TDT4501 Datateknikk, Literature study
Spring 2014

Educational Robotics

Jan Tore Stølsvik

Nicklas Utgaard

Department of Computer Science,
NTNU, Trondheim

July 11, 2014

Abstract

In the later years robotics has seen a huge increase within domestic use, and have now become an affordable tool in the daily life of most people [7, 5]. Yet robotics has only seen minimal use within an educational setting. Some researchers suggest that this may be due to the lack of empirical evidence supporting benefits of educational robotics [27]. The goal of this report is therefore to

1. look at how robotics can be utilized in an educational setting to promote STEM content knowledge and STEM attitude
2. create a systematic review of the current available evidence regarding this topic
3. propose future research

After finding a lot of papers relevant to these questions, we analyzed the content and purpose of each study. The reviewed articles suggest that educational robotics usually results in an increase of content knowledge and a more positive attitude towards STEM. Though there were also studies that reported that educational robotics did not yield any tangiable results. The studies that reported negative (no increase in content knowledge) do however form the minorty out of all the studies reviewed.

1 Introduction

In 1980 Seymour Papert published the book "'Mindstorms: Children, computers, and powerful ideas"'[19], where his ideas of a constructionismistic learning environment and robotics were presented. It was Papert's belief that educational robotics held a major potential improvement of the current learning environment. Allowing children to interact and construct their their own knowledge in way previously impossible.

Even though educational theorists believed robotics could be utilized in a learning environment with success, there has been little incorporation seen throughout the world. Some speculate that the limited adoption is due to lack of empirical evidence for the effect of robotics as a learning tool [27].

Another possibility is that the usage of robotics in education usually has been as a tool to teach students about robotics itself, and thus have formed a narrow field of applicability [21]. The third possibility comes down to the price of robotics equipment, e.g a lego mindstorm kit costs about 650 USD. An interesting field of research is therefore to look at how robotics can be utilized to teach about non-robotics subjects, and perhaps even be used as a motivational or attitude changing tool while still keeping the cost down.

2 Method

This review has been completed as several phases, based upon the Kitchenham's [9] and Khan's [8] guide for writing systematic reviews. The initial steps of identifying a need for the review and commissioning a review have however been omitted here. The steps followed is written down below.

Phase 1: Planning

1. Specifying the research question(s)
2. Developing a review protocol
3. Evaluating the review protocol

Phase 2: Conducting the review

1. Identification of research
2. Selection of primary studies
3. Study quality assessment
4. Data extaction and monitoring
5. Data synthesis

Phase 3: Reporting the review

1. Communicating the results through a report.

2.1 Planning the review

Initially, we preformed an inital general search into educational robotics, in order to obtain some fundemental knowledge regarding this subject. In this search we stumbled upon another review written in 2011 by Fabiane Barreto Vavassori Benitti[3], which to a very large extend covers the same topic as initially planned by this review. There is however some minor differences between our research question, papers relevant to Benitti will to a large extend be relevant for this review as well. Benitti asked general questions like "'*What topics are taught through robotics in schools*?"', "'*is robotics an effective tool for teaching? What do the studies show?*"', and "'*How is student learning evaluated?*"'. While this review is going to use more narrow question, limiting the research to math and how math can be taught in schools using robotics.

Question 1: Which concepts within math are taught through robotics in schools?

Question 2: How effective has these inquires been?

Question 3: Which, if any, secondary skills (teamwork, scientific inquiry etc) may also be improved through the utilization of robotics in education?

The review was done in February and March of 2014, with paper retrieved from all the major bibligraphic databases. These include, but not limited to, CiteSeer, ACM Digital Library, SpringerLink, ERIC, IEEE XPLORE, Wiley Inter Science, and ScienceDirect. In addition to these known the search query was run through the google scholars search engine to ensure that every study was found.

The general search query was created using groups of synonyms, concatenated by the `and/or` operators before adjustments to each unique database was done(e.g making sure the search query was compatible with the search engine at any given site). The search query used in this review was: `(math or stem or mathematics) and (education or learn or learning or educational or teach or teaching) and (robot or robotics or robots) and (school or k-12)`.

In order to prune the search result into a managable amount of papers we identified several inclusion and exclusion criteria.

IC1 The purpose of the paper is to investigate the usage of robotics in school, where the goal is not to teach about robotics itself.

IC2 The paper should contain some sort of assessment, quantitative or qualitative, of the learning outcome and/or experiences from the study.

IC3 The assessment must address the development of math skills.

IC4 The study should be done in an elementary, middle or highschool context.

IC5 The study should involve the use of physical robots.

These criteria diverge from Benitti's review in that qualitative assessments also are included. We justify this by acknowledging the fact that non-immediate returns of educational robotics may be equally important to immediate curricular related returns, and to reflect and investigate this we allow qualitative research to take part of this review.

By negating the inclusion criteria above we get a hold of the exclusion criteria used for this review. The only criteria which does not have any clear negated form is IC2, we therefore define EC2 to be "'does not include any form of assessment in the form of a study"'.

3 Result

3.1 Articles and studytype

For the classification of different study types we borrow from Donnelly and Trochim's *Research methods knowledge base*[4]. The study type representation is defined as:

R: random assignment	**N:** nonrandom assignment
O: measures/evidence	**X:** robotics intervention

If two lines is used for the classification then the first line is the timeline for the robotics group, whereas the second line will show the timeline for the control group. In the case of Hussain et al. [2006] you may interpret the classification as two randomly assigned group given the same pre/post-test scheme, with the only difference being that the robotics group was exposed to robotics between the pretest and posttest. In some cases the **X** may be suffixed by a number, in these cases the different groups were exposed to different robotics experiences.

Author	Article description	Study type
Hussain et al. [2006]	This study aim at investigating the effect of one year regular robotics traingin on students performance.	R O X O R O O
Lindh and Holgersson [2007]	To investigate the effect of regular robotics training on pupils performance.	R O X O R O O
Barker and Ansorge [2007]	Paper reports on a pilot program aimed at increasing the achievement scores of young people.	N O X O N O O
Nugent et al. [2009]	The goals of the program were to prepare youth for the workplace by providing them an opportunity to learn STEM concepts and foster positive attitudes towards STEM.	O X O
Mitnik et al. [2008]	Presents a novel application of robotics to education, where they use robotics to teach non-robotic related subjects.	N O X1 O N O X2 O
Nugent et al. [2008]	Study of 4-H program to increase STEM achievement and interest using robotics and geospatial technologies.	N O N O N O O
Williams et al. [2007]	Study the impact of a summer robotics camp on middle school students physics content knowledge.	O X O
Mitnik et al. [2009]	This study aims at developing graph construction and graph interpretations skills in students by graphing the movements of a robot in an interactive system..	N O X1 O N O X2 O
Norton [2004]	This study examines students learning ratio concepts while engaged in designing, constructing and evaluating simple machines that use cogs and pulleys.	O X O
Silk [2011] Study1	Observes a formal classroom unit using robots to learn math concepts. Part of an introductory experience to learning robotics in a step-by-step manner.	O X O

Author	Article description	Study type
Silk [2011] Study3	Observes a robot competition. The students had to use math to solve the problems, where other teams could use whatever they wanted.	O X O
Silk [2011] Study4	Students have to synchronize two robots with different wheel size by explicitly using math. Another group uses math explicitly to enter a robot competition.	N O X1 O N O X2 O

Table 1: Articles and studytype

3.2 Articles and findings

Article	How	What
Hussain et al. [2006]	322 pupils in robotics group, 374 pupils as control group. **Quantitative**: pre/post-test compared with control group using a generalized linear model. **Qualitative**: observation, interview, and inquiry.	Positive returns for 5th graders math knowledge, while no returns in 9th grade. No significant returns regarding problem-solving skills was found in 5th or 9th grade.
Lindh and Holgersson [2007]	322 pupils in robotics group, 374 pupils as control group. **Quantitative**: different tests in mathematics and problem solving using ANOVA test. **Qualitative**: observation, interview, and inquiry.	No statistical evidence that the average pupil benefits from robotics. Further analysis showed that the medium scoring students did however benefit from the tutoring.
Barker and Ansorge [2007]	14 pupils in robotics group, 18 pupils as control group. **Quantitative**: pre/post-test of non-random assigned pupils.	Increase of mean scores from pretest to posttest for robotics group.

Article	How	What
Nugent et al. [2009]	147 pupils in robotics group, 141 pupils as control group. **Quantitative**: quasi-experimental pre/post-test of children at summer camp. Analyzed using ANCOVA/split plot ANOVA.	Significant pre/post-test increase for robotics group within programming, mathematics, geospatial concepts. In addition they found an increase in interest towards STEM.
Mitnik et al. [2008]	Three different pairs of groups, with 12, 14, and 12 as the robotics group. And 6, 15, and 11 as the control groups. **Quantitative**: pre/post-test scheme of non-random assignment. **Qualitative**: observations	Significant increase in the assessment of teaching distances and angles, kinematics, and graph construction. In addition they saw that students in general was more motivated to continue learning when working with robotics, whereas the control group expressed their boredom.
Nugent et al. [2008]	38 pupils attending a summer camp, no control group. **Quantitative**: pre/post-test using the same assessment in both cases. Analysis done using t-tests.	Increased test scores within four content areas; mathematics, geospatial concepts, programming and engineering. The math tutoring focused on fractions, proportions, distancerelated formulas and geometry. The authors also provide a head-up warning that youth may not see the direct connections between robotics and STEM content learning.
Williams et al. [2007]	21 pupils attending a summer camp, no control group. **Quantitative**: pre/post-test using the same assessment in both cases.	Significant impact on students gains in physics conent knowledge related to diameter of the wheels, friction, energy flow etc. In addition they observed that the scientific inquiry skills did not increase.

Article	How	What
Mitnik et al. [2009]	16-year-old students. 12 in the robot group, 11 in the simulator group. 4 60min sessions over one week. **Quantitative**: pre/post-test using the same assessment in both cases. Collaboration and motivation post activity survey. **Qualitative**: in-site motivation and collaboration observations	Fostered learning in both implementations. However the real-robot activities worked twice as well. Motivation and collaboration was far better in the real-robot group. Proposes a change in the classroom dynamic, allowing students to be active participants in their experience of learning.
Norton [2004]	56 year 7 students. 10 weeks of lectures at a school. **Quantitative**: Paired t pre/post-test.	Most students improved their ability to explain mathematics concepts on pencil and paper tests. Believe that motivation is the main factor in these gains. Think that the link between the activities and the math concepts should be made more explicit.
Silk [2011] Study1	16 (9th and 10th grade) students. 4 math focused robotics lessons at a school as part of a bigger project. **Quantitative**: 2 Paired t pre/post-test. One for problem solving and one for attitude towards math, robotics and value of math for robotics.	Made significant improvement in problem solving but not in the wanted context(math). The math they did learn was not tightly aligned with their understandings or misunderstandings of robot movement. All the attitude results were negative.
Silk [2011] Study3	21 (elementary and middle school) students. 9 weeks of preparation time. **Quantitative**: 2 Paired t pre/post-test. One for problem solving and one for attitude towards math, robotics and value of math for robotics.	Significant increase in students overall problem solving. Attitude towards robotics decreased but the students did see the value of math for robotics. The success of using math was too variable for a conclusion.

Article	How	What
Silk [2011] Study4	29 (6-9th grade) students. 21 students synchronized two robot movements in 8 hours. 7 students entered a competition and used 32 hours. **Quantitative**:2 Paired t pre/post-test. One for problem solving and one for attitude towards math, robotics and value of math for robotics.	The synchronized movement task helped students improve their understanding of how robots work. Both groups made about the same improvement to problem solving skills. The synchronization group increased their value of math in robotics but decreased their interest in robotics. The attitude results for the competition group were inconclusive.

Table 2: Articles and findings

4 Discussion

In this section we discuss the results obtained in an attempt to answer the three questions presented in section 2.1.

4.1 Which concepts within math are taught through robotics in schools?

Almost all math concepts present in elementary and middle school can be taught in some way or another through robotics, something the diversity of the studies presented shows. This broad applicability of robotics within math also gives room for some of the bigger studies presented, which have been conducted over the course of a full school year [6, 10]. The results from these long term studies are very important as they may, to a better extent, measure the long term effects of educational robotics. Most studies are however conducted over a much shorter time span, often just an intensive week of robotics tutoring. Thus it may be harder to measure anything other than changes in content knowledge alone.

A summery of the different math concepts investigated can be seen in table 3.

Article	Math concepts
Barker and Ansorge [2007]	Decimals and geometry
Nugent et al. [2008]	Geospatial and GPS concepts
Nugent et al. [2009]	Geospatial and GPS concepts
Williams et al. [2007]	Physics
Mitnik et al. [2008]	Distance, angles, kinematics, and graph construction
Mitnik et al. [2009]	Graph construction and interpretation skills.
Norton [2004]	Ratio concepts.
Silk [2011]	Proportional reasoning.

Table 3: Articles and concepts

4.2 How effective has these inquires been?

Most of the papers presented, and otherwise seen, throughout this literature review have provide positive evidence that educational robotics may teach children about math. Out of the twelve papers presented in this review we found just two papers that did not provide any evidence of positive returns from using robotics (Silk [2011] , study 1 and 3). In Silk's forth study he did however find significant evidence of increased math content knowledge.

Silk argued that just because math is present in an activity, it does not mean that students will learn math [22]. His dissertation looks mostly at how the lessons have to be designed to generalize the knowledge students attain. Several problems were encountered and solutions were implemented gradually with increasing success. Thus his work provide important knowledge about how to design future endeavors into educational robotics.

The concerns around disassociation between robotics and math several times in other papers as well and a common suggestion is to make the link between activities and the underlying math very explicit [16].

Lindh and Holgersson study also provide interesting data regarding the effectiveness of educational robotics. They found that not every student may benefit from the use of robotics, and had to initially accepts their null hypothesis. Further investigation did however show interesting results. Pupils in ninth grade showed a negative t-statistic, indicating that they in fact perform worse after partaking in the robotics experiment. For low performing and high performing pupils in fourth grade there was no significant difference, while there was positive results for medium performing pupils in fourth grade. Some consolation was however found in the correlation between fourth grade scores and fifth grade scores. Which, as expected, showed a positive correlation between scores. But did show a significantly lower correlation for the robotics group, indicating a weakening of the relationship between poor performance in forth grade and poor performance in fifth grade.

4.3 Which, if any, secondary skills (teamwork, scientific inquiry etc) may also be improved through the utilization of robotics in education?

With regards to secondary skills there is a lot greater gap between the results, universally mentioned is however teamwork including social interactions and communication [12, 13, 17, 18]. When working with robots students tend to get a greater sense of community and start helping each other instead of competing. Students are also eager to help other groups and want to explain how they got their solution.

When testing for other secondary skills the results are to a large extent inconclusive or negative. Hussain et al. and Lindh and Holgersson identifies an insignificant increase in problem-solving, Hussain et al. also identifies an insignificant positive attitude change towards LEGO [6, 10]. For scientific inquiry Williams et al. found no significant difference when comparing the pretest and post test [27]. Though they argue that scientific inquiry may be a process to be learned through long exposure and that their study was to short. Nugent et al. [2008] identified an increase in interest and motivation, where pupils working with robots expressed their wish to continue working with robots. Whereas the control group would do the opposite [16].

5 Conclusion

The current state of educational robotics does seem promising, it does however also include a major obstacle before reaching the mass populous of school children. In most of the studies seen the robot only works as a feedback provider to the children, and this task could in many circumstances be achieved by the use of a simulator, flash game or app. Which in all cases would be cheaper and easier to acquire for the schools given the robotics landscape seen today. A pedagogical counter to this situation comes from Piaget and Papert in the form of constructionism and constructivism, the latter being the dominant at this point. Researchers are in addition to this driven by the belief that robots awaken a tremendous source of energy and motivation in children. Another benefit is the connection between abstract concepts and physical representation given by robots, this could be especially beneficial within STEM topics as they are usually very abstract and robots may therefore help by giving a concrete understanding of these concepts. Thus truly justifying robotics as a superior alternative to simulator etc.

In the literature search there are some areas of lacking research. Namely research involving the use of low cost robots in education. In general there is also a lack of research with good experimental design with a larger sample, often below thirty pupils. In general the lack of research can partly be blamed on the cost of robots. The most popular robot seems to be Lego Mindstorm. This robot construction kit costs 650 USD.

In educational robotics we differentiate between academic performance and secondary skills. Academic performance concerns how school curriculum can be tough by using robots, while secondary skills are skills outside the curriculum. These are skills that you learn because of working with the robots. Often academic performance is the main goal when introducing robots to students while other skills are merely a bonus that is often not taken into account.

5.1 Academic performance

Topics that are taught with robotics as teaching aid are mostly within the STEM (science, technology, engineering and mathematics) category. Specifically Newton's Laws of Motion, distances, angles, kinematics, graph construction and interpretation, fractions, ratios and geospatial concepts. In the systematic review carried out in [3] 80% of the papers focus on these topics. The two remaining papers discuss basic evolution and teaching basic social skills to kids with autism and asperger syndrome.

Most of the research done provide promising results. None have discovered that it worsens learning, but there are examples of it not making any difference compared to traditional methods. It is hard to pinpoint the factors that generates positive results, as the art of teaching and learning is extremely complex and different for each individual. For future research we would like to propose more longitudinal studies, observing the effect of educational robotics over a large time span. As this would truly investigate the true effect, and not only the immediate increase in content knowledge. More research into this field could also mitigate the concerns about lacking empirical evidence, and possible confirm that educational robotics is an untapped resource waiting to be utilized.

5.2 Secondary skills

These skills are often not measured, as the research focus is on content knowledge, but these skills may have important benefits later in school and life. The skills often include the technical skill as problem-solving, logic, and scientific inquiry. But also include non-technical skills as teamwork, social interactions, collaboration, attitude changes, and motivation. Benitti suggest the latter of these as main topics for future research, as some studies show positive trends within these skills. Many mention that skills such as these were improved when introducing robotics in education but more research is also needed to figure out how to train the specific skills separately.

References

[1] Dimitris Alimisis. Robotics in education & education in robotics: Shifting focus from technology to pedagogy. In *Proceedings of the 3rd International Conference on Robotics in Education*, pages 7–14, 2012.

[2] Bradley S Barker and John Ansorge. Robotics as means to increase achievement scores in an informal learning environment. *Journal of Research on Technology in Education*, 39(3), 2007.

[3] Fabiane Barreto Vavassori Benitti. Exploring the educational potential of robotics in schools: A systematic review. *Computers & Education*, 58(3):978 – 988, 2012. ISSN 0360-1315. doi: http://dx.doi.org/10.1016/j.compedu.2011.10.006. URL `http://www.sciencedirect.com/science/article/pii/S0360131511002508`.

[4] J Donnelly and W Trochim. The research methods knowledge base, 2007. URL `http://www.socialresearchmethods.net/kb/`.

[5] Thomas Hsiu, Steve Richards, Ajinkya Bhave, Andres Perez-Bergquist, and Illah Nourbakhsh. Designing a low-cost, expressive educational robot. In *Intelligent Robots and Systems, 2003.(IROS 2003). Proceedings. 2003 IEEE/RSJ International Conference on*, volume 3, pages 2404–2409. IEEE, 2003.

[6] Shakir Hussain, Jörgen Lindh, and Ghazi Shukur. The effect of lego training on pupils school performance in mathematics, problem solving ability and attitude: Swedish data. *Journal of Educational Technology & Society*, 9(3), 2006.

[7] Dan Kara. Sizing and seizing the robotics opportunity. *Presentation in RT Los Angeles by Robotics Trends, USA*, 2003.

[8] Khalid S Khan, Gerben Ter Riet, Julie Glanville, Amanda J Sowden, Jos Kleijnen, et al. *Undertaking systematic reviews of research on effectiveness: CRD's guidance for carrying out or commissioning reviews.* Number 4 (2nd Edition). NHS Centre for Reviews and Dissemination, 2001.

[9] Barbara A Kitchenham and Stuart Charters. Guidelines for performing systematic literature reviews in software engineering. 2007.

[10] Jörgen Lindh and Thomas Holgersson. Does lego training stimulate pupils ability to solve logical problems? *Computers & education*, 49(4): 1097–1111, 2007.

[11] Orazio Miglino, Henrik Hautop Lund, and Maurizio Cardaci. Robotics as an educational tool. *Journal of Interactive Learning Research*, 10(1): 25–47, 1999.

[12] Ruben Mitnik, Miguel Nussbaum, and Alvaro Soto. An autonomous educational mobile robot mediator. *Autonomous Robots*, 25(4):367–382, 2008.

[13] Rubén Mitnik, Matías Recabarren, Miguel Nussbaum, and Alvaro Soto. Collaborative robotic instruction: A graph teaching experience. *Computers & Education*, 53(2):330–342, 2009.

[14] Omar Mubin, Catherine J Stevens, Suleman Shahid, Abdullah Al Mahmud, and Jian-Jie Dong. A review of the applicability of robots in education. *Journal of Technology in Education and Learning*, 1.

[15] Stephen John Norton. Using lego construction to develop ratio understanding. *Mathematics education for the third millennium: Towards 2010*, pages 414–421, 2004.

[16] Gwen Nugent, Brad Barker, and Neal Grandgenett. The effect of 4-h robotics and geospatial technologies on science, technology, engineering, and mathematics learning and attitudes. In *World Conference on Educational Multimedia, Hypermedia and Telecommunications*, volume 2008, pages 447–452, 2008.

[17] Gwen Nugent, Brad Barker, Neal Grandgenett, and Vaicheslav Adamchuk. The use of digital manipulatives in k-12: robotics, gps/gis and programming. In *Frontiers in Education Conference, 2009. FIE'09. 39th IEEE*, pages 1–6. IEEE, 2009.

[18] Gina Owens, Yael Granader, Ayla Humphrey, and Simon Baron-Cohen. Lego® therapy and the social use of language programme: an evaluation of two social skills interventions for children with high functioning autism and asperger syndrome. *Journal of autism and developmental disorders*, 38(10):1944–1957, 2008.

[19] Seymour Papert. *Mindstorms: Children, computers, and powerful ideas.* Basic Books, Inc., 1980.

[20] Chris Rogers and Merredith Portsmore. Bringing engineering to elementary school. *Journal of STEM Education: Innovations & Research*, 5, 2004.

[21] Natalie Rusk, Mitchel Resnick, Robbie Berg, and Margaret Pezalla-Granlund. New pathways into robotics: Strategies for broadening participation. *Journal of Science Education and Technology*, 17(1):59–69, 2008.

[22] Eli Michael Silk. Resources for learning robots: Environments and framings connecting math in robotics. 2011.

[23] Florence R Sullivan. Robotics and science literacy: Thinking skills, science process skills and systems understanding. *Journal of Research in Science Teaching*, 45(3):373–394, 2008.

[24] Florence R Sullivan and Mary A Moriarty. robotics and discovery learning: pedagogical beliefs, teacher practice, and technology integration. *Journal of Technology and Teacher Education*, 17(1):109–142, 2009.

[25] Sarah Thomaz, Akynara Aglaé, Carla Fernandes, Renata Pitta, Samuel Azevedo, Aquiles Burlamaqui, Alzira Silva, and Luiz MG Gonçalves. Roboeduc: a pedagogical tool to support educational robotics. In *Frontiers in Education Conference, 2009. FIE'09. 39th IEEE*, pages 1–6. IEEE, 2009.

[26] L Elena Whittier and Michael Robinson. Teaching evolution to non-english proficient students by using lego robotics. *American Secondary Education*, pages 19–28, 2007.

[27] Douglas C Williams, Yuxin Ma, Louise Prejean, Mary Jane Ford, and Guolin Lai. Acquisition of physics content knowledge and scientific inquiry skills in a robotics summer camp. *Journal of Research on Technology in Education*, 40(2), 2007.