Evaluating the impact of robotics in education on pupils' skills and attitudes

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Abstract. This paper presents an ongoing study investigating the impact of robotics in education, and RoboCupJunior in particular, on technical and social skills as well as science related attitudes of pupils. The empirical study uses a quasi-experimental two-group design (experimental- and control-group) conducting pre- and post-tests by applying a multiple-choice student questionnaire as assessment instrument. This questionnaire is based on different already applied and proven assessment tools and survey instruments. The evaluation covers a period of approximately eight months. After conducting a pilot study in different schools in several Austrian regions the worldwide main study will start in autumn 2014.

Keywords: Educational robotics, RoboCupJunior, evaluation, empirical study, technical and social skills, quasi-experimental design

1 Introduction and motivation

The development in the area of science education in recent years shows an increasing disinterest of young people in science and technology. Fewer and fewer students decide to go into technical studies at university level or to pursue a technical profession. As a consequence many countries are already facing a lack of well trained engineers, technicians and researchers [1–3]. In this context robotics in education has gained an increased attention over the last decades. Using robots as a vehicle to interest pupils and young children in science and technology and in addition to improve their technical and social skills has become a widespread approach in various countries worldwide [4, 5]. Besides *RoboCupJunior (RCJ)* [6] a number of other educational projects and cross-cultural initiatives aim to encourage pupils and young students to get involved in science and technology by applying a project-oriented educational robotics approach. Although there is a subjective impression that this approach works well and even though, there exists a predominantly positive feedback by involved pupils, students, teachers and researchers, only a few studies focus on the investigation of the impact in a well-founded and empirical way covering a wider region and an extended period of

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time [3, 7–9]. In order to address this challenge we developed an evaluation concept comprising both quantitative and qualitative research methods. The basic aim is to evaluate the impact of robotics in education, and RCJ in particular, on pupils' technical and social skills and the effect on pupils' attitudes and interests towards science and technology. Quantitative methods of the study encompass pre- and post-tests using a quasi-experimental two-group design [10]. The assessment instrument designed for this empirical study is a 139-item multiple-choice student questionnaire which is based on different already proven assessment tools and survey instruments which have been validated and/or applied and tested in previous studies and theses [11–18]. To validate the basic study design and the applied instruments a eight month pilot study was initiated in autumn 2013. Based on the findings of the pilot study the main study will start in autumn 2014, covering schools worldwide. It is embedded in the *RoboCup* initiative [6] in order to gain access to schools around the globe.

This paper focuses on the empirical study applying quantitative research methods (details on the qualitative research can be found in [7]). The paper is structured as follows: Section 2 provides a review of related literature followed by Section 3 which deals with the study design and the applied instrumentation. Preliminary findings of the ongoing pilot study are presented in Section 4 whereas conclusions, limitations and further steps are discussed in Section 5.

2 Related research

The work in [19] focuses on the evaluation of the *FIRST (For Inspiration and Recognition of Science and Technology) Robotics Competition (FRC)* investigating the long-term impact of FRC on former participants. A similar study, evaluating the *FIRST Lego League (FLL)*, was carried out by Melchior and colleagues [20]. Within the scope of the *Roberta* project an empirical research evaluating the impact on participating girls' interest in science and technology and their further professional career was conducted [21]. The dissertation of Griffith [22] examines the relationship between pupils' participation in the FRC and their interests in science and technology. Data was gathered conducting pre- and post-tests using paper-and-pencil survey questionnaires. Results were compared between an experimental group (EG) and a control group (CG). One evaluation attempt focusing on RCJ was done by Sklar et al. [23] in 2004. The study did not comprise a CG nor an explicit assessment of skills was done. The dissertations of Jewell [24], Whitehead [25] and Welch [26, 2] focus on the evaluation of the impact of robotics curricula, FRC respectively, on high school students' beliefs, attitudes and interests towards science and technology. A quasi-experimental pre-/post-design with EG and CG (except for the work of Whitehead) was applied, but those studies only covered certain regions in the US and did not assess technical or social skills. Quantitative evaluations investigating the impact of educational robotics activities also on technical skills were done by Nugent et al. [11] and Cruz [12]. Again, both studies comprised only participants from certain regions in the US, examining a short period respectively. Various quantitative empirical

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studies have been carried out in different scientific fields (e.g. medicine, sociology, psychology, economy, education, early-childhood pedagogy [27–29]). Some of the methods and assessment instruments used in other empirical studies ([11–18]) were adapted and applied for our investigation.

3 Methodology

The main purpose of this study is to investigate the impact of robotics in education, and RoboCupJunior in particular, on pupils' and young students' technical and social skills. Furthermore, the study intends to determine the effects of educational robotics activities on pupils' attitudes and interests towards science, technology and social aspects.

3.1 Study design

In order to address the research questions this empirical study relies on a quasi-experimental two-group design including pre- and post-tests [10, 9, 22, 30]. Study participants are divided into experimental group (EG) and control group (CG). The EG consists of pupils and young students up to the age of 19 who participate in robotics activities (especially RCJ) for the first time whereas the CG comprises young students who actually do not participate in those robotics activities. In this context we cooperate with schools that take part in annual national/regional junior robotics competitions (RCJ) and/or offer regular robotics courses/projects during the semester. If possible students in the control and the experimental groups should be evenly distributed and share comparable demographic attributes (e.g. age, social and educational background). Responsible teachers at each participating school are asked to recruit pupils for EG and CG.

In order to determine differences in terms of technical and social skills as well as science related attitudes and interests, results of pre- and post-tests will be compared between experimental and control group. The instrument used in this regard is a multiple-choice questionnaire comprising different already proven survey assessment tools (see Section 3.2). Table 1 schematically depicts the study design. To measure study participants' base level both EG and CG are pre-tested (indicated as O_1, O_3 respectively) at the begin of winter term (t_1), right before the intervention (robotics activities during the semester; indicated as X) starts. Since in the context of this study special focus is given on RoboCupJunior it was decided to conduct the post-tests for EG and CG (O_2, O_4) right after a national/regional RoboCupJunior competition took place (t_2). Depending on national schedules this results in a time span of approximately eight months between both surveys.

Basically the study is divided in two stages. The first stage covers a pilot study in order to validate the general study design and the applied instruments. The main focus of this pilot study is on different types of Austrian secondary schools and different Austrian regions. Robotics in education, and RoboCupJunior in particular, is well established in Austria. A large number of schools have

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Table 1. Study design

	$\mathbf{t}_1$		$\mathbf{t}_2$	$t_{[1,2]}$...*time of measurement*
experimental group (EG)	O_1	X	O_2	*X...intervention (robotics activities)*
control group (CG)	O_3		O_4	$O_{[1..4]}$...*observations (pre-/post-tests)*

integrated robotics in their curriculum and participate in national and international RCJ competitions an a regular basis [1, 9]. In order to obtain results also in an international context we carry out the same study simultaneously in a selected school in Sweden. Pre-tests started in autumn 2013, post-tests of the pilot study will be completed by the middle of May 2014. Lessons learned and preliminary findings of the first series of pre-tests can be found in Section 4. Based on those findings, the second stage comprises the main study starting in autumn 2014. It will be completed by the middle of 2015 and covers young students from different countries worldwide. By applying this widespread, mid-term approach we aim to gather solid and valuable empirical data on a large geographical scale.

The overall study concept as well as the applied survey instrument (Section 3.2) was initially presented and discussed at the *Workshop on Educational Robotics (WEROB)* [9] within the scope of the RoboCup Symposium in July 2013. The feedback from experts in the field of educational robotics and national RCJ representatives flowed directly into the development of the study design. The context RoboCup eases the access to schools and mentors in order to recruit participants worldwide. Respecting legal and ethical requirements all collected information is treated confidentially. Participating pupils, their parents as well as the school administrations have to sign an informed consent stating the purpose and explaining the procedure of the study. The whole study approach was reviewed and approved by the ethics commission at Graz University of Technology.

3.2 Instrumentation

The main instrument for assessing technical/social skills and science and technology related attitudes/interests is a 120 item multiple-choice student questionnaire (MCQ) separated in several sub-sections. This questionnaire combines different standardized assessment tools as well as survey instruments which have been validated and/or applied and tested in previous studies and theses [11–18]. The reuse of proved methods gives security with regard to valid results. Permission to reuse those instruments in our work was obtained by corresponding authors in advance. In addition to the skill-/attitude-sections the questionnaire contains 14 items (partly multiple-choice, partly open-ended questions) dealing with demographic background information of study participants as well as a five item feedback part in the concluding section. Hence, the instrument comprises 139 items in total.

The process of developing the student questionnaire was done in cooperation with experts in the field of psychology respecting general rules of questionnaire-

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designing [31–33]. The instrument ran through several refinement and improvement steps (review by experts at educational robotics workshop [9]; review by pedagogues and teachers as well as experts in robotics; test run with young students). In order to conduct the survey in different European countries the questionnaire, initially in English, was translated into German, Swedish and Slovene working together with national RCJ representatives. To allow a convenient data collection from geographically distributed study participants we use the on-line survey tool *SurveyMonkey* [34]. Responsible teachers at participating schools organize and monitor the study conducting. To ensure the same conditions across all participating schools a step-by-step manual, containing detailed instructions regarding preparation and implementation, is provided to those teachers.

The questionnaire is structured around four main sections and divided into several sub-sections covering study-relevant topics. Main sections are numbered I-IV while sub-sections are enumerated using letters (applied instruments in italics). Study questions are in ascending order of difficulty level.

I **Demographic/background information** (14 items; MCQ/open-ended)
  (a) **Student alias**: anonymous information matching pre- and post-test
  (b) **Group classification**: EG, CG
  (c) **Confounding factors**: previous knowledge in robotics and programming (questions regarding previous involvements in robotics activities and experiences with graphical and/or textual programming languages)
  (d) **Statistical information**: age, gender, school, language, grade-level

II **Technical skills** (37 items; MCQ)
  (a) **General robotics/programming** (*4-H Robotics Questionnaire* [11]): basic knowledge of robotics and programming
  (b) **Graphical programming** (*4-H Robotics Questionnaire* [11]): analyzing programs; finding mistakes and providing solutions
  (c) **Computer science** (*Beaver Computing Challenge* [13]): keeping track of state; fundamentals of algorithms; abstraction; encoding; pointers and references; linking
  (d) **Textual programming** (*Programming Skills MCQ* [15]): tracing/analyzing code; loops; ability to write programs
  (e) **Mathematics** (*4-H Robotics Questionnaire, PISA released items*[11, 14]): fraction/ratio; converting units; uncertainty/ likelihood
  (f) **Science as an inquiry** (*Science Questionnaire* [12]): controlling scientific experiments; constructing/interpreting graphical representations
  (g) **Physical science** (*Science Questionnaire* [12]): relationship input/output; comparing graphs of acceleration and deceleration

III **Attitudes and interests / social skills** (83 items; MCQ/4-and 5-point Likert scale questions [10, 22])
  (a) **Science related attitudes and interests** (*TOSRA** [16]): attitude to scientific inquiry; adoption of scientific attitudes; enjoyment of science lessons; leisure interest in science; career interest in science
  (b) **Self-efficacy in robotics** (*4-H Robotics Quest.* [11]): self-confidence in solving robotics tasks (e.g. *"I am confident that I can program a robot to move forward two wheel rotations and then stop."*)

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(c) **Problem solving** (*4-H Robotics Quest.* [11]): self-evaluation regarding problem solving approaches (e.g. *"I use a step by step process to solve problems."*
(d) **Teamwork attitudes** (*4-H Robotics Quest.* [11]): attitudes regarding working together with other people (e.g. *"I like listening to others when trying to decide how to approach a task or problem."*)
(e) **Social skills and self esteem** (*Social Skill and Self Esteem Scale* [17, 18]): ability to get along with other people; aspects of self-worth; (e.g. *"If I want my friends to go along with me, I know what to say to them."*
(f) **Goal setting skills** (*Goal Setting Skill Scale* [18]): directing an effort to achieve a desired result (e.g. *"Once I set a goal, I do not give up until I achieve it."*)

IV **Feedback** (5 items; MCQ/Likert scale, open-ended)
(a) Overall feedback on the questionnaire: difficulty, length, clarity, further comments

TOSRA (Test of Science-Related Attitudes): The multidimensional instrument was developed by Fraser [16]. It has been extensively tested and applied in various different studies in the field of science education research [2, 24]. The test was developed to assess science related attitudes and interests of middle and high school students. It contains seven distinct sub-scales (social implications of science; normality of scientists; attitude to scientific inquiry; adoption of scientific attitudes; enjoyment of science lessons; leisure interest in science; career interest in science). Each sub-scale comprises ten items (e.g. *"I would prefer to find out why something happens by doing an experiment than by being told."*) whereby each sub-scale can be scored separately.

4 Participants and preliminary findings

In total 242 pupils (35.5% female, 60.3% male, 4.1% not stated[1]; EG: 130 pupils, CG: 112 pupils) completed the pre-test of the pilot study. The mean age of all participants was calculated with 13.6 (20.7% aged 9-11, 65.7% aged 12-16, 13.6% aged 17-19). Pupils attend nine different schools whereby eight schools are located in different urban, suburban and rural regions across Austria and one school is located in a smaller town in western Sweden. Types of schools range from polytechnic (1), secondary modern school (2), secondary school of higher education in economy and tourism (2), high school (3) and junior high school (1). A first analysis of pre-tests as well as feedback from teachers revealed that the initial questionnaire was too difficult for pupils aged 9-11 (with regard to understanding of questions, solving tasks in the technical-skills part). It also turned out that, due to the large number of items, the time for completing the questionnaire exceeded the duration of a regular classroom lesson (which was problematic in some cases concerning timetable management). Participants

[1] all percentage values rounded

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rated the length of the questionnaire with 40.9% as "too long" followed by 37.5% as "appropriate". The post-tests will be completed by middle of May 2015 after which an extensive statistical analyses on the gathered data will be performed.

5 Discussion and further steps

In this paper we presented our concept of conducting an extensive empirical evaluation on the impact of robotics in education, and RoboCupJunior in particular, on young students' technical/social skills and attitudes/interests towards science and technology. The goal is to conduct this evaluation using a well-proven methodology. Therefore we use a quasi-experimental two-group design (experimental- and control-group) including pre- and post-tests and applying a multiple-choice student questionnaire as assessment instrument. It is based on different already applied and tested tools and instruments. The study covers a period of approximately eight months and comprises both a pilot study (different selected schools in Austria and Sweden) and a main study (schools worldwide). The ongoing pilot study, validating the applied methodology and instruments, was initiated in autumn 2013 and pre-tests have been administered. The first series of post-tests will start by end of April 2014. Using the software package *SPSS* and applying methods of inferential statistics ([10, 30]), a comprehensive statistical analysis will be performed after finishing all post-tests. Therefore first empirical results will be available by end of May 2014.

We are aware that the quasi-experimental evaluation design applied in this study has some limitations and shortcomings (i.a. no randomized assignment of participants to EG and CG; confounding factors like foreknowledge, influence of teacher; learning effects between pre- and post-test; motivation of participants; applying the study in different countries; ...) [10]. In order to face those challenges as far as possible specific actions are taken (i.a. calculating difference between results of pre-test (base level) and post-test; assessing confounding factors in the questionnaire; eight month time-gap between pre- and post-test; providing incentive for participants; translation of questionnaire in different languages by native speakers; ensuring similar assessment situation in different participating schools; ...). Currently we are in the detailed planning phase for the main study, contacting RCJ national representatives as well as schools and teachers in order to recruit potential participants. Taking into account the findings and results of the pilot survey, the applied instrumentation will be adapted for the main study starting in autumn 2014. In this context we will reduce the overall amount of items for the questionnaire by removing non relevant/redundant items and/or sub-sections. In addition we plan to develop a special questionnaire focusing on assessing skills and interests of pupils aged 9-11. First results of the main study are finally expected by the middle of 2015.

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