas. The results suggest that students do not directly perceive the various connections between robotics and STEM concepts. When robotics is embedded into a natural experiential learning environment, as opposed to the more traditional STEM learning environment, students may become excited about robotics, but not recognize that STEM learning is being integrated into the robotics activities.
Sullivan (2008)	11–12-Year-olds	Thinking Skills, Science Process Skills and Systems Understanding	Lego Mindstorms (RCX)	26 students	Both observational and experimental methods were employed to address the research questions. Pre–post tests of systems understanding were administered on the first and last day of each camp session.	The article shows that all or nearly all of the students utilized seven out of the eight thinking skills and science process skills described by the author: - “Thinking”: (i) observation; (ii) estimation; and (iii) manipulation. - “Science process”: (i) evaluation of solution; (ii) hypothesis generation; (iii) hypothesis testing; and (iv) control of variables. In addition to use thinking skills and science process skills to solve the robotics challenge, students who took part in this robotics course also improved their systems understanding. The pre- and posttest results show a clear gain in systems understanding.	The only thinking skill that was not used by the majority of the students was computation.

Owens et al. (2008)	Between 6 and 11 years old	Social communication skills (individuals with autism do not naturally acquire these sophisticated social skills)	Lego	31 Children	Non-parametric tests were used for statistical analyses. * Indirect Measures: GARS-SI and VABS. * Direct Measures: Playground Observations.	Autism-specific social difficulties reduced by following LEGO therapy, in contrast to no change in the SULP group or control group. The magnitude of this change was small, but it suggests that LEGO therapy may be more effective than SULP at reducing autism-specific social difficulties. In the direct observations of social behavior in the school playground, the LEGO therapy group showed a small yet statistically significant increase in the duration of social interactions while the SULP group did not. This suggests some generalization of skills in the LEGO group, consistent with previous research; however, this change did not result in significant differences between the two therapy groups after intervention and was very small in magnitude.	There was a trend for both intervention groups to improve more on socialization and communication than the no-intervention control group, though there was no significant difference between the groups on these measures. There was no difference in the number of self-initiated social interactions in the LEGO or SULP group.
Mitnik et al. (2008).	7th and 10th Grades	Math and Physics. Activity 1 focused on teaching distances and angles, while Activity 2 focused on teaching kinematics and graph construction and interpretation.	AEMRM: Autonomous Educational Mobile Robot Mediator (created by the authors)	70 students	Experimental and control groups with pretest–posttest scheme. To determine and compare the impact of the experimental and control treatments, the authors used an ANCOVA analysis. The required normality assumption was supported by the results obtained in the Kolmogorov–Smirnov test. Collaboration and motivation were analyzed based on qualitative in-site observations and quantitative results obtained from a post activity survey.	Only positive results were mentioned. The authors observed statistically significant difference on the learning assessment focused on: (i) teaching distances and angle; and (ii) teaching kinematics, graph construction and interpretation. Comparing the experimental and control groups, a greater amount of collaborative interactions were observed at the students of the experimental groups. Regarding motivation, students of the experimental groups usually expressed their wish to continue working with this kind of activities. On the contrary, students of the control groups usually showed and verbally expressed their boredom after two activity sessions. Social interactions were measured using sociograms in which each student scored his/her social appreciation of each of his/her classmates. When comparing the results of the sociograms, completed before and after the activities, it could be seen that the enhancement of the social bonds of the experimental students surpassed that of the control students.	
Nugent et al. (2009)	k-12 (Robotic group–age mean 12.28 and control group – age mean 11.39)	Topics in computer programming, mathematics (including fractions and ratios), geospatial concepts (coordinate estimation based on location), engineering (such as gears and sensors), and robotics (such as looping and multi-tasking).	LEGO Mindstorms NXT	288 Students	The research study used a quasi-experimental design involving comparisons of a treatment (robotics) versus a control group (no robotics). The data were analyzed using Analysis of Covariance (ANCOVA), with the independent variable being intervention (robotics versus control condition) and the dependent variables being student learning (total score on content assessment) and STEM attitudes (overall mean score on attitude survey). The covariate was the pretest scores on both the learning and attitudinal instruments. Because of a violation of the homogeneity of slopes assumption for the ANCOVA analysis for the cognitive results, a split plot ANOVA was used instead.	The authors observed that the benefits to student involvement, may well be increased STEM conceptual knowledge (experimental group had significant pre–post increases in learning of computer programming, mathematics, geospatial concepts, and engineering/robotics concepts). Yet, the students increased interest in science, engineering and technology subject areas; greater self-efficacy in performing technology-based tasks; and an increased use of effective problem-solving approaches.	The authors did not find increased interest of the student in GPS/GIS task and they observed nonsignificant results for teamwork.

(1983), who states that random sampling in the area of education is generally the best way to draw a sample from a population, we see that only 20% of the studies involve a good sampling and consider the criteria of a true experimental design (Table 3).

True experimental design is considered the most accurate form of experimental research, in that it attempts to prove or disprove a hypothesis mathematically, through statistical analysis. For an experiment to be classified as a true experimental design, it must fit all of the following criteria (Shuttleworth, 2008):

- The sample groups must be randomly assigned.
- There must be a viable control group.
- Only one variable can be manipulated and tested. It is possible to test more than one, but such experiments and their statistical analysis tend to be cumbersome and difficult.
- The tested subjects must be randomly assigned to either control or experimental groups.

4.3. Is robotics an effective teaching tool? What do the studies show?

Many of us believe that robotics provides a tremendous source of energy that can be used to motivate children's learning. However, Johnson (2003) recalls that before rushing headlong into new education programs, we need to understand exactly what is that robotics has to offer to the educator. We need to resist getting caught up in what may turn out to be nothing more than a passing fad.

In general, the results of the articles show a learning gain with the use of robotics. On the other hand, the articles selected allow us to observe that there are indeed cases where the use of robotics has not brought any significant increase in student learning, as can be observed in studies of specific situations (see the column "major findings" in Table 5) in Hussain et al. (2006), Lindh and Holgersson (2007), Barker and Ansorge (2007), Williams et al. (2007) and Nugent, Barker, and Grandgenett (2008), Sullivan (2008), Owens et al. (2008) and Nugent, Barker, Grandgenett, and Adamchuk (2009).

Analyzing the results obtained from the studies, we can see that these are mainly concentrated into two aspects: (i) contributions on the learning of concepts/subjects; and (ii) skills development. In this sense, Table 6 shows the aspects in which the authors have shown significant progress, as well as aspects where nonsignificant results were observed.

Regarding the subject discussed, the researches support the use of educational robotics to increase academic achievement in specific STEM (Science, Technology, Engineering and Math) concept areas. Generally, the studies described self-directed learning experiences that promote personalized comprehension of STEM concepts through experimentation, with significant results. However, we cannot argue that the use of robotics to teach STEM concepts, necessarily, will bring benefits to student learning, as the authors of four studies reported nonsignificant increase observed in some cases. Nevertheless, we cannot isolate the variables that contributed to the success (increased learning) of the experiments.

In terms of developing skills through robotics, we can see that the skills involved are focused on: (i) thinking skills (observation, estimation and manipulation), (ii) science process skills/problem-solving approaches (like solution of evaluation, hypothesis generation, hypothesis testing and control of variables), and (iii) social interaction/teamwork skills. However, the observed results are absolutely inconclusive, because for each skill found in the researches there are as well results with significant improvement as results without significant improvement. In this regard, we note that more research is needed to point out how to work with educational robotics to develop specific skills of students.

So, what can be said is that robotics has much potential to assist in teaching, however, the gain in learning by students is not guaranteed just by the simple application of robotics, as there are several factors that can determine the outcome. In summary, the authors of the selected studies indicate some factors considered important for an effective use of educational robotics:

Table 6
Context of the articles and major findings.

Proved results	Non-proved results
Knowledge areas/subjects	
• Mathematics (Barker & Ansorge, 2007; Nugent et al., 2009) ○ for students in grade 5 (Hussain et al., 2006) ○ for students with medium scores (Lindh & Holgersson, 2007) ○ specifically: fractions, proportions, distance-related formulas, and geometry topics associated with degrees and circles (Nugent et al., 2008) • Computer programming, geospatial concepts and engineering/robotics (Barker & Ansorge, 2007; Nugent et al., 2008, 2009) • Basic principles of evolution (for Non-English Proficient students) (Whittier & Robinson, 2007) • Physics ○ Newton's Laws of Motion (Williams et al., 2007) ○ Distances and angle (Mitnik et al., 2008) ○ Kinematics, graph construction and interpretation (Mitnik et al., 2008) • Systems (Sullivan, 2008)	• Mathematics in grade 9 (Hussain et al., 2006) • Mathematical and logical problems for students with high and low scores (Lindh & Holgersson, 2007) • Geospatial concepts (trigonometric ratios and coordinate distance formulas) (Nugent et al., 2008) • Computation (Sullivan, 2008)
Skills	
• Thinking skills: observation, estimation and manipulation (Sullivan, 2008). • Science process skills: evaluation of solution; hypothesis generation; hypothesis testing and Control of variables (Sullivan, 2008). • Social interactions (including children with autism) (Mitnik et al., 2008; Owens et al., 2008) • Problem-solving approaches (Nugent et al., 2009)	• Problem-solving approaches (Hussain et al., 2006; Williams et al., 2007) • Skills in conducting scientific inquiry (Williams et al., 2007) • Socialization and communication (children with autism) (Owens et al., 2008) • Teamwork (Nugent et al., 2009)

- Hussain et al. (2006) and Lindh and Holgersson (2007) emphasize the role of the teacher, they observe that the teacher plays an important role in stimulating pupils in their school work and giving them positive attitudes, because the teacher has considerable influence over the way in which these tools are received by the pupils.
- There needs to be a large space for the pupils to work, they must be able to spread the material on the ground, "play around" and test different kind of solutions for each kind of project they face (Lindh & Holgersson, 2007).
- The working groups should not be too big (maximum 2–3 pupils/Kit) (Lindh & Holgersson, 2007).
- The task given to the pupils must be both relevant and realistic to solve. It is very important that the pupils can relate the material to their ordinary school work and their different subjects (Lindh & Holgersson, 2007).
- Williams et al. (2007) suggest that short lessons, tutorials, and debriefings embedded in the problem-solving activities could help students to make the connection between experience and scientific concepts. However, the authors observed that the short tutorials and debriefings could be more interesting to students if they were offered in a more just-in-time manner.
- It is important to provide an opportunity for students to explore the robotics kit before requiring them to work on a design challenge (Williams et al., 2007).
- Middle-school students, in particular, seem to need relatively specific guidance on how the robotics activities relate to science and engineering processes (Nugent et al., 2008).
- Sullivan (2008) highlights that the structure of the robotics environment combined with specific pedagogical approaches foster the thinking and science process skills. There are two design aspects of the robotics environment and one instructional design aspect of the pedagogical approach utilized in this study, that afford activity structures and modes of participation that result in the use of thinking skills and science process skills as follows: (1) the tool-rich nature of the environment, (2) the immediate feedback built into the system, and (3) the open-ended and extended nature of student inquiry.
- Mitnik et al. (2008) believe that part of the success of their proposed educational framework resides in the fact that, even though it has to operate in real time in the real world, the activities implemented possess a high-level of structure that helps the robot to correctly guide the activities and the students through them.

These recommendations are supported in the literature. Thomaz et al. (2009) believes that meaningful benefits will only be obtained if the technology is used skillfully by the teachers, aligning the tools with the students' educational needs. This fact brings up another aspect to be considered when opting for robotics education, as reported by Vollstedt, Robinson, and Wang (2007), who observe an obstacle in implementing program involving robotics: "providing teachers with sufficient training to ensure that they are comfortable programming. Many of the teachers displayed much discomfort in using the computer, which makes them uncomfortable answering their students' questions involving the Robolab software. This discomfort with the use of computers makes the teachers reluctant to teach programming to their students."

Investments in training teachers, in addition to the purchase cost of equipment (robots), reinforce the need for investigative studies/research that clearly demonstrate the benefits of each approach to the use of robotics in education, seeking to guide schools toward effective use of this technology. Various robot designs with lower cost are found in the literature (as mentioned earlier), but there is a lack of broader perspective projects, contemplating systematic evaluations and reliable experimental design, with proximity to the reality of the schools and clear guidance on the "safer routes" to powering the benefits of learning about robotics.

5. Conclusions

This study presents a review of recently published literature on the use of educational robotics, with a view to identifying the potential contribution of robotics as an educational tool, in the context of elementary, middle and high schools, summarizing relevant empirical findings and indicating future research perspectives.

In fact, we could have had 70 articles contributing to the discussion of the effectiveness of robotics as a teaching tool, but few studies (only 10 articles) presented a quantitative evaluation, enabling more effective analysis of the potential of robotics as a teaching tool for schools. In this way, the review conducted suggests that there are few empirical studies involving learning through the use of robotics for broader education, i.e., supporting the teaching of subjects that are not closely related to the field of Robotics, i.e. outside the areas of robot programming, robot construction, or mechatronics (see Section 4.1). Two experiments (Owens et al., 2008; Whittier & Robinson, 2007) show that the use of robotics is feasible for teaching or developing skills in areas not closely related to the field of Robotics *per se*, and initially, these same experiments have presented positive learning results, pointing to a promising line of research.

The results also showed that, the most common outcome is the use of robotics to aid the understanding of concepts related to the STEM areas. Although in most cases the results were positive, this research pointed to cases in which the robot showed no difference in student learning. In this sense, we recommend observing the factors suggested (Section 4.1) to enhance success in further experiments.

This study opens a new perspective for future research focused on experience with educational robotics with students aged 11–12, since none of the articles included studies working with this educational level (as highlighted in Section 4.2). Another point demonstrated in this study is the lack of empirical research involving the use of low cost robots in education (Section 4.2 points to 90% of researches using Lego). Another suggestion for future research is to try to assess specifically the use of robotics as a tool for development of skills (thinking skills, problem-solving skills and teamwork skills). This is an area in which the results are inaccurate. To elaborate assessment tools for this area and apply them to a significant sample, is an interesting and necessary research.

The empirical evidence to support the effectiveness of educational robotics is still rather limited. However, as deduced from the overview, and from Table 5, it presents a positive picture. This study has shown that in the most frequently used experimental designs, the participants were not randomly assigned, and 40% of the experimental designs did not use a control group. Therefore, there is an evident need to conduct further studies involving good experimental design and more significant samples.

It should be acknowledged that this study was based on ten articles located using specific search criteria in six bibliographic databases. Other criteria and databases would, perhaps, have yielded more articles. The study should, therefore, be considered an attempt to explore the potential of educational robotics, rather than a complete overview.

This study has shown that educational robotics have an enormous potential as a learning tool, including supporting the teaching of subjects that are not closely related to the Robotics field. It is hoped that the study will provide useful guidance for educators, practitioners and researchers in the area of Education.

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