Dissertation

Development and Evaluation of Innovative Concepts in Educational Robotics and Education in Artificial Intelligence

Martin Kandlhofer

Graz, 2016

Institute for Software Technology
Graz University of Technology

Supervisor/First reviewer: Univ.-Prof. Dipl.-Ing. Dr. techn. Franz Wotawa
Second reviewer: Univ.Prof. Dipl.-Ing. Dr.techn. Gerald Futschek

Abstract (English)

In recent years it could be observed that the interest of young people in science and technology is decreasing. As a consequence, many countries are already facing a lack of well-trained engineers, technicians and researchers as well as a serious shortage of manpower in the scientific field. In this regard the use of robots in the educational context (referred to as *educational robotics* or *robotics in education*) has gained increased attention and importance worldwide. Given the fact that children and young people are fascinated by robots the basic idea behind educational robotics is to use robotics as a pedagogical learning tool to awake interest for science and technology and, furthermore, to foster technical- as well as social- and cognitive-skills. The constructionist nature of educational robotics provides a hands-on, motivating and fruitful learning environment.

Following two main issues drove this thesis: First, various subjective stories of success and anecdotal reports by students, teachers, mentors and researchers regarding the positive impact of educational robotics can be found in current literature. Nevertheless, hardly any systematic empirical studies exist which focus on the investigation of the impact in terms of change or improvement of students' technical- and social-skills as well as science related attitudes and interests. Furthermore, hardly any studies exist which cover a wider region, an extended period of time, different age groups and a broader population. Addressing this challenge, a comprehensive empirical evaluation concept combining quantitative and qualitative research methods and relying on a proven, well-grounded methodology was developed and implemented. The quantitative evaluation aims at investigating the impact of educational robotics on students' technical- and social-skills as well as on their attitudes towards science and technology and their personal/career interests. It utilizes a widespread (students from various different middle/secondary schools), mid-term approach (approximately eight months), aiming at gathering solid and valid empirical data on a larger geographical scale (participants from Europe, Australia, Asia). Based on a well-proven methodology a quasi-experimental two-group design (experimental- and control-group) comprising pre- and post-tests is applied. The assessment instruments are student questionnaires based on different already proven assessment tools and survey instruments which have been validated and/or applied and tested in previous studies. The summarized results of the quantitative research (using well-grounded statistical methods for data analysis) show that educational robotics has a significant positive impact on a group of content-related topics rather than on single thematic topics. These findings suggest that educational robotics should not only focus on separate, isolated topics but rather should be applied as an integrated approach, fostering a holistic understanding and acceptance of different areas and fields. The qualitative evaluation aims at identifying the motivational factors inherent to the educational robotics approach and, furthermore, at the extraction of role models and later careers of young people who participated in educational robotics activities. In this regard the primary research method applied is the technique of conducting and analyzing semi-structured qualitative interviews with several former RoboCupJunior participants. Summarized results suggest that educational robotics generates three important motivational factors (*social experience*,*engaged community*, *feelings of success*) and that there is an obvious positive relationship between educational robotics and future careers.

Second, Artificial Intelligence (AI) plays an increasingly important role in our daily life. Sound knowledge about AI and the principles of computer science will be of vast importance for future careers in science and engineering. Science and technology are changing rapidly and people have to be prepared for this development. Therefore, it is crucial to start familiarizing children with science and technology already from an early age on, using age-appropriate pedagogical methods and learning tools. Despite this necessity, applying technological learning tools like educational robotics in early childhood education is quite rare and, furthermore, teaching fundamental topics of AI and computer science at school or pre-school level hardly exists at the moment. In order to address these challenges two innovative educational intervention concepts were developed considering pedagogical and didactic aspects by applying well-proven, age-appropriate learning tools (among others educational robotics, computer science unplugged) and teaching methods. The first educational concept applies a cross-generational approach focusing on kindergarten children and integrating school students as well as senior citizens in order to initiate a vital social process among the different age groups. The goal is to familiarize the target audience (in particular pre-school children and school students) with science and technology in a playful way using educational robotics as learning tool. A pilot project in a kindergarten was conducted and empirically evaluated. The second educational concept focuses on familiarizing children and students from kindergarten to university with fundamental topics of artificial intelligence (AI) and computer science. By using an analogy with the process of developing reading/writing literacy this novel AI education concept aims at fostering AI literacy. The concept comprises modules for different age groups on different educational levels. Fundamental AI/computer science topics addressed in each module are, amongst others, problem solving by search, sorting, graphs and data structures. Four proof-of-concepts modules for kindergarten as well as middle school, high school and university were developed, conducted and empirically evaluated. Summarizing the evaluation results after analyzing all gathered data it can be concluded that both novel educational intervention concepts were working as expected.

The AI education concept developed and evaluated within the scope of this thesis serves as basis for extensive follow-up projects aiming at fostering AI literacy on a larger scale. Outcomes of the empirical evaluation of the impact of educational robotics will further be used to improve support measures provided by university institutions and to enhance educational robotics activities at school level. Furthermore, the evaluation concept and instrumentation developed can be applied to evaluate other initiatives and projects as well.

Abstract (German)

Im Laufe des letzten Jahrzehnts ist das Interesse von jungen Menschen an Naturwissenschaften und Technik stetig gesunken. Infolgedessen besteht in vielen Ländern bereits jetzt ein Fachkräftemangel in technischen Berufen sowie im wissenschaftlichen Bereich. Weltweit gewann in diesem Zusammenhang der Einsatz von Robotern im Bildungskontext (bezeichnet als *Educational Robotics* oder *Robotics in Education*) zunehmend an Bedeutung. Roboter üben eine enorme Faszination auf Kinder und Jugendliche aus. Dieser Umstand bildet die Grundlage von Educational Robotics: Der Roboter dient dabei als pädagogisches Werkzeug um das Interesse für Wissenschaft und Technik zu wecken und darüberhinaus technische, soziale und kognitive Fähigkeiten zu fördern. Der konstruktionistische Ansatz von Educational Robotics bietet eine interaktive, motivierende und anregende Lernumgebung.

Die folgenden zwei Kernthemen bilden den Schwerpunkt dieser Arbeit:
Erstens: In der Literatur finden sich zahlreiche subjektive Erfolgsgeschichten und Schilderungen von Studierenden, Mentoren, Lehrern und Wissenschaftlern hinsichtlich der positiven Effekte von Educational Robotics. Nichtsdestotrotz gibt es kaum empirische Studien, welche die Auswirkungen auf Schüler hinsichtlich einer Verbesserung oder Änderung von technischen und sozialen Fähigkeiten sowie von wissenschaftsbezogenen Einstellungen und Interessen systematisch untersuchen. Zudem finden sich kaum Studien, welche größere Regionen, eine längere Zeitspanne sowie unterschiedliche Altersgruppen und Länder umfassen. Zur Bewältigung dieser Herausforderung wurde ein umfassendes Evaluierungskonzept, basierend auf fundierten quantitativen und qualitativen empirischen Forschungsmethoden entwickelt und umgesetzt. Ziel der quantitativen Evaluierung ist die Untersuchung des Impacts von Educational Robotics auf Schüler hinsichtlich a) technischer und sozialer Fähigkeiten, b) der Einstellung/Meinung gegenüber Wissenschaft und Technik sowie c) persönlicher bzw. karrierebezogener Interessen. Die quantitative Evaluierung fußt auf einer breitgefächerten (Schüler aus verschiedenen Schulen der Mittel- und Oberstufe), mittelfristigen (Beobachtungszeitrum von ca. acht Monaten) Vorgehensweise zur Sammlung fundierter und valider empirischer Daten in einem größeren geographischen Maßstab (Studienteilnehmer aus Europa, Australien und Asien). Auf Grundlage einer fundierten Methodik kommt ein quasi-experimentelles 2-Gruppen Forschungsdesign (Experimental- und Kontrollgruppe) mit Pre- und Post-Test zum Einsatz. Als Erhebungsinstrumente dienen Fragebögen, welche auf bereits in früheren Studien angewandten bzw. validierten und bewährten Erhebungsinstrumenten basieren. Die zusammengefassten Ergebnisse der quantitativen Evaluierung (unter Verwendung von etablierten statistischen Methoden für die Datenanalyse) zeigen, dass Educational Robotics einen signifikant positiven Einfluss auf eine Gruppe von inhaltsverwandten Themenbereichen und weniger auf einzelne, isoliert betrachtete Themen hat. Diesen Erkenntnissen zufolge sollte Educational Robotics als integrierter Ansatz betrachtet werden, welcher ein holistisches Ver-

ständnis von unterschiedlichen Themenbereichen und Fachrichtungen fördert. Ziel der qualitativen Evaluierung ist die Identifizierung von Motivationsfaktoren, welche charakteristisch für Educational Robotics sind. Im Zuge dessen werden Vorbilder (Rollenbilder) identifiziert bzw. die Karrierewege von jungen Menschen, welche in ihrer Schulzeit in Educational Robotics involviert waren, näher beleuchtet. Als Forschungsmethode dienen qualitative Leitfadeninterviews mit früheren RoboCupJunior Teilnehmern. Die zusammengefassten Ergebnisse zeigen, dass Educational Robotics einerseits u.a. drei wichtige Motivationsfaktoren generiert (*die soziale Erfahrung*, *die engagierte Community*, *das Erfolgserlebnis*). Andererseits zeigt sich eine positive Korrelation zwischen Educational Robotics und erfolgreichen Karrierewegen.

Zweitens: Künstliche Intelligenz (KI) spielt eine immer wichtigere Rolle in unserem täglichen Leben. Fundierte Kenntnisse über KI und Grundlagen der Informatik sind von enormer Bedeutung für künftige Karrieren in wissenschaftlich-technischen Bereichen. Aufgrund der rasanten technischen Entwicklung bzw. der Schnelllebigkeit der Technik ist es essentiell, dass bereits junge Kinder mit technisch-wissenschaftlichen Grundlagen vertraut gemacht werden. Diese muss unter Verwendung von altersgerechten pädagogischen Methoden und geeigneten Lernwerkzeugen erfolgen. Trotz dieser Notwendigkeit ist der Einsatz von technischen Lernwerkzeugen, wie beispielsweise Educational Robotics, in der vorschulischen Bildung wenig verbreitet. Darüberhinaus gibt es derzeit kaum Ansätze, welche grundlegende KI bzw. Informatik Themen in der Schule oder bereits im Kindergarten behandeln. Um diese Herausforderungen in Angriff zu nehmen, wurden zwei innovative Ausbildungskonzepte entwickelt. Unter Berücksichtigung pädagogisch-didaktischer Aspekte wurden im Zuge dessen verschiedene bewährte, altersgerechte Lernwerkzeuge und Unterrichtemethoden integriert (unter anderem Educational Robotics, Informatik Unplugged). Das erste Ausbildungskonzept bedient sich eines generationsübergreifenden Ansatzes. Der Fokus liegt auf Kindergartenkinder und integriert Schüler sowie Senioren, um auf diese Weise einen fruchtvollen sozialen Lernprozess in Gang zu setzen. Ziel ist es, vor allem Kindergartenkinder und Schüler auf spielerische Weise und durch den Einsatz von Educational Robotics als Lernwerkzeug mit Naturwissenschaften und Technik vertraut zu machen. Ein Pilotprojekt im Kindergarten wurde umgesetzt und empirisch evaluiert. Ziel des zweiten Ausbildungskonzepts ist es, Kinder und junge Menschen vom Kindergarten bis zur Universität mit den Grundlagen von KI bzw. Informatik vertraut zu machen. In Analogie mit der Entwicklung von Schreib- und Lesekompetenz fokussiert sich dieses neuartige KI Ausbildungskonzept auf die Entwicklung einer grundlegenden "KI Kompetenz". Es umfasst Module für unterschiedliche Altersgruppen auf unterschiedlichen Ausbildungsstufen. Grundlegende KI/Informatik Themen, welche in jedem Modul in unterschiedlicher Komplexität behandelt werden, sind Problemlösung durch Suche, Sortieralgorithmen, Graphen und Datenstrukturen. Vier Proof-of-Concept Module für den Kindergarten, die Mittel- und Oberstufe sowie für die Universität wurden entwickelt und empirisch evaluiert. Die Evaluierungsergebnisse lassen darauf schließen, dass die beiden neuartigen Ausbildungskonzepte funktionieren und die gesetzten Ziele mehrheitlich erreicht wurden.

Das im Zuge dieser Dissertation entwickelte und empirisch evaluierte KI Ausbildungskonzept dient als Basis für ein umfangreiches Nachfolgeprojekt, welches die weitere Etablierung einer KI Kompetenz in größerem Maßstab zum Ziel hat. Die Ergebnisse der empirischen Evaluierung des Impacts von Educational Robotics werden in weiterer Folge für die Verbesserung der Supportmaßnahmen für Schüler/Lehrer seitens der Universität sowie für die Intensivierung von Educational Robotics Aktivitäten auf Schulebene verwendet. Das im Rahmen der Dissertation entwickelte Evaluierungskonzept (inklusive der Erhebungsinstrumente) kann schließlich auch zur Evaluierung von weiteren Projekten oder Initiativen im Bildungsbereich verwendet werden.

Acknowledgement

This thesis would not have been possible without the support and help of many people. Big thanks to all of them!

First of all, I would like to thank Gerald Steinbauer for his great support, trust and mentoring, not only during the course of this thesis but also during my professional career. He provided a motivational, inspiring work environment and enabled the realization of many exciting ideas and projects.

I would also like to thank my supervisor Franz Wotawa for his professional input and suggestions. His door was always open for questions and discussions, supporting my research endeavor and academic career.

Special thanks go to my external reviewer Gerald Futschek for the inspiring discussions during educational robotics workshops and his valuable, constructive feedback regarding this thesis.

Furthermore, I would like to thank the staff of the Institute of Software Technology, especially Wolfgang Slany for his professional support and Petra Pichler for her outstanding guidance in almost all matters. Without her help and her patience many projects would not have been feasible.

Many thanks are owed to all the colleagues and experts I worked with during the last years: Dietrich Albert, Lisa Winter and Michael Bedek for their valuable input regarding empirical evaluation methodologies; Harald Burgsteiner for the collaboration in the context of education in artificial intelligence; Petra Huber, Sabine Hirschmugl-Gaisch and Hans Eck for providing the opportunity to cooperate with kindergartens, schools and youth organizations; Lara Lammer for providing new intriguing perspectives on the topic; Astrid Weiss and Petra Sundstroem for their help with my first paper. Last but not least thanks to my workmates and all my friends for many fruitful off-topic discussions.

Big thanks also go to Timothy Jump, Damian Baraty, Kirsten Hoogenakker as well as the staff and students of The Hill School and Benilde-St.Margaret's School for providing me the opportunity to do my research stay abroad.

Finally, I would like to thank all the teachers, students and schools in Austria and worldwide who supported this research either by participating in the empirical study or by participating in several pilot implementations of novel educational robotics/artificial intelligence courses.

Most of all, I would like to thank my family. Words cannot describe my gratitude.

Martin Kandlhofer, Graz 2016

Statutory Declaration

I declare that I have authored this thesis independently, that I have not used other than the declared sources / resources, and that I have explicitly marked all material which has been quoted either literally or by content from the used sources.

Graz, ______________________   ______________________

Place, Date   Signature

Eidesstattliche Erklärung

Ich erkläre an Eides statt, dass ich die vorliegende Arbeit selbstständig verfasst, andere als die angegebenen Quellen/Hilfsmittel nicht benutzt, und die den benutzten Quellen wörtlich und inhaltlich entnommene Stellen als solche kenntlich gemacht habe.

Graz, am ______________________   ______________________

Ort, Datum   Unterschrift

Contents

List of Figures

List of Tables

Chapter 1

Introduction

In recent years an increasing disinterest of young people in science and technology could be observed. Fewer and fewer students decide to go into science or technical studies at university level or choose to pursue a profession in that areas. Studies show that students in most of the industrial countries are not willing to become scientists or technicians (Sjøberg and Schreiner, 2006; Demo et al., 2012). As a consequence many countries are already facing a lack of well trained engineers, technicians and researchers (Welch, 2010; Bredenfeld et al., 2010; Hofmann and Steinbauer, 2010) as well as a serious shortage of manpower in the scientific field (Osborne and Dillon, 2008; Gago, 2004; Teitelbaum, 2007; Demo et al., 2012). The demand for highly skilled personnel in these areas increases faster than the number of people deciding to follow this career path (Rockland et al., 2012). In this context the use of robotics in education has gained increased importance and attention worldwide (Eguchi, 2012; Miller et al., 2008; Mataric, 2004). The educational approach of using robotics as a tool to interest young people in science and technology and in addition to foster STEM (science, technology, engineering, mathematics), computer science as well as social and cognitive skills is commonly referred to as *educational robotics* or *robotics in education* (Alimisis, 2013; Eguchi, 2010). Over the last decades educational robotics has become a widespread approach in various countries worldwide (TOE, 2013; Kandlhofer et al., 2014). The recent popularity and interest in educational robotics is based on several different factors. For instance, there is the undeniable fact that children and young people are fascinated by robots. Building a robot, programming it and observing its behavior is of tremendous excitement. Providing a tangible connection between hardware and software is therefore one of the motivating key assets of educational robotics. Furthermore, by the constructionist nature of educational robotics students are actively involved in the learning process. It provides teachers and researchers a vehicle which encourages motivating, hands-on activities and awakens children's and students' curiosity and interest. (Papert, 1993a; Barker et al., 2012a; Alimisis, 2009, 2012, 2013; Kumar and Meeden, 1998; Eguchi, 2010).

1.1. Motivation and Problem Statement

A number of educational projects, initiatives as well as competitions aim to encourage young people to get involved in science and technology by applying a project-oriented, hands-on educational robotics approach (Sklar and Eguchi, 2005). Many different educational robotics approaches and frameworks with different characteristics and goals, aiming at different target groups and applying different settings, tools, platforms and learning techniques exist (Lammer et al., 2016a). Various conferences, workshops and symposia have been organized around the topic in the last decades (Balogh, 2010; Merdan et al., 2016) together with a great number of published articles, theses and books (RAS, 2016; Barker et al., 2012a; Jewell, 2011). Many publications present local projects (e.g. school projects, regional competitions, ...) or for the most part deal with technical aspects (e.g. development of new educational robotics platforms) rather than focusing on the underlying learning concepts and methodologies (Alimisis, 2012; Altin and Pedaste, 2013). Although using robotics as a learning tool at school level (primary, middle and secondary school) has become a worldwide phenomenon, educational robotics at pre-school level/kindergarten is less widespread. The idea behind the concept of educational robotics in kindergarten is to use the robot as pedagogical tool to familiarize children aged between three and six years with science and technology in a playful way. Science and technology are changing rapidly and young children have to be prepared for this development. Due to the fast moving nature of technology the focus must be put on fundamental principles and concepts fostering computational thinking in general. Therefore, it is crucial to familiarize children with technology at an early age using age-appropriate pedagogical methods (Kandlhofer et al., 2014). As artificial intelligence (AI) already plays an essential role in our daily life it is of tremendous importance as well to familiarize people with fundamental concepts and techniques behind AI from an early age on. The prevalence and impact of AI not only on our everyday life but also on the working world is still growing. In general, we currently face an increasing digitalization of different life/work areas. People use different devices, applications and services which are based on the principles of AI. Examples would be intelligent household appliances like autonomous vacuum cleaners or lawn mowers as well as services and smartphone applications like *Google (Maps, Now, ...)*, *Cortana* or *Siri*. In contrast, hardly anybody knows about the concepts and techniques behind those services and applications. There is a need to shift from solely *using* towards *understanding* technology. Teaching fundamental topics of AI and computer science at school or pre-school level hardly exists at the moment (Burgsteiner et al., 2016b). Considering the current technological development, sound knowledge about AI and the principles of computer science will be of vast importance for future careers in science and engineering. Looking towards the near future, jobs will largely be related to AI as it will be the basis of the products where our future wealth will be built on (smart production, internet of things, autonomous driving, robotics ...). In this context literacy in AI and computer science will become as important as classic literacy (reading/writing). Research in the area of classic literacy shows that starting to learn those basic skills at an early stage is essential for developing profound abilities (Myberg, 2007; Genlott and Gronlund, 2013). In order to develop AI literacy it is crucial as well to familiarize people with the underlying concepts of AI and computer science as early as possible by applying well-proven learning methodologies and tools (amongst others, educational robotics).

The use of robotics as an educational tool has become a widespread, worldwide phenomenon and represents a field which is still growing. Educational robotics as a learning tool has the potential to enrich education at multiple levels, from STEM and computer science education to non-technical education (e.g. arts, language, geography, ...) (Alimisis, 2013; Eguchi, 2010). There is the subjective impression, based on a predominantly positive feedback by involved students, teachers, mentors and researchers that the educational robotics approach works well. Various stories of success and anecdotal reports regarding the positive impact of educational robotics can be found in current literature Alimisis (2013). Because educational robotics is a relatively young field existing literature often deals with self-reported data as far as positive learning effects are concerned (Barker et al., 2012a). Although such descriptions are important and provide initial indications of the powerful potential of educational robotics, it is crucial as well to provide valid information and verifiable data to prove its effectiveness and positive impact. The necessity and importance of a systematic evaluation in order validate the impact of educational robotics through research evidence is stressed in current literature. There is a need for quantitative studies applying a standardized evaluation methodology and a reliable experimental design (Barker et al., 2012a; Alimisis, 2013; Stubbs et al., 2012; Bredenfeld et al., 2010; Barreto and Benitti, 2012). Despite that fact, hardly any empirical studies exist which focus on the systematic investigation of the impact in terms of change or improvement of students' technical- and social-skills as well as students' science related attitudes and interests, covering a wider region, an extended period of time, different age groups and a broad population. Furthermore, there is a need for investigating the long-term effects of educational robotics on students' ways through school, college and later careers (Cole, 2012; Catlin and Blamires, 2010). Nevertheless, relatively few studies investigate this issue (Stubbs et al., 2012).

1.2. Research Objectives

Given the broad scope of the problem statement illustrated in the previous section following major driving factors for this thesis can be identified which are basically divided into a) *development of educational intervention concepts* and b) *empirical evaluation of the impact of educational robotics*:

a) identifying open issues and challenges regarding the use of robotics as an educational tool; determining the current status and open issues in the area of education in artificial intelligence; developing and implementing novel educational intervention concepts to address those challenges;

b) determining/verifying the need for empirical evaluations in the area of educational robotics; investigating the impact of educational robotics on young people and identifying the motivational factors inherent to the educational robotics approach; evaluating the efficacy of the educational intervention concepts developed;

Based on this definition the following detailed main research questions (Q[a,b]) have been deduced which set the overall scope of this thesis:

- Qa_1: *What are open issues and challenges in educational robotics (in the context of using robotics as a learning tool)*?
- Qa_2: *What is the current status and what are open issues in teaching fundamental concepts of artificial intelligence at different educational levels ('education in AI')?*
- Qa_3: *Which novel educational intervention concepts are needed to address those challenges (applying, amongst others, educational robotics as a learning tool)?*
- Qb_1: *What are the motivational factors and inherent values of educational robotics and, furthermore, what is the long-term effect of the involvement in educational robotics activities on the individual career development of school students?*
- Qb_2: *Are the novel educational intervention concepts (cross-generational educational robotics / education in AI) working as expected?*
- Qb_3: *Is there a difference/change in the outcome (compared between before and after participating in educational robotics activities) in terms of technical skills, social aspects and soft*

skills and science-related attitudes and interests between school students participating in educational robotics activities compared to school students not participating in educational robotics activities?

- $Qb_{3.1}$: *Is there a difference/change in the outcome (compared between before and after participating in educational robotics activities) in terms of technical skills, social aspects and personal interests between young students (up to the age of 12) participating in educational robotics activities compared to young students not participating in educational robotics activities?*
- $Qb_{3.2}$: *How do students intending to participate in educational robotics activities differ from students not intending to participate in educational robotics activities in terms of technical skills, social aspects and soft skills, science related attitudes, career and personal interests as well as attitudes towards their teacher?*

1.3. Contributions

Following an overview of the major contributions of this thesis together with a summary and publication remarks for each contribution.

1.3.1. Pre-School Educational Robotics in a Cross-Generational Context

The idea behind the concept of educational robotics in kindergarten is to use robotics as pedagogical tool to familiarize children in pre-school age with science and technology in a playful way. Integrating new technology in the education of children between three and six years of age cannot be considered in isolation but must rather be accomplished by applying a multi-dimensional approach. Therefore, a novel educational intervention concept within the field of educational robotics was developed, implemented and empirically evaluated. It combines different age groups (kindergarten children, school students (aged from eleven to thirteen) and senior citizens) as well as different scientific and educational institutions (kindergartens, schools, universities) in a cross-generational and cross-institutional educational robotics project.

The overall educational intervention concept was first published in Eck et al. (2013). The detailed approach including evaluation methodology and results was finally published in Kandlhofer et al. (2013) and Kandlhofer et al. (2014).

1.3.2. Education in Artificial Intelligence

Artificial Intelligence (AI) already plays a major role in our daily life. Sound knowledge about AI and the principles of computer science will be of vast importance for future careers in science and engineering. Looking towards the near future, jobs will largely be related to AI. In this context literacy in AI and computer science will become as important as classic literacy (reading/writing). By using an analogy with this process a novel AI educational intervention concept aiming at fostering AI literacy was designed. The concept comprises modules for different age groups on different educational levels applying well-proven, age-appropriate learning methodologies and tools (amongst others, educational robotics). Four proof-of-concepts modules focusing on kindergarten as well as middle school, high school and university were developed, conducted and empirically evaluated. The evaluation was done applying a proven and sound qualitative and quantitative evaluation methodology. The complete AI education concept including evaluation methodology and results was published in Kandlhofer et al. (2016b). An extended abstract of this work was published in Kandlhofer et al. (2016a).

The module focusing on AI education in high school (design, methods, evaluation, results) was published in Burgsteiner et al. (2016b) as well as in Burgsteiner et al. (2016c) and Burgsteiner et al. (2016a). In addition, the kindergarten module was presented at Kandlhofer et al. (2015).

1.3.3. Evaluating the Impact of Educational Robotics: Qualitative Pre-Study

The qualitative pre-study aimed at identifying the motivational factors inherent to the educational robotics approach and, furthermore, at the extraction of role models and later careers (investigating long-term impact aspects) of young people who participated in educational robotics activities. This was accomplished by means of investigating careers and stories of former participants of junior robotics competitions, in particular *RoboCupJunior*. The approach of conducting and analyzing semi-structured qualitative interviews was the primary research method. Instead of gathering quantitative performance data here the goal was to gather and analyze qualitative data to gain insights into the reoccurring motivational factors of an educational robotics approach like RoboCupJunior. This qualitative study formed the basis for the development of the quantitative main study.

The overall evaluation endeavor and design of the pre-study was published in Kandlhofer et al. (2012) (workshop paper). The final work (including results) was published in Kandlhofer et al. (2012) (conference paper).

1.3.4. Evaluating the Impact of Educational Robotics: Quantitative Main Study

The goal of the quantitative main study was to evaluate the impact of educational robotics on students' technical- and social-skills and the impact on students' attitudes and interests towards science and technology in a systematic way. The conducted study applied sound evaluation techniques and relied on well-grounded empirical methods encompassing pre- and post-tests and using a quasi-experimental two-group design (experimental- and control-groups). The assessment instrument was a student questionnaire based on different already proven assessment tools and survey instruments which have been validated and/or applied and tested in previous studies, theses and investigations. Basically the quantitative main study was divided in two stages (stage I, stage II). Stage I addressed the main research question investigating whether there is a difference between control group and experimental group (before and after the experimental group participated in educational robotics activities). It covered a period of approximately eight months and comprised students from different types of secondary schools in Austria and Sweden. In addition, after applying the overall evaluation design and instrumentation within the context of stage I, stage II of the quantitative main study dealt with two sub-research questions. On the one hand it encompassed the evaluation of the impact of educational robotics on young school students (middle school). Therefore, another evaluation instrument specially tailored to young school students was compiled and a pilot study was conducted in two selected middle schools. On the other hand stage II focused on the investigation of distinctive features between experimental- and control-group students and comprised participants from different types of secondary schools in eight different countries worldwide (Europe, Asia, Australia). Therefore, based on the findings and lessons learned from stage I of the study, the assessment instrument was adapted, extended and translated into the respective languages. All gathered data were analyzed using well-proven statistical methods.

The overall evaluation concept was initially published in Kandlhofer and Steinbauer (2013). The complete evaluation design including the assessment instrument (stage I) was published in Kandlhofer and Steinbauer (2014). The complete stage I evaluation design (methods, instruments) as well as results and findings were published in Kandlhofer and Steinbauer (2016). Evaluation design and results were also presented at Kandlhofer and Steinbauer (2015).

1.3.5. Educational Robotics Landscape

Within the scope of a workshop organized by Lammer et al. (2015) experts from different domains worked together in order to find common grounds and contact points regarding different educational robotics approaches. The paper summarizing the results as well as introducing a concept to categorize educational robotics approaches using a tagging framework was published in Lammer et al. (2016b) and Lammer et al. (2016a).

1.3.6. Using Robotics to Teach STEM Principles - a Field Research

In the United States educational robotics has a long history. Many ideas, concepts and innovations in that area originate from different US universities, schools and further educational institutions. Therefore, within the scope of this PhD thesis a research stay was carried out in April/May 2016 at two US high schools which have integrated a three-year STEM/robotics program in their regular curriculum. The program focuses on topics related to mechanical, electrical and computer science engineering using educational robotics as a learning tool.

1.4. Outline

The remainder of this thesis is structured as follows: Chapter 2 reviews the relevant literature and discusses the underlying concepts, theories and challenges in educational robotics, education in artificial intelligence (AI) and empirical evaluation research. Chapter 3 describes the methodology (learning methods, goals, structure, content) and proof-of-concept implementations of two educational intervention concepts dealing with the major challenges and open issues regarding educational robotics as a learning tool as well as education in AI at different educational levels (from kindergarten to university). Chapter 4 describes the design (structure, methods, instruments, study components) and implementation and discusses results and shortcomings of an extensive empirical evaluation investigating the impact of educational robotics on students' skills and attitudes. Finally, Chapter 5 summarizes the covered topics and findings of this thesis and discusses shortcomings, limitations and future work.

Chapter 2

Review of Literature and Background

This chapter reviews the relevant literature and discusses the underlying concepts and theories behind educational robotics (Sections 2.1 and 2.2)). Section 2.3 reviews current literature in the field of education in artificial intelligence ('AI education') while Section 2.4 discusses relevant literature and theories concerning empirical evaluations in the context of educational robotics. Finally, Section 2.6 summarizes findings and discusses challenges, open issues and next steps.

2.1. Educational Robotics

In the last decades the use of robots in education has gained increased importance and attention worldwide (Eguchi, 2012; Miller et al., 2008; Mataric, 2004). The educational approach of using robots as vehicle to foster STEM (science, technology, engineering, mathematics), computer science as well as social and cognitive skills is commonly referred to as *educational robotics* (ER) or *robotics in education*. The ER approach offers a learning tool for teachers and researchers which encourages motivating, hands-on activities and awakens children's and students' curiosity and interest (Alimisis, 2013; Eguchi, 2010; Lammer, 2016).

A number of (slightly) different definitions and interpretations of educational robotics can be found in literature. For instance, Eguchi (2012) provides following definition: *"Educational robotics uses robotics kits, programming software and computers as hands-on learning tools. It can create a learning environment that can enhance collaboration and communication among students, problem-solving skills, critical thinking skills, and creativity." (p. 30).*

In line with this, Alimisis (2009) characterizes educational robotics *"as a powerful, flexible teaching/learning tool stimulating learners to control the behavior of tangible models using specific programming languages (graphical or textual) and involving them actively in authentic problem-solving activities." (p. 7).*

Demo et al. (2012) define educational robotics as *"the use of Robotics for Educational purposes connected with school curriculum. At the beginning robotics is the object of study, but later on robotics is a tool for learning other subjects like mathematics, sciences, physics, informatics, languages, etc..." (p. 91).*

Mataric (2004) concludes from her research of using robotics as educational tool that it *"has the potential to significantly impact the nature of engineering and science education at all levels" (p. 1).*

Current literature identifies three major dimensions in educational robotics (Eguchi, 2012):

(a) robotics as **learning objective**: In this context the focus is on teaching skills in engineering, robotics, computer science and artificial intelligence by means of secondary/post-secondary courses in order to prepare students for a career in theses field (Miller et al., 2008).

(b) robotics as **learning aid**: This means to use robots as a supporting tool in the classroom (e.g. by assisting a teacher in, for instance, an English class as described by You et al. (2006)) or as an assistive therapeutic tool (for instance as described by Feil-Seifer and Mataric (2008)).

(c) robotics as **learning tool**: In this regard robotics is used to enhance the learning process in the classroom. Robots act as pedagogical vehicles for teaching and learning different subjects at different educational levels. Therefore, robotics aims at engaging and boosting students' motivation to learn and explore. Moreover, the goal is to stimulate students' imagination and creativity while fostering technical-, problem-solving- and further social- and soft-skills (e.g. critical thinking, communication, teamwork, language, ...) (Miller et al., 2008; Eguchi, 2014b, 2012; Alimisis, 2009). In this context educational robotics is a vehicle to support teaching, learning and education in general (Alimisis, 2012; Kumar and Meeden, 1998).

The focus of this thesis is on using robotics as pedagogical learning tool.

2.1.1. Related Research, Background and Viewpoints

Educational robotics has its roots in the late sixties when Seymour Papert investigated possibilities of teaching programming to children. As part of this research at the *MIT Artificial Intelligence Laboratory* he developed programmable bricks (equipped with inputs (sensors) and outputs (motors)) as well as the programming language *Logo* (Papert, 1993a). In the early eighties the first educational robotics kit called *Hero-1* was sold (Miller et al., 2008). In the nineties Papert cooperated with the *LEGO* company which finally released the successful and widely known *Mindstorms RCX* robotics kit (including a graphical programming language) in 1998. Nowadays an enormous range of different educational robotics kits, platforms and corresponding programming languages/environments for different age- and target-groups and for different educational levels/purposes are available and the number of such kits is still growing (Barker et al., 2012b; Miller et al., 2008; Ruzzenente et al., 2012). Yet, one of the most common robotics kits are the successor models to the RCX, namely the *LEGO Mindstorms NXT* and *EV3* (Kawell and Schafer, 2015; Kim and Jeon, 2007; LEGO, 2016). In the emerging years of educational robotics (around the turn of the millennium) two main learning objectives were defined: First, using robots to raise children's interest in technology (Handler, 2000). Second, using robots as learning vehicle to motivate children with engaging activities while imparting concepts and contents which would be complicated to impart with traditional teaching methods.

Many different educational robotics (ER) approaches and frameworks with different characteristics and goals aiming at different target groups exist. They are applied in different settings, use different tools, platforms and learning techniques. Literature reports different views on ER and various ways to categorize or classify those educational robotics approaches (whereas classification schemes show overlapping areas). In this context, the following section presents and discusses common viewpoints and approaches (Lammer et al., 2016a; Alimisis, 2013).

Eguchi (2010) and Alimisis (2013) propose the following general categorization of ER approaches:

- *theme-based*: curriculum topics are structured around certain themes (e.g. Cacco and Moro (2015) use the theme 'hedgehog' in order to teach STEM and arts topics; Rockland et al. (2012) describe the use of 'medibotics', a way of incorporating information technology, engineering and robotics into classroom lessons by means of building and programming robots to solve problems in the area of biomedical engineering)
- *project-based*: students explore and solve real-world problems through group work (e.g. Jump (2015) applies a project-based approach (designing and building rescue robots) to teach high-school students engineering concepts; Lammer and Vincze (2015) present an approach where an entire class (divided into sub-teams) works on a project to develop a special robot for children)
- *goal-oriented*: students work to achieve certain goals (often in out-of-school time), in particular by participating in robotics competitions (e.g. RoboCupJunior (RCJ, 2016; Sklar and Eguchi, 2005); FIRST Lego League (FLL, 2016; Rosen et al., 2012); Botball (Botball, 2016; Koppensteiner et al., 2015); further examples for such a out-of-school, goal-oriented approaches would be robotics clubs (e.g. as presented by Eronen et al. (2005))

A similar approach is used in the book by Barker et al. (2012a). The authors introduce the three categories *educational robotics in formal learning* (robotics programs in classrooms and curricula), *educational robotics in out-of-school time* (robotics programs and implementations in an after-school/out-of-school time setting) and *learning through educational robotics competitions* (increasing students' interest in STEM topics by means of robotics-based tournaments and competitions).

Stager (2010) proposes five general ways of using/classifying robotics in education based on different objectives and the level of teacher involvement:

- *robotics as a discipline*: focusing on teaching specific robotics concepts (e.g. localization, path planning, . . .);
- *teaching STEM concepts*: using robotics to teach, for instance, concepts of physical science (e.g. force, friction, . . .), engineering (e.g. gears,. . .), mathematics (e.g. variables, trajectories, arithmetic operations, . . .), computer science (e.g. programming, debugging, . . .);
- *thematic units*: applying robotics in the context of a certain theme to teach school subjects/topics (e.g. using robotics to model machines or systems, e.g. an airport or a factory);
- *curricular themes*: using robotics as a vehicle to solve curriculum-specific tasks (e.g. students learn about the behavior of certain animals (natural science/biology) by programming a robot to imitate this behavior;
- *freestyle*: students/children are free to experiment with robotics material (hardware and software); in this context robotics acts as a tool for self-expression (e.g. building and programming a robot to express and share moods, emotions, identity, . . .);

Catlin and Blamires (2010) suggest a framework of 10 educational robotics applications principles ('ERA principles'). These principles can be used to categorize and describe the benefits of educational robots as well as to explain how robots can assist/support learning. The framework also discusses underlying concepts and cognitive processes behind educational robotics activities. Furthermore, the principles provide a 'how-to' for people who intend to develop educational robotics activities or who want to create educational robots. The 10 ERA principles are grouped into the three main categories technology, student and teacher:

- Technology

Overall Concept	**Strategy** #top-down #bottom-up	**Setting** #classroom #after-school	**Target Group** #kindergarten #elementary #K12	**Structure** #exploration #activity
Educational Goals	**Focus** #STEM #literature	**Teaching Goals** #robotics #collaboration skills	**Theory/Method** #inquiry-based #project-based	
Materials	**Principle** #white-box #black-box	**Software** #text-based #visual interface	**Coding concepts** #high-level #low-level	
Evaluation	**General** #evaluated #not evaluated	**Methodology** #quantitative #qualitative	**Focus** #technical skills #interests	**Target Group** #student #teacher

Table 2.1.: Tagging framework with exemplary tags (indicated with '#') in order to categorize educational robotics approaches (according to Lammer et al. (2016a))

   - *intelligence* ('intelligent' behavior of robots as essential part of educational activities)
   - *interaction* (interacting/working with robots represents an active learning process)
   - *embodiment* (physical, tangible robots provide a positive learning experience)
- Student
   - *engagement* (children's fascination for robots fosters a positive learning environment and attitude)
   - *sustainable learning* (educational robotics encourages long-term learning, life skills and self-knowledge)
   - *personalization* (personalization of the learning experience in order to fit students' individual needs)
- Teacher
   - *pedagogy* (educational robotics activities applying established learning theories and methodologies can enable effective learning)
   - *curriculum and assessment* (educational robotics activities can be integrated in the regular curriculum (comprising teaching, learning and assessment situations))
   - *equity* (robotics in education can successfully support equity principles (e.g. gender, race, social/cultural background, age, . . .))
   - *practical* (robots used in educational robotics activities have to meet practical requirements regarding formal and informal learning situations)

The paper of Lammer et al. (2016a) introduces a concept to categorize educational robotics approaches using a tagging framework in order to enable better communication between experts from different domains. The framework uses tags to label educational robotics approaches based on their characteristics. Therefore, tags serve as attributes whereas more than one tag can be assigned to an approach and new tags can be introduced. Table 2.1 shows the tagging framework with exemplary tags arranged in a matrix representation.

Eguchi (2012) discusses how educational robotics can enhance students' learning, its benefits and characteristic features as well as settings that enable learning through ER:

- *ER as interdisciplinary approach*: Many different subject areas and disciplines (technology, science, mathematics, reading/writing literacy, social studies, arts, . . .) can be integrated by applying an educational robotics approach (Alimisis, 2012). For instance, an ER student project could comprise social studies (e.g. students investigating people's behavior in a shopping street), interviewing certain people, transcribing those interviews and writing up people's stories (literacy). Afterwards students build, design (incorporating arts) and program robots to retell those stories (applying concepts of mathematics, physics, computer science). Further examples for interdisciplinary projects are described by Hamner et al. (2016) and Desmond et al. (2016).
- *ER as motivational factor*: Researchers, teachers and educators reported the potential of robots to motivate and excite children and students (Miller et al., 2008). The hands-on aspect provides an inspiring learning environment and engages students to work on STEM related topics and to develop unique, 'own' solutions to given problems. Building and programming robots provides students an opportunity to transfer their imagination into the real world (Eguchi, 2012).
- *ER as a way to translate abstract to tangible*: Robots are tools which help students to comprehend abstract concepts since robots provide immediate feedback (e.g. changing gears of the robot - concept of gears; programming robot's movement - concept of cause and effect) (Bers, 2008). Therefore, by using robotics in education abstract ideas and concepts are made tangible. Furthermore, due to the immediate feedback students' learning gets reinforced (Eguchi, 2012; Atmatzidou et al., 2008).
- *ER as a way to foster teamwork*: ER offers opportunities for students to work together in groups on joint robotics projects (sharing ideas, joint decision making process, acquiring communication skills) (Miller et al., 2008; Eguchi, 2007).
- *ER as as way to foster* 21^{st} *century and computational thinking skills*: By transferring abstract concepts into the real world educational robotics provides a learning environment where a set of 21^{st} century skills[*] (i.e. information, media and technology skills, critical thinking, communication, collaboration, innovation, creativity, . . .) as well as computational thinking skills are fostered (formulating problems, organizing and analyzing data logically, using abstraction to represent data (e.g. models), applying algorithmic thinking to automate the solutions (series of ordered steps), identifying and implementing solutions (combination of steps), performing a generalization and transferring the problem-solving process to other problems; Wing (2006); Barr et al. (2011)) (Eguchi, 2012, 2014a).
- *Learning through ER competitions*: Competitions are a project-based educational approach. Students work in teams towards a common goal, preparing their robots to compete in different disciplines. There are many different educational robotics competitions worldwide, and the number is still growing. Various studies report positive effects of such competitions on participating students (Eguchi, 2012; Sklar et al., 2002; Melchior et al., 2005).
- *Learning through ER projects*: Despite the reported positive effects of robotics competitions, different authors also express their concerns and provide alternative settings. For instance, Hamner et al. (2008) discuss the possibility that a competition might act as deterrent factor for students not comfortable with competitive situations. Therefore, the authors propose an approach focusing on using ER as a tool for expression and communication (Hamner et al., 2008). Another alternative to the competition setting is proposed by Martin (2007). The authors present

[*] A framework of key skills and student outcomes for the new century playing a key role in the educational reform e.g. in the US, Australia, Finland, Singapore,...; also see (P21, 2016; Eguchi, 2014a)

a project-based approach combining computer science (programming) and arts. Alimisis and Kynigos (2009); Turbak and Berg (2002); Rusk et al. (2008) argue that exhibitions and public demonstrations of students' projects could provide the same motivational benefits as competitions without being exposed to a stressful situation. Further examples of alternatives to a competition-centered approach are discussed by (Eguchi, 2012).

With educational robotics as a growing field, a large number of conferences, workshops and symposia have been organized around the topic in the last decades (Bredenfeld et al., 2010; Balogh, 2010; Stelzer and Jafarmadar, 2011; Obdrzalek, 2012; Moro and Alimisisi, 2012; Granosikr, 2013; Alimisis et al., 2014; Dessimoz et al., 2015; Merdan et al., 2016). Several books have been published (Barker et al., 2012a; Alimisis, 2009), special issues of journals and magazines have been released (TOE, 2013; RAS, 2016; JAMRIS, 2014) as well as master theses (Neppel, 2014; Jomento-Cruz, 2010; Wulf, 2012; Ebelt, 2012) and PhD theses (Whitehead, 2010; Welch, 2007; Jewell, 2011) have been written dealing with various aspects of educational robotics. In addition, further events and initiatives focus on educational robotics, such as international and regional tournaments and competitions for school students and undergraduate students (e.g. *RoboCupJunior* (RCJ, 2016), *FIRST (Lego League, Tech Challenge, Robotics Competition)* (FIRST, 2016), *Botball* (Botball, 2016)), teacher training courses (e.g. *TERECoP* (TERECoP, 2009), *Roberta teacher training* (Roberta, 2016)) as well as local and international networks (e.g. *euRobotics Topic Group on Education and Training* (TGET, 2016)).

In addition to the aforementioned books, theses, conferences, initiatives and competitions related to educational robotics, numerous papers and articles have been published (Lammer et al., 2016a; Kandlhofer et al., 2012). As explained by Bredenfeld et al. (2010) many publications deal with technical aspects of various robotics platforms for education. Other papers deal with the development of robotics curricula and teaching materials, as well as the integration of robotics into classes. For example, Singh et al. (2005) present a low cost micro-controller board for teaching robotics in schools in Australia. The authors describe design objectives, technical specifications and advantages of this controller board. Merino et al. (2016) present the ongoing work on an affordable educational robotics platform (based on Arduino) which can be used to enhance STEM education. The paper mainly focuses on the design process and implementation methodology of the platform. The article by Balch et al. (2008) presents the use of personal robots to teach computer science to undergraduate students. The paper describes the robot hardware and software and outlines the content of the undergraduate course. Nourbakhsh et al. (2005) describe the process of designing robotics platforms and a curriculum for a high school robotics course. The authors provide a detailed technical description of the developed robotics platform (regarding hard- and software). The final chapter deals with the findings of a short-term course evaluation. Petrovic (2011) gives an overview of different educational robotics competitions of the last decades and describes one specific educational competition (organized in Slovakia) in particular.

As Altin and Pedaste (2013) argue a lot of educational approaches focus on the technology (robotics platform) rather than on the underlying learning/teaching concepts and methodologies. Though most of the developed platforms are based on the constructionism theory formulated by Seymour Papert (see next section), the actual implementation of this theory in the classroom is neglected (Sullivan and Moriarty, 2009). In this context Alimisis (2012) demands to shift the focus in educational robotics from "technology to pedagogy".

A number of publications discuss the *benefits and positive effects* of educational robotics on student's learning (Eguchi, 2012). For instance, Bers (2007) argues that ER supports students in inquiring scientific concepts in order to develop 'technological fluency'. Several other papers stress that ER provides 'effective learning opportunities' in different subjects and fields like mathematics, science, physics, biology, geography, electronics and engineering while also fostering skills in the area of problem solving, communication, reading/writing, researching, decision making and teamwork (Alimisis, 2009; Atmatzidou et al., 2008; Miller et al., 2008; Eguchi, 2012; Sklar et al., 2002; Sklar and Eguchi, 2005; Kolberg and Orlev, 2001; Carbonaro et al., 2004; Oppliger, 2002). Khanlari (2016) states that educational robotics can establish an 'authentic learning environment' in the context of computer and electrical engineering. Students of all ages and educational levels apply their skills, knowledge and the previously learnt contents in order to work on real-world problems and meaningful challenges (Samuels and Haapasalo, 2012).

Alimisis (2013) stresses the need to broaden the target group of educational robotics in order to address also children, students and teachers who are not yet interested in or related to robotics or a similar technical field. As literature suggests many existing ER approaches focus on teaching subjects closely linked to robotics (e.g. mechatronics, engineering, robot construction/programming) (Barreto and Benitti, 2012). In order to address this issue Rusk et al. (2008) suggest following strategies (so called 'new path ways'):

- *focus on themes* (instead of just focusing on challenges; e.g. Cacco and Moro (2015));
- *combining arts and engineering* (e.g. Lammer (2016); Desmond et al. (2016); Hirschmanner et al. (2015));
- *encouraging storytelling* (e.g. Westlund and Breazeal (2015); Bers (2008));
- *exhibitions* (instead of competitions; e.g. Bers and Ettinger (2012));

Summing up, a large number of different educational robotics approaches and projects can be found in current literature. There is a broad range of different goals, target groups, applied settings and robotics platforms. Different ways to classify or categorize educational robotics approaches currently exist. In order to foster a better communication between educational robotics experts but also between 'users' (e.g. teachers) and providers (e.g. researchers) a common categorization framework would be needed. Many publications in the area of educational robotics deal with technical aspects of various robotics platforms or present local projects or competitions. Nevertheless, there is a need to also emphasize the underlying learning/teaching concepts and methodologies, shifting the focus in educational robotics from "technology to pedagogy" (Alimisis, 2012; Altin and Pedaste, 2013; Sullivan and Moriarty, 2009). Furthermore, it is important to broaden the target audience (e.g. by combining different aspects like arts and engineering) in order to address also children and young people who are not yet interested in such technical topics. Many publications stress the positive effects and benefits of educational robotics but further well-grounded, systematic evaluations are needed (in this context see Section 2.4).

Context RoboCupJunior in Austria

RoboCupJunior (Sklar et al., 2002; RCJ, 2016) is part of the international scientific initiative *RoboCup* (Steinbauer and Ferrein, 2016; RoboCup, 2016) that fosters research in advanced robotics and artificial intelligence. In order to address children and young students as well, RCJ was established within the scope of the RoboCup world championship 1998 in Paris. In 2000 the first international RCJ competition took place in Melbourne. Twenty-five teams from different schools in Australia, USA and Germany participated (Sklar and Eguchi, 2005). In the course of the years the number of participants grew. At the RoboCup 2011 in Istanbul there were 955 junior participants from 30 different countries forming 251 teams. This was the highest number of junior participants to date (in 2016 in Leipzig 807 students in 207 teams participated) (Eguchi et al., 2012; RCJ Wiki, 2016). Every year the international RCJ competition, co-located with the RoboCup, takes place in a different city all over the world. (Kandlhofer et al., 2012)

The project-based international RCJ initiative has a strong focus on education (Sklar, 2004). School and undergraduate students up to the age of 19 are encouraged to get involved in science and engineering. The goal is to improve technical and social skills, to foster teamwork and creativity, as well as to promote international contacts and knowledge exchange.

RCJ, the competition, comprises of four disciplines: (1) Rescue, (2) Soccer, (3) OnStage and (4) CoSpace. The task in RCJ Rescue is to construct and program an autonomous robot to find its way through a rescue arena. Here the challenge is to follow a black line on the floor, to avoid debris, to deal with gaps and a ramp and finally to detect and rescue 'victims'. The arena is composed of different rooms, each room increases the level of difficulty. In RCJ Soccer four robots, usually one striker and one goalkeeper per team, play soccer. Detecting the ball, identifying opponent players and team-mates, as well as locating the goals are some of the challenging issues to deal with. Robots are only limited in size and weight so students can work out different innovative solutions. RCJ OnStage is a discipline that focuses on the combination of technical skills and creativity. The goal is to prepare a short on-stage performance of robots and humans. Important evaluation criteria are choreography, costumes, and decoration, as well as technical aspects of robot construction and programming. In RCJ CoSpace students work with virtual and real robots combining digital simulation, game-based learning and educational robotics. (Ferrein et al., 2011; Eguchi and Shen, 2013)

Except for some minor adaptations each discipline remains the same from one tournament to the next. The basic idea behind is to give students the chance to improve their robots at each competition and to make progress visible (Hofmann and Steinbauer, 2010). Students are allowed to use standard robotics kits (such as the LEGO Mindstorms) as well as self-designed robots. Figure 2.1 shows the excitement of junior participants at the RoboCup 2009 as well as an example of a self-designed rescue-robot.

Figure 2.1.: A winning junior team at *RoboCup 2009* and a self-designed rescue-robot at *RoboCupJunior Austrian Open 2013*.

RCJ is well established in Austria. There is a strong cooperation between universities and schools located in urban, suburban and rural Austrian regions. Every year many school teams participate and succeed in national and international RCJ competitions. A remarkable number of former RCJ participants have studied/are now studying at university. In Austria RCJ was introduced in 2007. Various activities and events were organized in order to promote the initiative and to establish the first RCJ regional education center in Austria. Due to a rapidly increasing number of schools interested in participating in RCJ further regional centers were build up in order to establish a nationwide network. By now the Austrian RCJ network consists of eight regional centers, distributed among almost all Austrian provinces under the umbrella of the "RoboCupJunior Austria" society (RCJ Austria). In general, a regional center offers standardized service packages to encourage schools, students and teachers to participate in RCJ. These include presentations at schools, robotics introduction courses and workshops for students, training courses for teachers, summer research camps, regular robotics clubs, lending robotics kits to schools, open-lab days, as well as special events such as science weeks for students or special-topic workshops. Presentations at schools usually serve as a first introduction for teachers and students to RCJ. Interested school classes can attend an introduction course, which lasts for about three hours. The courses have a strong focus on hands-on experiences. Using LEGO Mindstorms robotics kits, attendees are introduced to the principles of robotics and programming. In addition, training courses provide teachers with a basic knowledge and tools to integrate educational robotics/RCJ into their classes. Summer camps, advanced courses and special-topic workshops deal with different programming languages, advanced hardware or special topics around robotics and AI. During the so-called open-lab-days teams and interested people can come to a center's robotics lab and use the available facilities (e.g. rescue arenas, soccer fields, robotics hardware) in order to prepare for a competition. Furthermore, experts answer questions and give hints on how to solve specific problems (Hofmann and Steinbauer, 2010). Within the scope of robotic clubs children and youths regularly come to a robotics lab in order to work on their projects. They can use the available infrastructure/know-how and are working alongside researchers and undergraduate/graduate students experiencing cutting edge research.

The Institute for Software Technology at Graz University of Technology (TUG) is one of the founding members of the RCJ Austria society and also host of a regional education center. TUG organized the first national RoboCupJunior competition in 2008 and one year later the RoboCup world championship. In 2011 an international research and education project *Technology and Education for Search and Rescue Robots (TEDUSAR)* was initiated in cooperation with University of Maribor (Slovenia) (Maurer et al., 2014). A central project objective was to build up a similar regional center structure in Slovenia, as well as to foster RCJ in both countries. A general problem is the increasing disinterest of young people, in particular girls in science and technology studies. By improving and extending the support activities already provided by universities and regional centers, as well as by attracting more public attention, the aim was to counteract the recent negative development and to attract more students to science and technology studies.

2.1.2. Educational Robotics in Pre-School

As discussed in the previous section the level of awareness and importance of educational robotics rose over the last decades. A great number of conferences, workshops, papers and books have been addressing this topic. Various different projects, initiatives and competitions aim to interest young children and students up to the age of nineteen in science and technology. The review of literature revealed that, on the contrary, educational robotics approaches with special focus on children aged between three and six years (kindergarten, pre-school) are less widespread. Due to the fast moving nature of technology the focus must be put on fundamental principles and concepts fostering computational thinking in general. The idea behind the concept of educational robotics in kindergarten is to use the robot as pedagogical tool to familiarize children in pre-school age with science and technology in a playful way (Eck et al., 2013; Kandlhofer et al., 2013). A short look in the history reveals that already in the early 19^{th} century the German pedagogue Friedrich Froebel, who coined the term 'kindergarten', developed a series of educational toys and hands-on learning strategies. Many modern learning tools, such as the *LEGO Mindstorms* robotics kit, are also based on his work (Stoeckelmayer et al., 2011; Kafai et al., 2010).

The use of educational robotics in pre-school education is not as widespread as in primary and secondary school (Kandlhofer et al., 2014). Nevertheless, various papers and articles exist which describe robotics platforms and projects for young children. For example, Sapounidis and Demetriadis (2016) present a review of 'tangible' programming languages and robots which can be used to address pre- and primary-school children. Ferreira et al. (2012) present the experiences made introducing robotics in a kindergarten using the *LEGO WeDo* robotics kit. Children had to build a small robot step by step. Afterwards they interacted with the robot, which was actually programmed by a teacher.

Petre and Price (2004) describe how robotics can act as a tool to teach primary and secondary school students the basics of engineering and programming. The authors also present an empirical study in order to investigate why robots seem to motivate young children, even if they were not technically interested beforehand.

Bers et al. (2002) describe the integration of robotics in early childhood education following a constructionist strategy (learning by designing, using concrete objects to explore, identification of powerful ideas, self-reflection).

Pekarova (2008) presents the use of the educational robot *Bee-Bot* in a pre-school setting. Different activities and games for kindergarten children and teachers were designed and qualitatively evaluated. The focus of this research was on robot programming instead of construction and design. It turned out that although all children involved in the study basically enjoyed playing with the Bee-Bot and were not afraid of using this new technology the robot itself was not interesting to them for a longer period of time. The author also states that some of the children showed a basic understanding of the robot's control principles whereas others seemed to be too cautious to increase their self-confidence during the work with the Bee-Bot.

The paper of Bers and Ettinger (2012) presents an educational robotics approach which focuses on introducing kindergarten children to computational thinking by familiarizing them with computer science and engineering concepts. They describe a curriculum structured around the six main topics robotics, engineering design process, sequencing/control flow, loops/parameters, sensors and branches. The curriculum was implemented during a one month-long period in a kindergarten and empirically evaluated. The authors conclude that educational robotics can be a valuable learning tool in kindergarten provided that children's needs and abilities are considered appropriately. The applied technology and the activities have to be integrated with other areas of the regular kindergarten curriculum.

Gennari et al. (2012) performed short robotics introduction courses (duration about 45 minutes) for pre-school children at the university. Their goal was to demonstrate the difference between intelligent, programmed behavior and radio-controlled behavior of robots. Therefore, they developed different games where children could watch and interact with the robots (e.g. pushing a button on a LEGO Mindstorms robot to start a line-following program).

The work of Virnes and Sutinen (2009) investigated the interaction between kindergarten children and a certain educational robotics technology called *Topobo* (a flexible system where children can assemble robots from single functional blocks). A series of workshops in six kindergartens were conducted and qualitatively evaluated. The authors reported that the applied educational robotics technology can be an effective and stimulating tool to foster dedicated learning in pre-school.

Demo et al. (2012) describe an approach of inquiry-based science education applied in kindergarten and early primary school years. They developed different games using the educational robot *Bee-Bot* (pressing the buttons on the back (forward, backward, rotate left, rotate right) children could enter a sequence of commands which then were executed by the robot). The topics covered by those games were discovering the Bee-Bot, reasoning about distances, discovering programming, reasoning about geometrical shapes, discovering connections between programming and math.

Educational robotics for primary and secondary schools is well established in Austria. On the contrary only a few initiatives and projects can be found which use robotics in kindergarten and pre-school education. One example would be the project "Technical and natural science in playschool" of Vienna University of Technology. Children aged between four and six years have the opportunity to visit different departments of the university and to participate in scientific hands-on exercises and experiments. Within this project one of the main topics is robotics (TU Vienna, 2016). In addition, different scientific institutions and universities offer training courses and workshops for educators and children. For instance, the Austrian Computer Society (OCG, 2016) offers robotic workshops in order to teach kindergarten pedagogues how to integrate robotics into teaching. The Vienna Museum of Technology (VMT, 2016) organizes workshops for children between the age of four and seven to teach basics of programming and robotics. Another pre-school educational robotics project would be the course "Robots for Kids" for kindergarten children at the age of four to six years. Within the classes children can actively participate and in parallel they get a first impression of scientific working (Stoeckelmayer et al., 2011).

Evaluating the robotics course "Robots for Kids"

Wulf (2012) conducted an empirical evaluation investigating the question whether settings and contents are reasonable and helpful to teach pre-school children the principles of programming by applying robotics as a learning environment. The aim was to analyze the impact of the course on children's cognitive processes in the context of executive functions.

In sum four kindergartens participated in the project. Two kindergartens (16 children) took part in the robotics course (test group) while the other two kindergartens (27 children) did not participate in this course and therefore acted as control group. The minimum age of the children was 4.5 years. The course was divided into six units which were held by university students at weekly intervals (duration one hour). Bee-Bot robots were chosen due to their simple user interfaces and the possibility to utilize them in team constellations. The tasks of each unit were defined in advance in order to guarantee that both kindergartens (test and control group) had the same conditions. (Eck et al., 2013; Wulf, 2012)

The performances of the children were compared before and after the course. Therefore, four hypotheses were stated and tested (Wulf, 2012): $\mathbf{H}_1$: "The performances of the children who attended the robotics course have improved in the post-test compared to those of the pre-test. If there is a significant difference, the results of the test group have to be compared with those of the control group." $\mathbf{H}_2$: "After attending the course the performance of the executive functions is significantly better in the test group than in the control group." $\mathbf{H}_3$: "The statistical connection between the variables *inhibition, shifting* and *planning* is significant." $\mathbf{H}_4$: "Demographic factors have an influence on the performance at the pre-test." (Eck et al., 2013; Wulf, 2012)

Both test- and control-group have been pre-tested approximately one week before the robotics course started and post-tested six weeks after finishing the course. Following psychological instruments have been applied:

- Kaufmann Assessment Battery for Children (Melchers and Preuss, 2009): The instrument measures the intelligence level and the language skills of children.
- Dimensional Change Card Sorting Test (Zelazo et al., 1996): It determines whether children are able to apply newly learned rules ('shifting' - cognitive flexibility).
- Day-Night-Stroop (Gerstad et al., 1994): This test measures the inhibition (the endurance respectively) and the ability to concentrate over a certain period of time.
- Truck Load (Carlson et al., 2004): The instrument investigates whether children are able to plan their next steps.

The results and findings of the evaluation can be summarized as follows (Eck et al., 2013; Wulf, 2012): Regarding the performance of the test group it could be figured out that there have been improvements in the area of planning and cognitive flexibility, but these have not been statistically significant. However, the results concerning inhibition were significant. As a result it can be stated that the performance of the children who attended the robotics course has been improved in the field of endurance and the ability to concentrate over a certain period of time. On the contrary it could not have been proved that the overall performance of the test group (after participating in the robotics course) was significantly better than the performance of the control group. The improvements have been nearly equally. The third hypothesis was accepted since there was a statistical connection between the three variables *inhibition, shifting* and *planning*. Concerning the demographic factors (fourth hypothesis), simply the level of education of the children's parents had a significant effect on the different performances at the pre-test in the field of planning.

Summing up, the results do not show statistically significant improvements (except for inhibition), respectively no improvements at all. Reasons for this issue could be affiliated by the applied test instruments. It is possible that those instruments have not been sensible enough to indicate the changes of the executive functions caused by the robotics course. Furthermore, the learning effect (caused by the use of the same testing instruments at the pre- and post-test) could be one possible explanation for the almost equal improvements of both groups Wulf (2012); Eck et al. (2013).

2.2. Theories Behind

Empirical studies showed that a project-orientated learning approach is important for students' motivation and attitudes towards a specific topic. Studies also investigated the positive correlation between students' attitudes towards science and their achievement in science classes (Welch, 2010; Germann, 1998; Hidi and Harackiewicz, 2000). Educational robotics as a project- and hands-on oriented approach is supported by a number of established learning theories, methodologies as well as pedagogical concepts and principles of which the most relevant for this thesis will be described in the following.

Constructivism One of the basic theories behind educational robotics is Jean Piaget's constructivism theory (Piaget, 1973). The theory says that children construct new knowledge by interacting with their environment (e.g. people, experiences, things, ...). Thereby new knowledge is linked to personal prior-knowledge (Piaget et al., 2013; Altin and Pedaste, 2013). The social development theory developed by Lev Vygotsky is one of the underlying concepts of constructivism. Basically this theory states that social interaction is a major factor in cognitive development. It also promotes an active role of students in the learning process (Vygotsky, 1978; Moll, 2013).

Piaget argued that children do not reject their 'working theory' or 'believe system' easily. Just showing them a better theory does not destabilize this believe system. In this context it is crucial for children to construct knowledge by manipulating objects (so called 'artefacts'). Learning means building up new knowledge based on already existing knowledge by manipulating those artefacts and watching their reaction. Therefore, an effective educational approach has to provide opportunities for children to engage in hands-on activities and to explore new views and theories on their own (Ackermann, 2001; Eguchi, 2012).

Constructionism Next to the previously discussed constructivism, constructionism represents the second fundamental theory behind educational robotics. It was developed by Piaget's student Seymour Papert (Papert, 1993a). Basically constructionism means that children are learning by constructing things. The theory emphasizes the active involvement of children in the learning process acquiring knowledge by using already known information (on the contrary instructionism describes activities which are teacher-focused and mainly non-interactive) (Johnson, 2005; Alimisis and Kynigos, 2009).

Papert defines constructionism as follows: *"Constructionism - the N word as opposed to the V word - shares constructivism's connotation of learning as "building knowledge structures" irrespective of the circumstances of the learning. It then adds the idea that this happens especially felicitously in a context where the learner is consciously engaged in constructing a public entity, whether it's a sand castle on the beach or a theory of the universe." (Papert and Harel, 1991) (p. 1)*

As Papert's constructionism is based on Piaget's constructivism both theories argue that children's interaction with their environment actively constructs new knowledge. Though, the focus of constructionism is on *learning* (as opposed to *knowledge* in constructivism). Furthermore, Papert's theory goes one step ahead and states that the knowledge construction taking place in the mind gets supported by constructing tangible, physical objects in the real world which can be touched, examined, presented and discussed with other people. In this context Vygotsky's concept of 'tools' is worth mentioning. He stated that, since we apply tools which have an impact on our external environment also tools which have an impact on our behavior (internal environment) are needed (Wertsch, 1986). Papert describes robots as such physical tools, representing "objects to think with" (Papert, 1993a). In that sense the activity theory, based on Vygotsky's work, phrased the concept of a mental interaction with a "world of objects" (Catlin and Blamires, 2010; Engeström et al., 1999; Davydov and Radzikhovskii, 1985).

The externalization of ideas and thoughts plays a crucial role in constructing new knowledge. An effective educational approach provides children with opportunities to explore and investigate (instead of teaching or instructing). This also includes the possibility of children 'reinventing the wheel' (Eguchi, 2012; Ackermann, 2004). In this context Bers (2007) emphasises that "making, discovering and designing own objects" supports successful, effective learning. Duckworth (2005) introduced the pedagogy of *critical exploration* which basically follows a constructionist approach (learning by exploration; using tangible objects; no direct teaching by adults). This pedagogy also requires a paradigm shift from traditional, teacher-centered teaching towards a more student-centered approach where a teacher acts as a mentor or a coach rather than an instructor. Papert (1993a) argues that technology can act as a powerful learning vehicle by supporting projects which are personally meaningful and interesting to children. This provides opportunities for children to explore their ideas.

The programming language *Logo* and later on the programmable brick *RCX* (robotics command explorer) successfully implemented the constructionism theory. The RCX was the central element of LEGO's first educational robotics kit called *Mindstorms*. Educational robotics takes the principles of constructionism/constructivism into account by offering children artefacts which can be manipulated and which provide immediate feedback. Those tangible objects allow children to transform their abstract ideas into the real world offering a concrete and highly personal way of learning (Eguchi, 2012; Martin et al., 2000; Resnick et al., 1988; Sullivan and Moriarty, 2009).

The concepts discussed in the following basically follow the principles of constructivism and constructionism and/or are based on or extend those theories.

Discovery Learning Following a constructionist approach this methodology focuses on learning by interacting with the environment, conducting experiments as well as manipulating and exploring objects (Ormrod, 1995). Students are given an assignment and while working on this task they 'discover' the learning content by themselves (Hammer, 1997). The teacher might act as a guide who supports students, provides hints and gives feedback ('guided discovery learning'). Educational robotics provides tools (robots) which foster exploration by manipulation. Students are encouraged to conduct experiments in order to solve given problems and assignments. Since there is always more than one solution to a specific problem students are engaged in a continuous discovery process. (Sullivan and Moriarty, 2009)

Inquiry Learning This self-directed, constructivist approach developed from discovery learning. It has a strong focus on exploring and discovering through experimentation while applying a scientific methodology (describing a problem, stating a research question, formulating a hypothesis, conducting experiments, analyzing data, discussing findings and conclusions). Robots offer an excellent opportunity for students to apply those scientific methods. An educational robotics approach applying inquiry learning could increase attractiveness and effectiveness of learning science-related topics (De Jong and Van Joolingen, 1998; Altin and Pedaste, 2013). For instance, Demo et al. (2012) present an inquiry-based science education (IBSE) framework applied in different educational robotics activities at different school levels (from kindergarten to secondary school).

Experiential Learning Experiential learning basically means learning through experience. It is structured in a cyclic way comprising four stages. The first stage involves the concrete, immediate experience. Stage two deals with observation and reflection. The third stage comprises the abstraction and generalization of concepts. Finally, stage four focuses on testing hypothesis and creating new experiences (Felicia, 2011).

Kinesthetic Learning Kinesthetic learning comprises perception of information (e.g. touch, smell, taste) as well as processing of information (e.g. to move things around or to actively do something) (Felder and Silverman, 1988). Effective learning approaches should address students on multiple levels considering different learning styles and involving different senses. In this context kinesthetic considerations play an important role since students are an active part with different senses involved in the learning process. Educational robotics with its tangible objects meets these considerations (Futschek and Moschitz, 2011).

Competition-Based Learning In this methodology the focus is on learning through a competition whereas the learning outcomes are independent from the performance in the actual competition (Burguillo, 2010; Altin and Pedaste, 2013). Competition-based learning has successfully been applied in science education as well as in various educational robotics approaches in order to teach STEM subjects. While preparing for competitions students design, build, program and debug their robots. Throughout this process students gain knowledge in various science-/technology-related areas and subjects. Papert (1993b) states that skills/knowledge learnt through this method is better memorized and understood (compared to skills learnt through traditional learning methods). Various publications report the motivational aspect of competitions (Pedaste et al., 2012; Jung, 2013; Sklar et al., 2002). Nevertheless (as previously discussed), a competition-based approach might address only a limited group or a certain type of learners (e.g. due to high costs for participating in competitions, feeling uncomfortable in competitive situations, . . .). (Altin and Pedaste, 2013; Hamner et al., 2008)

Project-Based Learning Students are organized in groups and work together as a team on certain tasks (investigating, exploring and solving real-world problems or researching specific issues). Project-based learning also comprises elements of collaborative learning. Students apply a critical thinking approach while they refine questions, analyze data, discuss results and share their ideas and findings within their group and amongst other groups. Communication, labor division and teamwork are crucial aspects in this learning approach. Project-based learning can be an effective strategy to motivate students and to foster self-directed learning (Blumenfeld et al., 1991; Karahoca et al., 2011; Altin and Pedaste, 2013). Various different educational robotics projects successfully implemented a project-based learning approach (just to name a few examples: Alimisis (2009); Jump (2015); Lammer and Vincze (2015); Karahoca et al. (2011), . . .).

Problem-Based Learning / Problem Solving Jonassen (2000) defines a problem as the difference between two states - the start state and the goal state (he calls this the 'unknown entity'). In this context problem solving is the process of finding this unknown entity by applying a number of cognitive operations (Anderson, 1990). By using robotics in education students are encouraged to apply a problem solving approach. Problem-based learning in educational robotics has been reported as a very successful method to teach STEM related concepts (Thompson et al., 2004; Petre and Price, 2004). For instance, Sartatzemi et al. (2005) discuss how robots can be used to teach programming to secondary school students. The authors describe how students evaluated their solution to a given problem by executing the program on the robots. In this situation the robots provided immediate feedback on whether students' solution was correct or not. A new program led to a new (current) state somewhere between start and goal state. The current state was the starting point for students to solve the next problem in order to reach the goal state. Being involved in such a problem solving scenario supports students' learning process. Using robots together with a problem-based learning approach follows the principles of constructionism (physical, concrete manifestation (robot) of an abstract problem (software))(Altin and Pedaste, 2013; Grandgenett et al., 2012).

Collaborative Learning Learners with different competencies work in a group towards a common goal whereas a certain role is assigned to each group member. Knowledge is created by sharing the same goals and solving problems together. In collaborative learning teachers and learners (students) are more or less on a same knowledge level. Teachers interact and learn together with the students. This fosters a sense of community among those groups. Collaborative learning is an underlying concept of many educational robotics approaches, and vice versa, educational robotics can be a very suitable tool to foster a collaborative learning environment. (Denis and Hubert, 2001; Altin and Pedaste, 2013)

Peer Teaching/Learning Basically peer teaching means students teach other students. It dates back in the 1960s when first publications reported the deployment of undergraduate students as tutors and teaching assistants (Goldschmid and Goldschmid, 1976). Peer teachers and peer learners play an active role with both sides benefiting from this approach. On the one hand, peer teachers have to go through the material which they will teach later on in detail. As a result they get a much better understanding of the topic. Furthermore, investigations showed that there is a difference in the cognitive processing between studying material to teach others and studying material for an exam (Bargh and Schul, 1980). On the other hand, peer learners profit from the peer teachers' ability to teach "at the right level" (Whitman and Jonathan, 1988; Schwenk and Whitman, 1984; Frager and Stern, 1970).

Social Learning The basic idea behind the social learning theory is that learning happens by direct experience or by observing other people or media (so called 'models'). Learning is promoted if the learner (the so called 'observer') has a strong identification with the model (Bandura and Walters, 1977; Ormrod, 2007; Bandura, 1988). In the context of educational robotics robots as well as other students can serve as models. After each modification of the program students learn by observing the behavior of the robot. Learning also happens when students watch other students while they solve similar problems (e.g. during robotics competitions).

Storytelling Story-telling and -writing are established methods in values education (Bers and Urrea, 2000). In the context of technology enhanced education this approach connects an artefact (e.g. a toy, a robot or any other piece of technology) with a story, making the artefact an active part of the narrative (Bers, 2008). This means that contents and topics to be learnt are wrapped in a story whereas e.g. a robot is the tool to tell this story. Several educational robotics approaches apply the technique of storytelling. For example, Martin et al. (2000) applied storytelling together with the LEGO Mindstorms robotics kit to foster technological fluency in primary education. Westlund and Breazeal (2015) used a storytelling game together with a robot (acting as a robotic learning companion) to investigate the impact on pre-school children's language development.

Back Door Learning Back door learning could be seen as a general feature of robotics in education combining a number of aforementioned constructionist learning approaches. In this context robots are used as tools which make students learn about different topics and subjects. This means content to be learnt comes through the back door while working and experimenting with robots. For instance, Petre and Price (2004) use this approach to teach primary and secondary school students principles of engineering and programming. The authors observed *"that children find robotics stimulating and motivating, and that their interest in, and focus on, 'making the robot do what I want' leads them 'via* *the back door' to learn about programming and engineering in a way that is both well-grounded and generalizable." (p. 1)*

Positive Technological Development Positive Technological Development (PTD) is a pedagogical framework to guide the development, implementation and evaluation of technology-enhanced educational interventions. Following Papert's constructionism PTD represents a multi-disciplinary approach integrating aspects of collaborative learning, computer-mediated communication and computer-supported learning. The framework defines six key aspects which have to be supported by new technologies in an educational context: *Content creation* (e.g. by programming/constructing robots); *Creativity* (e.g. by an open-ended nature of a task/problem); *Collaboration* (e.g. by applying a project-based, teamwork-oriented approach); *Communication* (e.g. by presenting the results of a robotics project to visitors, parents, ...); *Community building* (e.g. by sharing the solutions with other teams/people, for instance in the context of educational robotics competitions); *Choices of conduct* (character building, e.g. students have the choice to act responsibly by sharing limited material with others). (Phelps et al., 2009; Bers and Ettinger, 2012; Bers, 2010)

2.3. Education in Artificial Intelligence

Artificial intelligence (AI) plays an increasingly important role in our daily life. In contrast, hardly anybody knows about the concepts behind, and furthermore, teaching fundamental topics of AI and computer science at school or pre-school level hardly exists at the moment (Burgsteiner et al., 2016b; Cole, 2012).

Looking at the current literature, teaching basic concepts and techniques of AI and computer science at school level is quite rare. To go further, teaching those topics independently from specific programming languages or learning tools (e.g. specific robotics platforms, software, ...) on different educational levels adapted for different age groups (kindergarten, primary school, middle school, high school, university) hardly exists (Burgsteiner et al., 2016c). What current approaches have in common is the relatively narrow focus on specific target- and age-groups (e.g. on undergraduate or graduate university students or on certain school levels).

Many existing approaches focus on teaching AI concepts to undergraduate or graduate students at university or college level (e.g. Torrey (2012), McGovern et al. (2011), Kumar and Meeden (1998), Torrey et al. (2016), Li et al. (2014), Barik et al. (2013), Albu (2012)).

A few attempts exist focusing on teaching the basics of AI to teacher trainees (students who are going to become a teacher). For instance, Dilger (2005) approached topics like problem solving by search, planning, multi agent systems, robotics and neural networks within a course entitled 'Artificial Intelligence in Schools'.

Educational approaches which teach selected topics of AI at school level like Heinze et al. (2010) or Fok and Ong (1996) only deal with certain aspects of AI such as history of AI, the Turing Test (Shieber, 2004), chat bots or neural networks. Others only use specific tools or platforms to illustrate AI concepts. For instance, Featherston et al. (2014) use an educational tool which integrates virtual and real-world robotics in order to teach sophisticated, advanced AI/robotics algorithms and concepts.

Other approaches focus on teaching certain programming paradigms relevant to AI. For example, the work of Reyes et al. (2016) deals with declarative programming in high schools. Other publications are only partially focused on certain AI topics. For instance, Layer et al. (2012) describe a three-week summer research camp where high school students worked on a broad range of topics including GPS/mapping, cryptography, the internet, game programming but also artificial intelligence.

Various approaches exist which aim at fostering STEM or STEM-C education (science, technology, engineering, mathematics, computer science). For example, Bojic and Arratia (2015) describe a project which introduces school students (K-8 up to K-12) to STEM-C fields. Tsukamoto et al. (2015) discuss an approach of teaching primary school students programming using a text-based language.

Many approaches exist which use AI as a learning tool in terms of Artificial Intelligence in Education (AIED; e.g. intelligent tutoring systems, interactive learning environments, ...; Roll and Wylie (2016)). Pareto (2014) uses an AI based learning environment in order to foster understanding and reasoning of mathematical concepts in primary school education. This learning environment comprises teachable agents (programmes behaving based on their knowledge). Students learn by teaching those agents to play mathematical games. Corbett et al. (1997) describe two intelligent tutoring systems successfully applied in the field of mathematics/programming and electronics troubleshooting.

Sklar and Parsons (2002) discuss how robotics and robotics competitions (in particular *RoboCupJunior*) could be a vehicle to introduce school students to AI, robotics and computer science. Furthermore, they outline the use of robotics in undergraduate education to teach AI and computer science. In this context the authors define the term *technical literacy* as *"comfort with and understanding of technology" (p. 1)*. Thus, technical literacy means understanding topics like state machines, dynamic systems, search heuristics, planning, logic, knowledge representation and uncertainty. In line with this definition this thesis introduces the more specific term *AI literacy* and presents a comprehensive AI education concept that addresses kindergarten children, primary and middle school students, high school students as well as undergraduate university students (see Section 3.3 of Chapter 3). This education concept uses educational robotics as a learning tool (along with a broad range of other tools and methods) to teach fundamental concepts of artificial intelligence to kindergarten children, school students (primary, middle, secondary/high school) and undergraduate university students.

2.4. Empirical Evaluation

The use of robotics as educational tool to interest young people in science and technology and in addition to improve technical- and social-skills has become a widespread approach in various countries worldwide (TOE, 2013; Lammer et al., 2016a). A number of educational projects and initiatives aim to encourage young people to get involved in science and technology by applying a project-oriented, constructionist educational robotics approach.

There is the subjective impression by students, teachers, mentors and researchers that the educational robotics approach works well. One can observe a predominantly positive feedback as well as various stories of success and anecdotes regarding the positive impact of educational robotics. A lot of reports are based on observations or anecdotal descriptions of individual initiatives (Petre and Price, 2004). Although such descriptions are important and provide indications of the powerful potential of educational robotics, it is crucial as well to provide valid information and verifiable data to prove its effectiveness and positive impact. The necessity and importance of a systematic evaluation is stressed in current literature (Barker et al., 2012a; Stubbs et al., 2012). In general, there is a lack of systematic (quantitative), reliable evaluations which provide validated results regarding the impact of educational robotics on students' learning and skill development (Alimisis, 2013). As stated by Cole (2012) there is also a need for investigating the long-term effects of such pedagogical approaches on students' ways through school, college and later careers. Catlin and Blamires (2010) also stress the importance of longitudinal evaluations which should cover time spans of more than three years. Nevertheless, relatively few studies investigate this issue (Stubbs et al., 2012; Alimisis, 2013).

For instance, Petrovic (2011) gives a brief overview of different educational robotics competitions and describes one specific contest in particular. This educational contest has been organized for ten years but the paper does not cover any evaluation aspects. Nourbakhsh et al. (2005) describe the process of designing a robotics platform as well as a high school robotics curriculum. The authors provide a detailed technical description of the platform and discuss findings of a short-term course evaluation in the final chapter.

Melchior et al. (2005) provide an evaluation of the *FIRST Robotics Competition (FRC)* (FIRST, 2016). FRC, which was founded in 1989, is a high school robotics initiative. The program aims at getting young people interested in science and technology. The main goal of this evaluation was to assess the long-term impact of FRC on participating students (in terms of career trajectories, average school grades, attitudes towards science and technology and social skills) as well as to investigate the impact on schools and other supporting institutions. As a first step the authors conducted a retrospective survey with 173 former FRC participants who graduated high school between 1998 and 2003. The survey, which was distributed by email and mail, contained predefined questions regarding students' careers after graduating high school, working experiences and self-reporting impact of FRC. The study authors compared selected outcomes of FRC participants (treatment group) with outcomes of students who did not participate in FRC (comparison group). As a second step the authors also visited ten different FRC teams and conducted interviews with team leaders, school administrators and mentors in order to gather information on the implementation of FRC in different schools as well as on the impact on schools and supporting institutions. Although, the evaluation covered a period of several years the surveyed region was limited to two metropolitan areas (New York City and Detroit/Pontiac). Results indicated (among others) that former FRC participants showed a stronger performance in math and science classes (compared to national averages) as well as a positive attitude regarding teamwork and various social skills.

A similar study evaluating the impact of the *FIRST Lego League (FLL)* (FIRST, 2016) on participants, schools and other involved institutions was conducted in 2004 by Melchior et al. (2004). One of the main objectives of this study was to find out strengths and weaknesses of the initiative in order to improve the FLL program. Methods used in this evaluation included surveys, on-site visits at competitions and schools as well as telephone interviews with mentors and coaches. The two evaluations of Melchior et al. (2005) and Melchior et al. (2004) address several questions similar to those of this thesis, for example the investigation of the impact on former participants or the evaluation of strengths and weaknesses in order to take steps for improvement. They also comprise both quantitative and qualitative evaluation methods and data. Since these studies were limited to certain US regions and specifically focused on FRC/FLL it is difficult to draw more general conclusions about the effects of educational robotics.

Within the scope of the *Roberta* project (using robots to attract girls to science and technology) an empirical research, evaluating the impact on participating girls' interests, their self-confidence in science and technology and their further professional career was conducted (Petersen et al., 2007; Leimbach, 2008; Roberta, 2016). The authors reported mainly positive impacts on those topics.

The dissertation of Griffith (2005) examines the relationship between students' participation in the FIRST Robotics Competition and their interests and attitudes towards science and technology. Data were collected conducting pre- and post-tests (experimental- and control-group (EG, CG)). The focus of this work was on public high school students in South Carolina (US). Results indicated that attitudes did not change significantly between pre- and post-test in either EG or CG. Griffith, Melchior et al. and the *Roberta* project did not evaluate the impact on students' improvement or change of technical skills (e.g. skills regarding computer science, programming, mathematics, robotics, scientific investigation, . . .).

Lindh and Holgersson (2005) investigated the effects of a specific LEGO robotics course applying both quantitative and qualitative research methods by focusing on mathematics and problem solving skills. The study comprised different schools in Sweden only. Researchers did not find significant statistical evidence for improvements for the entire group of study participants but they reported improvements in some cases for a sub-group of students.

A more comprehensive study with special focus on *RoboCupJunior (RCJ)*, covering a four-year period (2000-2004), has been conducted by Sklar and Eguchi (2005). The authors collected data during the annual international RCJ events. The study provides both statistical data (number of students, participating countries, gender distribution) as well as evaluative results. As a pilot study authors conducted open-ended video-taped interviews with mentors at the RCJ competition in 2000. In the subsequent years quantitative questionnaires were used in order to get feedback from students and mentors. The study aimed at providing a status report on the initial four years of RCJ, however only from a quantitative perspective, such as performance data (e.g. number of teams) and self-reporting data (i.e. questionnaires). The qualitative experience of RCJ was not investigated. There is a lack of knowledge on the stories behind participants' careers or their future educational and personal development. Data was exclusively collected at annual international RCJ competitions (no pre-/post-tests). The study also did not comprise a control group nor an explicit assessment of skills. (Sklar et al., 2000, 2002; Sklar and Eguchi, 2005)

Hofmann and Steinbauer (2010) outline results of an evaluation of the first three years (2007-2010) of RCJ in Austria. The paper presents only preliminary results though, again focusing on statistical data regarding number of participating students, teams, mentors and countries at annual national competitions. As already stated by the authors a more systematic evaluation, covering more than these three years and also considering later careers and the qualitative experiences of participants is needed. Beside the two works of Sklar and Eguchi (2005) and Hofmann and Steinbauer (2010) very few long-term evaluations of RCJ can be found. As stated by Bredenfeld et al. (2010) most evaluations are limited regarding the observation period and population.

The dissertations of Jewell (2011), Whitehead (2010) and Welch (2007) focus on the evaluation of the impact of robotics curricula (respectively the FIRST Robotics Competition) on high school students' beliefs, attitudes and interests towards science and technology. A quasi-experimental pre-/post-design with experimental group EG and control group CG (except for the work of Whitehead) was applied. Findings of Welch indicated that students in EG had a more positive attitude towards science in four out of seven different categories (Welch, 2010). Whitehead reported that not all of the results were statistically significant but concluded that robotics could have a positive impact on middle school students' interests towards science, technology, engineering and mathematics (Whitehead, 2010). Jewell also investigated differences regarding enjoyment of science lessons, leisure interest in science as well as career interest in science by grade level, gender and ethnicity of students. Results indicated significant differences for grade and ethnicity regarding enjoyment of science lessons and career interest in science as well as for ethnicity regarding leisure interest Jewell (2011). All of those studies only covered certain regions in the US and did not assess technical nor social skills. Jewell (2011) conducted pre- and post-tests solely on science related attitudes of a treatment group (= experimental group EG; students who participated in an elective LEGO robotics class) and a control group (CG; students who participated in a science class). There was no random assignment of students into EG and CG. Welch (2007) also conducted pre- and post-tests with EG (students who participated in FIRST Robotics) and CG (students from the same US school who did not participate in FIRST), solely focusing on science related attitudes and interests. Whitehead (2010) investigated middle school students' interests toward science and technology applying pre- and post-tests (in sum 107 participants from ten schools in Pennsylvania, US). Nevertheless, this study did not comprise a control group.

A quantitative evaluation of an educational robotics course for kindergarten children was conducted by Wulf (2012). The study comprised pre- and post-test as well as experimental- and control-group and applied psychological assessment tools (see Section 2.1.2 for further details).

Further quantitative studies evaluating the impact of educational robotics activities also on technical skills were done by Nugent et al. (2010), Jomento-Cruz (2010) and Varnado (2005). Varnado investigated the effects of participating in the FIRST Lego League (FLL) competition on students' problem solving confidence. The author applied methods of self-assessment and observation. Summarized results indicated that FLL participants aged 9-14 showed significant improvements in areas such as technological problem-solving, problem clarification or developing and evaluating a design solution. Recent work of Nugent et al. (2014) investigated the impact of robotics camps, clubs and competitions. Results indicated that those activities promoted youth's knowledge of engineering, design and programming but hardly fostered mathematics knowledge. They also reported that the increase of youth's positive attitudes towards science and technology was marginal. Nevertheless, career interests in engineering and self-efficacy in robotics increased consistently. Again, those studies comprised only participants from certain regions in the US, examining a short period respectively.

An extensive meta-study was done by Barreto and Benitti (2012). The authors provide a systematic review of published work on robotics in education with special focus on applied empirical evaluation methods and designs as well as on evaluation results. Some of the reviewed papers reported significant impacts on students' learning (especially on certain sub-groups or on certain topics of the investigated subject). In contrast, however, several studies also reported non-significant results. In addition, (Alimisis, 2013) stresses that most available publications provide descriptive reports or teachers' stories of small scale projects discussing the positive effects of educational robotics.

A number of quantitative empirical studies have been carried out in various other scientific fields such as sociology, psychology, economy, medicine, early-childhood pedagogy and education in general (e.g. UNICEF (2008); Orpinas et al. (2000); Severson et al. (1997); Epp (2008); Wulf (2012)). In these fields there already exists a big amount of knowledge regarding quantitative, qualitative and mixed research methods (Borrego et al., 2009; Hove and Anda, 2005; Flick et al., 2004). Some of the methods and assessment instruments used in already conducted empirical studies (Nugent et al. (2010); Jomento-Cruz (2010); Dagienė and Futschek (2008); University of Waterloo (2013); Austrian Computer Society (OCG) (2013); OECD (2006); Clark (2004); Fraser (1981); Hansen and McNeal (1997)) were adapted and applied for the investigation within the scope of this PhD thesis (see Chapter 4, Section 4.4 for detailed explanation of applied/adapted methods and instruments).

2.4.1. Evaluation Methodology - Theoretical Background

As previously discussed, literature stresses the importance of a systematic evaluation of educational robotics programs (Barker et al., 2012a; Stubbs et al., 2012; Cole, 2012; Catlin and Blamires, 2010). In order to measure the impact of such programs and projects in an objective, comprehensible manner well-grounded empirical methods have to be applied. Choosing the appropriate evaluation methodology depends on various parameters (e.g. maturity and length of the program to be evaluated (short-/middle-/long-term), participants (background, prior knowledge, age group), sample size, location, available resources, ...). All those factors have an influence on the selection of methods and evaluation design Stubbs et al. (2012).

Basically a distinction is made between *formative* and *summative* approaches. Formative evaluations are carried out while the program to be evaluated is still under development. The focus is on getting feedback, for instance regarding the applied robotics platforms, curricula or teaching materials in order to modify and rerun the program. Summative evaluations are carried out in order to investigate the effectiveness or impact of a program on its target group. In the context of science education summative evaluations often investigate students' learning success or their change of attitudes. Depending on whether a formative or a summative approach is applied one has to define a) the *evaluation method* (overall data collection strategy defining when and from which target group data is collected; e.g. pre- and post-tests, ...) as well as b) the *measurement method* (instruments applied to collect data from the target group; e.g. interviews, questionnaires, ...). (Friedman, 2008; Stubbs et al., 2012)

Conducting evaluations in the area of education is well established (Cohen et al., 2013). Therefore, these methods can also be used to evaluate educational robotics approaches in a comprehensible, repeatable and objective way. Well-grounded and commonly used evaluation methods are pre- and post-tests and comparison groups. Established and proven measurement methods are interviews, observations, questionnaires and collection of demographic information (Stoner, 1996; Stubbs et al., 2012).

Stubbs et al. (2012) and Friedman (2008) propose the following 4-step evaluation design approach:

1. *Identifying the target audience*: Which group of persons should be investigated (e.g. students, teachers, mentors, ...)?
2. *Determining the impact categories*: What kind of impact (e.g. skills, knowledge, attitudes, interests, behavior, ...) should the program have on the target audience? Friedman (2008) defines six impact categories:
    - skills: measurable development or improvement of skills (e.g. mathematics and problem solving skills (Lindh and Holgersson, 2005))
    - knowledge/understanding: measurable change/improvement regarding knowledge or understanding of certain topics or concepts (e.g. knowledge of fractions, gears, sensors and program flow (Nugent et al., 2009))
    - engagement/interest: measurable change regarding interest or engagement in a certain topic (e.g. interest in careers related to robotics (Scribner-MacLean et al., 2008))
    - attitude: measurable change regarding the attitude towards a certain topic (e.g. students' positive attitudes towards robotics, engineering (Nourbakhsh et al., 2003))
    - behavior: measurable change in the behavior in connection with certain topics (e.g. students decide to study engineering at college (Melchior et al., 2005))
    - program specific other categories (e.g. museum visitors finishing an entire demo interaction (Nourbakhsh et al., 2005))
3. *Defining the required evidence*: What are the specific, measurable (observable) results to prove that the desired impact has been achieved (e.g. applying self-reports in order to assess students' enjoyment of certain subjects)?

Qualitative Research

Characteristics / Strengths:
applying qualitative methods (e.g. a grounded theory approach) to generate a theory/hypothesis describing the observed phenomena
gathering people's personal viewpoints, experiences or feelings
detailed description of phenomena in the local and social context
possibility of investigating dynamic processes
reacting 'on the fly' to changes which occur during the conducting of a study
useful when investigating a small number of cases in detail or for gathering individual case information
data collection in a 'naturalistic setting'
even one important case may demonstrate a phenomenon in an illustrative way
Limitations:
findings might not be generalizable to other populations or settings
difficult to test hypothesis or to make predictions
data collection and analyzing is time consuming
it is more likely that the researcher personally influences the results (e.g. personal opinions, biases)

Table 2.2.: Characteristics, strengths and weaknesses of the qualitative research paradigm (based on Johnson and Onwuegbuzie (2004)).

4. *Selecting evaluation and measurement methods*: Which data collection strategy and which instruments need to be applied?

Qualitative and Quantitative Research In the field of empirical evaluation research basically three paradigms can be identified: *qualitative*, *quantitative* and *mixed* research methods (Newman and Benz, 1998; Diekmann, 2007).

One main characteristic of qualitative research is that the researcher acts as primary data collection and analysis 'instrument'. The focus is on induction, exploration and discovery as well as on generating theories and hypotheses. Data are collected in form of words, anecdotes, pictures or objects using data collection methods like interviews, observations or field notes (see Table 2.2 for further characteristics, strengths and weaknesses of the qualitative research paradigm).

Quantitative research is mainly characterized by its focus on standardized data collection and statistical data analysis, deduction, theory development, testing of hypotheses as well as on explaining and predicting results. Quantifiable data (e.g. numbers) are collected using, for instance, questionnaires or surveys. While qualitative methods are recommended during the early phase of an evaluation project (generating theories/hypotheses), quantitative methods are recommended during the latter phases (testing/validating theories/hypotheses). Table 2.3 provides an overview of the major characteristics, strengths and weaknesses of the quantitative research paradigm.

Finally, a mixed research approach combines qualitative and quantitative methods. Multiple data is collected applying different strategies and techniques in order to benefit from the strengths of both quantitative and qualitative research methods (Johnson and Onwuegbuzie, 2004; Jahoda et al., 1960).

Quantitative Research
Characteristics / Strengths:
testing/validating of already constructed theories/hypotheses
possibility to generalize findings and results to different populations
confounding factors (variables) can be considered in the statistical data analysis
relatively fast and uniform quantitative data collection methods (e.g. paper-and-pencil questionnaires)
collecting of precise, quantitative, numerical data
using statistical software to ease data analysis
results and findings independent from the researcher (e.g. statistical significance, effect size)
possibility to investigate a large number of cases
Limitations:
research categories and theories might not reflect study participants' understanding
certain effects or phenomena might be missed because the focus is on testing/validating theories/hypotheses rather than on generating theories/hypotheses
results/findings might be too abstract or too general for an immediate application

Table 2.3.: Characteristics, strengths and weaknesses of the quantitative research paradigm (based on Johnson and Onwuegbuzie (2004)).

Evaluation Methods In the context of educational robotics pre- and post-tests (also called pre- and post-surveys) are used to measure the knowledge gain or the attitude change between two measurement points (before and after an intervention). The same set of questions are used for both pre- and post-test. Pre- and post-tests are usually applied to evaluate longer periods (e.g. a week- or semester-program). Shorter periods like a day or several hours might be too short to have a significant, measurable impact on the target group. In addition, potential learning effects have to be considered (study participants remembering the correct answers from the pre-test while doing the post-test) (Stubbs et al., 2012; Hamner et al., 2010).

Comparison groups are used to gather further information on the impact of the intervention on the experimental group. The experimental group (also called treatment group) receives an intervention while the comparison group (also called control group) does not undergo this intervention. Both groups should have the same demographic background. Comparison groups are less widespread due to the high logistical and organizational effort. Establishing a comparable control group in an educational robotics context poses a number of great challenges. For instance, students (for the most part) voluntarily take part in robotics activities and are therefore already biased. Determining and controlling the influence of the teacher on students in control- and experimental-group represents another crucial factor to be dealt with (Cohen et al., 2013; Stubbs et al., 2012). Further confounding factors (including counter measures) particularly related to the study conducted within the scope of this study are discussed in Chapter 4, Section 4.4.9.

Measurement Methods Questionnaires are the most commonly used data collection method. A questionnaire can comprise multiple-choice questions, open-ended questions and/or Likert scale questions. It is important to find a good balance between open-ended questions (providing deeper insight/additional information but difficult to analyze) and multiple-choice/Likert scale questions (less effort for answering and analyzing but additional information/complete feedback might not be available) (Stubbs et al., 2012). Various studies investigating the impact and effectiveness of educational robotics programs apply questionnaires which use a combination of multiple-choice, Likert scale and/or open-ended questions (e.g. Melchior et al. (2005) (mainly Likert scale/multiple-choice, several open-ended), Sklar (2004) (mainly Likert scale), Griffith (2005) (Likert scale and multiple-choice)).

The interview is a flexible, open-ended data collection method which allows the interviewer to react to the interviewee and include new questions on the fly. Furthermore, an interview might generate more narrative and might lead to further discussion. Nevertheless, planning, conducting, transcribing and analyzing an interview is a challenging and time consuming task. Next to the main target group (e.g. students) other groups of persons might also be sources of information (e.g. teachers, mentors, parents) (Stubbs et al., 2012). For instance, interviews were applied in the studies of Sklar and Eguchi (2004); Melchior et al. (2005); Hamner et al. (2008).

Observations represent a decent method to gather first-hand data in a natural social environment. A structured observation sheet helps the observer to stay focused on the overall goals of the investigation while still being open to explore unexpected situations. Observing (and maybe also video-taping) of the target group provides an objective, external view on the investigated program (Stubbs et al., 2012; Cohen et al., 2013; Stoner, 1996). A number of researchers used observations (often in combination with interviews and questionnaires) to assess the impact of educational robotics approaches (e.g. Nourbakhsh et al. (2003, 2005); Weinberg et al. (2007)).

Impact Categories When evaluating the impact of an educational robotics approach/program on its participants the previously discussed six impact categories of Friedman (2008) can be condensed into the three main categories *student learning* (knowledge/understanding gain, skill improvement), *student attitudes* (change of attitudes, interests, engagement), *student behavior* (careers, studies, further aspects). (Stubbs et al., 2012)

Students' learning can be assessed using quantitative methods like questionnaires, quizzes or self-reports which provide a measurable indication on the impact of the program on students' knowledge gain and improvement of skills. For instance, Nugent et al. (2009) used a 37 item paper-and-pencil questionnaire to assess students' robotics/STEM skills before and after being involved in a robotics activity. Sklar et al. (2002) applied self-reports during RoboCupJunior competitions asking students and mentors how the involvement in this competition improved or hurt their STEM skills.

Students' attitudes reflect their perceptions and interests towards the topics of the program. The exposure to those topics during the participation in the program might have an impact (positive or negative) on students' attitudes. Questionnaires comprising Likert scale questions (answering a question by using a scale, e.g. from 1: strongly disagree to 5: strongly agree) are a common data collection instrument (e.g. Nugent et al. (2010)). A combination of those quantitative instruments with additional qualitative instruments (for instance interviews) can also be found in literature (e.g. Weinberg et al. (2007)). In order to determine a change in students' attitudes pre- and post-tests are workable means. For example, Scribner-MacLean et al. (2008) applied pre-/post-test questionnaires to investigate students' attitudes towards STEM subjects and career plans.

Finally, it is also important to evaluate how a program impacts *students' behavior* and future careers (e.g. which courses they take, which profession they follow, which field of study they choose, ...). Investigating this long-term impact is a challenging task (e.g. maintaining and updating contact information or performing a retrospective study). Therefore, relatively few studies exist which investigate the impact of educational robotics programs on students' further careers. One of those examples would be the longitudinal study of Melchior et al. (2005) which investigates the career path of former FRC (FIRST Robotics Competition) participants (Stubbs et al., 2012). It is also worth mentioning that students' behavior and students' attitudes usually correlate (e.g. students change their behavior and choose a certain career due to a preceding change of their attitude).

Research Designs In the context of educational evaluations following common research designs can be identified (Barreto and Benitti, 2012; Trochim et al., 2015):

- *non-experimental*
  - $[XO]$: one single observation (O; =post-test) after an intervention (X); no comparison (control) group; ⇒ This design faces threats to internal validity since cause and effect relationships (between the evaluated program (intervention) and the outcome) can not be measured properly (Trochim et al., 2015).
  - $[OXO]$: two observations (O) before and after an intervention (pre-/post-test); no comparison group (e.g. (Sullivan, 2008)); ⇒ Cause and effect relationships can be measured in a better way compared to the previous design. Nevertheless, potential single group threats have to be considered (e.g. maturation threat: the same outcome could be achieved without the intervention; testing threat: by conducting a pre-test participants are more aware of the intervention and are therefore better prepared for the post-test (the outcome is based on the pre-test rather than on the actual intervention); ...) (Trochim et al., 2015).
- *quasi-experimental*: The following quasi-experimental study designs use two groups (experimental group and comparison group) and are therefore strong against single group threats (Trochim et al., 2015).
  - $[NXO]$ $[N-O]$: post-test only (O); two non-equivalent groups (N); the experimental group EG receives an intervention (X), the comparison group CG does not receive an intervention (-); ⇒ There is no measurement of the base-line (pre-test), therefore cause and effect relationships can not be measured properly. Participants are not randomly assigned to a group (e.g. instead using two different school classes for EG and CG), therefore EG and CG may not be similar to each other. Since there is no pre-test the groups might already differ prior to the investigation and outcomes might not be related to the actual intervention (Trochim et al., 2015).
  - $[NOXO]$ $[NO-O]$: pre- and post-test (two observations O); two non-equivalent groups; the experimental group receives an intervention (X), the comparison does not receive an intervention (-) (e.g. (Nugent et al., 2009)); ⇒ This is one of the most common research designs. Although there is no randomized assignment of participants to EG and CG the pre-test serves as a base-line assessment of both groups. This allows comparing the groups prior to the study (to ensure that they are similar) as well as to analyze the change/gain between pre- and post-test (e.g. grades/scores) (Trochim et al., 2015).
  - $[NOX_1O]$ $[NOX_2O]$: pre- and post-test (two observations O); two non-equivalent groups (N); the experimental group receives an intervention (X_1), the comparison group receives a control intervention (X_2); ⇒ In general, this design differs from the previous one only by introducing a control intervention. This allows analyzing/comparing the outcomes of two different interventions (e.g. different learning activities (Mitnik et al., 2008)).

- *experimental*: The following experimental study designs use a random assignment of study participants to EG and CG (which is the main difference to the previously discussed quasi-experimental designs). This randomization ensures that both groups a equivalent (up to a certain probability) at the study begin. A pre-test to assess the similarity/difference of both groups is therefore not absolutely necessary but may be useful, e.g. to determine covariances or to measure the degree of equality (Trochim et al., 2015).
  - $[RXO]$ $[R-O]$: post-test only (O); two random assigned groups (R; groups are similar to each other); the experimental group receives an intervention (X), the comparison group does not receive an intervention (-);
  - $[ROXO]$ $[RO-O]$: pre- and post-test (two observations O); two random assigned groups (R); the experimental group receives an intervention (X), the comparison group does not receive an intervention (-) (e.g. (Hussain et al., 2006; Lindh and Holgersson, 2005));
  - $[ROX_1O]$ $[ROX_2O]$: pre- and post-test (two observations O); two random assigned groups (R); the experimental group receives an intervention (X_1), the comparison group receives a control intervention (X_2);

Data Collection and Analysis In order to obtain statistically significant results, the following aspects have to be considered during evaluation design, data collection and data analysis (Stubbs et al., 2012).

Validity and reliability of the measurement methods (instruments) ensure the accuracy of evaluation results. *Validity* refers to what extent the instrument measures what it is intended to measure. Validating a quantitative instrument involves data collection and analysis (i.e. in terms of pilot testing). *External validity* refers to what extent the results are generalizable (i.e. to what extent the sample represents a population). *Content validity* refers to what extent the content of the instrument (e.g. questions, ...) assesses what the researchers wants to investigate.
Reliability refers to the consistency of an instrument. Consistent instruments provide the same results when applied repeatedly in comparable settings. A common method to test the internal reliability of an instrument is to calculate *Cronbach's Alpha* (Bortz and Döring, 2006; Biddix, 2016).

For the purpose of the *data analysis* the use of proven, well-grounded statistical methods is important. Analyzing quantitative data (e.g. originating form questionnaires) can be done applying both descriptive and inferential statistical procedures. Descriptive statistics is the basis of most quantitative studies. It describes the characteristics of the gathered data (e.g. average age or number of participants, ...) and condenses large quantities of data into a simpler, more comprehensible form. Examples for commonly used descriptive procedures would be the calculation of mean, median, standard deviation or distribution. On the contrary, inferential statistics draws conclusions based on the gathered data (e.g. analyzing whether a monitored difference between two groups is dependable (to a certain probability) or not). Therefore, more general information is deduced from the given data. With respect to experimental and quasi-experimental designs (as previously discussed) most commonly used inferential procedures are referred to as general linear model, comprising, for instance, the t-test, the analysis of variance (ANOVA) or the analysis of covariance (ANCOVA). (Trochim et al., 2015; Martin, 2007; Huck et al., 1974; Mayers, 2013; Meyers et al., 2013; O'Brian and Kaiser, 1985; Delisle et al., 2010).

Qualitative data (e.g. from interviews, observations, open-ended questions, group discussions, field notes, journals, reports, case studies, ...) can be analyzed using proven methods from the field of qualitative social research. The basic steps of qualitative analyses are: 1) collecting and scanning all gathered material (e.g. in case of interviews transcribing the interviews or videos from observations), 2) developing a coding scheme, 3) categorizing the data according to the coding scheme, 4) identifying inherent patterns and connections and 5) interpreting the results. (Renner and Taylor-Powell, 2003; Flick et al., 2004; Borrego et al., 2009; Wengraf, 2001; Corbin and Strauss, 2014; Diekmann, 2007; Stubbs et al., 2012).

The *sample size* represents the number of people participating in the evaluation. A larger sample size might lead to a higher significance of results (especially in the context of pre-/post-tests and comparison groups). With smaller sample sizes evaluation results are harder to generalize.

Gathering *demographic data* (e.g. gender, age, ethnicity, social background, ...) provides important additional information and also allows to investigate the impact of the program on multiple target audiences (Stubbs et al., 2012).

2.5. Using Robotics to Teach STEM Principles - a Field Research

In the United States educational robotics has a long history. Many ideas, concepts and innovations in that area originate from different US universities, schools and educational institutions. Therefore, within the scope of this PhD thesis a field research (as part of a research stay; see appendix A.12) was carried out in April/May 2016 at two US high schools. The main host institution *"The Hill School"* (Pottstown, Pennsylvania) implemented a three-year STEM/robotics program in 2015. The second host institution, *"Benilde-St.Margaret's School"* (BSM; Minneapolis, Minnesota) integrated this program in the regular high school education for several years. The program focuses on topics related to mechanical, electrical and computer science engineering using educational robotics as a learning tool. It has proven successful, several different US high schools have integrated the engineering program in their science/technology education and a large number of graduates pursued engineering degrees and careers (Jump, 2015; *Engineering*^{3} , 2016).

Program Overview The program, called *Engineering*^{3}, has underwent a development of 20 years. It comprises a three-year course program where high school students explore mechanical, electrical and computer science engineering concepts. In the first year students are introduced, amongst others, to the engineering design cycle, principles of problem solving, forces, vectors, component testing as well as data collection and analysis. Year two deals with computer-aided design and modelling, custom parts design, fabrication (using 3D printers, laser cutters) and assembly as well as prototyping, testing, re-design, re-testing and implementation. Finally, the third year focuses on control design/systems, electronic applications, sensor integration, embedded logic, number systems, scripting and programming. The ultimate objective of the program is to build and program a robust, reliable robot which explores a maze searching for 'victims' to be rescued while negotiating ramps, obstacles, stairs and further debris. After completing all three years of the program students get the chance to join the robotics competition team and to participate in the annual robotics world championship RoboCup (2016). (*Engineering*^{3} , 2016; Pohlen, 2015)

Objectives and Methodology The main emphasis of this field research was put on following three aspects: First, learning new concepts / teaching techniques and getting insights into recent advances in technology-enhanced STEM education and, furthermore, getting insights into the application of educational robotics to teach science/engineering topics to high school students. Second, discovering the development and successful integration of a three-year high school engineering/educational robotics program/curriculum. Third, gathering accurate, first-hand empirical data of program participants. In this regard the focus was on students' and teachers' point of view and stories by applying different methods and techniques of qualitative empirical research. A large part of the stay focused on getting familiar with the program by reviewing and discovering the first-year implementation at The Hill School, closely working together with the host researcher who developed the program. Furthermore, the goal was to gather empirical data and to collect stories of students who were in the middle of year one of the program at the time of the study. In order to discover the full scope of the three year implementation and to gather data from year two and year three students, the second part of the research stay was done at Benilde-St.Margaret's School.

The main empirical methods applied were expert interviews (see below) and qualitative observations. The systematic documentation of social interactions using field notes, protocols and/or further recording methods (e.g. audio, video) is called observation and represents one of the fundamental methods in empirical social science (Diekmann, 2007). In general, observations can be categorized according to the role of the observer (*participatory*, *non-participatory*), the degree of structuredness (*structured, semi-structured, unstructured*) and naturalness (*laboratory, field*) as well as the type of observation (*open*, *covert*) (Diekmann, 2007; Clark et al., 2009; Grümer, 1974). In this field research a passive participatory, semi-structured and open observation was applied. The researcher took on the part of a passive observer, being present at the daily engineering/robotics classes but not actively taking part in the activities (*passive participatory*). At the beginning of each class he was introduced to the students (name, affiliation, aim of the research, . . . ; *open observation*). A *semi-structured* observation uses an observation guideline instead of a pre-defined, rigid observation scheme (which is usually applied in structured observations). This semi-structured approach was chosen because of the exploratory character of the research objective and in order to get an internal perspective on the everyday situation in the engineering classes (Langer, 2000). According to Mayring (2002) the observation plan covered the following five steps:

1. development of an observation guideline (was done before the field research started)
2. establishing direct contact to the field of investigation (introduction to students at the beginning of each engineering/robotics class)
3. conducting participatory observation (daily engineering/robotics classes in April/May 2016 at The Hill School and Benilde-St.Margaret's School)
4. taking field notes and generating observational protocols
5. data structuring and analysis

In addition to participatory observations, several semi-structured expert interviews (using questioning guidelines) with the developer of the program as well as with teachers at both high schools have been conducted. Further interviews have also been conducted with students during their engineering classes. Conducting interviews is another major qualitative research technique commonly used in the area of psychology and sociology (Flick et al., 2004). Notes were made during the interview and afterwards qualitatively analyzed by means of a content analysis (Neuendorf, 2002).

Insights and Findings The essential parts of this engineering/STEM program could be condensed as follows (*Engineering*^{3} , 2016):

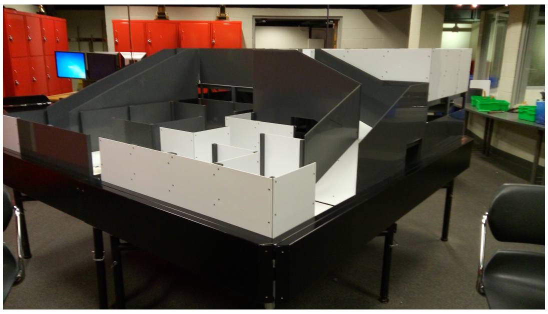
- infrastructure (laboratory, engineering/robotics kits, study/work materials, tools)

- curriculum (modules covering the topics of all three years, extensive textbook)
- teachers (specially trained teaching staff) and students (teamwork, peer-teaching, motivation, maturity and autonomy, role models)

The *infrastructure*, specially tailored to the program, forms the backbone of a fruitful learning environment. The laboratory offers sufficient space for testing and exploring. It comprises several workstations (equipped with desktop computers and a large bench) which are grouped around a central robot testing area (year 1: a large table, partially covered with debris; year 2 and 3: a 'maze' with ramps, obstacles, stairs and further debris) as well as a fabrication station/workshop (equipped with laser-cutter, 3D printer, ...). In addition, there are lockers for each student team to store their equipment as well as a teacher's area ('open-door office'). Each team is equipped with an engineering/robotics kit (LEGO parts, electronic components, control elements, sorting boxes, ...). Figure 2.2 exemplary shows the laboratory environment.

(a) workstations, testing area, lockers

(b) robot testing area (year 1)



(c) robot testing area 'maze' (year 2,3)

(d) teachers, students and robots (one out of seven year 1 classes, The Hill School)

Figure 2.2.: Laboratory environment as well as teachers and students with their robots

The *curriculum* comprises several thematic modules structured around year one, two and three of the Engineering^3 program. The engineering classes are integrated into the regular school schedule (e.g. as elective subjects) and usually take place every day with a duration of approximately 45 minutes each. An extensive textbook which has undergone a continuous development over the last decades covers the topics of all three years and forms the heart of the curriculum. It includes detailed explanations and student assignments for each module. Furthermore, it comprises illustrative examples, frequently asked student questions, tips on common errors as well as original data sheets of electronic components (sensors, motors, microcontrollers, ...). Students exclusively work with this textbook, no traditional teacher-centred teaching is applied. The goal is to foster independent learning (e.g. by using original (not simplified) data sheets of sensors students learn how to read/interpret such material correctly).

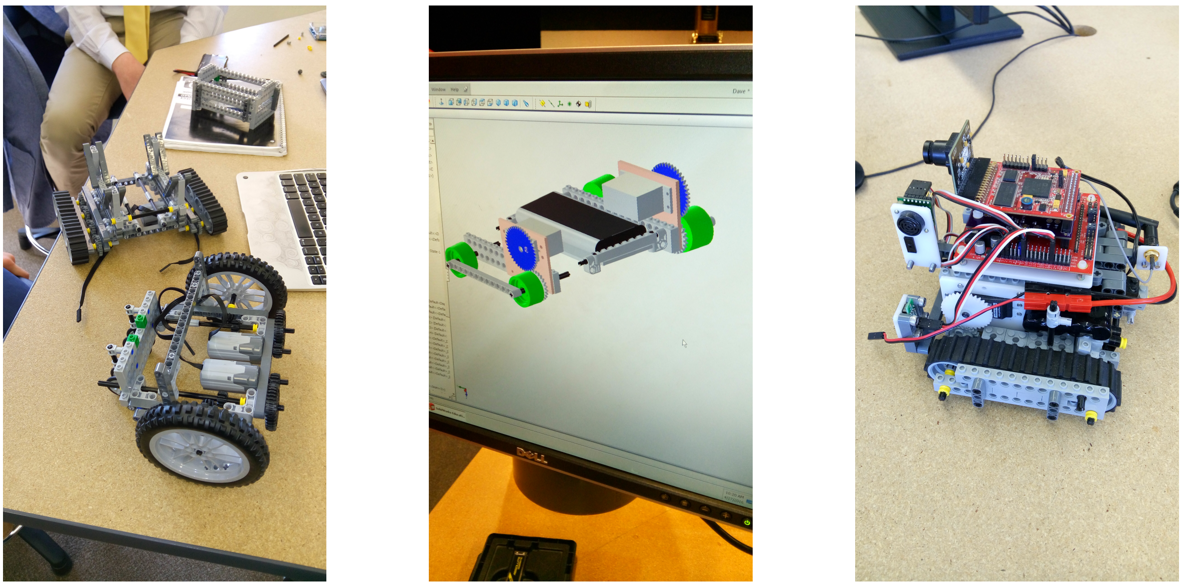
The role of the *teacher* in this program is more or less that of a mentor or coach. *Students* work on their tasks (usually in teams of two) independently whereas they are always free to ask the teacher for help. Nevertheless, most times those questions are answered with a counter question fostering the development of students' problem solving skills. Students are encouraged to find out things themselves, even at the risk of failing or demotivation. In general, the following teaching approach is applied: At first, students experiment and try to solve a given problem/task on their own (using the textbook and consulting classmates). Only afterwards the theoretical/technical background (or in certain cases also sample solutions) are discussed together with the students. This approach ensures that students are attentive and really understand the content and underlying concepts. As interviews and observations showed, this approach is quite unusual for teachers who are used to more traditional teaching styles. Therefore, it is crucial that teachers **a)** adjust to such an educational approach (no precisely planning of every minute of the class; no formal instructions or teacher-centred teaching; giving students enough time to explore (trial and error) and also allowing them to fail; not providing specific instructions or proposals for solutions) and **b)** that teachers are trained and firm regarding the technical aspects of the program.

For each module students get enough time to explore, test and experiment and finally to work in a focused way on completing the assignments. Nevertheless, each module assignment has a strict deadline and working in the laboratory outside the regular classes is not allowed. The aim is that students learn to manage the available time and workload in a way to comply with given submission deadlines. At the time of the field research year one students were working on building and testing a robot that drives in a straight line (i.e. to become familiar with the engineering design process) while year two students were modelling robots using CAD software, respectively working on a rescue robot/RoboCup competition robot (year three students). Instancing, Figure 2.3 shows pictures of some of those robots.

Students' performance assessment is based on an exercise interview on completion of each module (including an acceptance test of students' robots) as well as unannounced exams. This serves the purpose of understanding a subject and to foster an intrinsic motivation rather than learning contents by heart or learning in order to achieve good grades. In this context the key is working towards a meaningful, achievable goal (e.g. building a straight-line robot, later on building a rescue robot, ...). In order for such an educational program to operate properly, students have to participate voluntarily, be intrinsically motivated and show a certain degree of maturity and autonomy.

During the field research it could be observed that students were motivated, open-minded and eager and proud to talk about their work (demonstrating their robots, explaining their test- and experiment-setup, discussing their robot design, ...). They stressed the project-oriented focus of the program as well as the possibility to work independently. Some students explicitly mentioned the intrinsic motivation fostered by this educational approach. Students (especially in the latter years) also reported that the first year is quite demanding (learning the required basics, theoretical principles, ...) but not overburdening. The prospect of joining the competition team at the end of year three was highlighted by many students and definitely represents a motivational factor. Students of this competition team also served as role models for younger students (providing tips and advices, acting as reason to join the program, ...); quoting a year two student who discussed the design of his robot with a member of the competition team: *"She just mentioned that her team had a similar design last year - that really delights me!"*. Overall, it could be observed that the combination of all those aspects created a vibrant atmosphere which encouraged teamwork and fostered a vital interaction between students (sharing knowledge, experiences, consulting classmates, exchanging ideas, ...) and teachers (cooperative relation, acting as mentor).

Observations, interviews and discussions with students, teachers and researchers showed that the described program on the one hand successfully imparts technical aspects (STEM, robotics, computer science, ...). On the other hand, most of all, it fosters social- and soft-skills (project management, teamwork, acting/working independently, ...) and familiarizes students with the application of a systematic scientific approach in order to prepare for college/university. These findings are supported by various stories of success told by students as well as by qualitative data collected and analyzed within the scope of the thesis by Pohlen (2015). As described in this work (Pohlen (2015), p. 65) the major elements of an authentic learning environment (open-ended/complex problems, choice/creativity, student independence, real world relevance, products of students' own effort, collaboration/relationships, role of the teacher) could be observed during this field research.



(a) straight-line robot (year 1)

(b) designing a robot using CAD software (year 2)

(c) fully assembled small rescue robot (year 3)

Figure 2.3.: Students' robot designs at different levels of the engineering/robotics program

The conducted field research at the host institutions, the direct interaction with students and teachers as well as the cooperation with the host researcher enabled the discovery of novel concepts and techniques in educational robotics/STEM education and revealed new methodological perspectives. Insights gained, experiences made and lessons learned will be used to improve support measures provided by university (e.g. robotics courses for students at the university; see Section 2.1.1) as well as to enhance and foster educational robotics activities at schools and further educational institutions.

2.6. Summary, Conclusions and Challenges

As the review of literature in this chapter revealed, educational robotics represents an emerging field in the context of technology enhanced education. Educational robotics as a learning tool has the potential to enrich education at multiple levels, from science and technology education (STEM) to non-technical subjects, and from kindergarten to university (Alimisis, 2013; Eguchi, 2010).

This chapter first reviewed the definitions of and ideas behind educational robotics (ER) and discussed the major dimensions in ER (learning objective, learning aid, learning tool) as reported in current literature (Eguchi, 2012). It also presented and discussed the major learning theories, methodologies as well as pedagogical concepts and principles behind a project- and hands-on oriented approach like educational robotics.

Many different educational robotics approaches, initiatives, projects and frameworks with different characteristics and goals aiming at different target groups exist. In this context, the chapter discussed common viewpoints on educational robotics and presented various different ER approaches and ways to categorize or classify them. The chapter also shortly reviewed the history of educational robotics in general as well as the context of this thesis with regard to educational robotics.

Although educational robotics at school level has become a worldwide phenomenon in the last decades educational robotics at pre-school level (kindergarten) is less widespread. The idea behind the concept of educational robotics in kindergarten is to use the robot as pedagogical tool to familiarize children aged between three and six years with science and technology in a playful way. In this context the chapter reviewed existing approaches which focus on the use of robotics in a pre-school learning environment.

As artificial intelligence (AI) plays an increasingly important role in our daily life this chapter reviewed existing approaches focusing on teaching AI at pre-university level. Nowadays, hardly anybody knows about the concepts and techniques behind AI. Furthermore, teaching fundamental topics of AI and computer science at school or pre-school level hardly exists at the moment. Within the context of this thesis *education in AI* is defined as teaching fundamental topics and concepts of AI at different educational levels using different educational tools and platforms. Among other things, educational robotics is one of those tools.

Finally, this chapter dealt with the empirical evaluation of the impact of educational robotics. In the course of this existing empirical studies and evaluations of educational robotics projects have been reviewed. Furthermore, the theory behind and methodology needed to design and conduct an empirical evaluation investigating the impact of educational robotics has been discussed.

Conclusions Considering the findings from this chapter's literature review following conclusions can be drawn.

Educational robotics is a learning tool to support teaching, learning and education in general and to foster STEM (science, technology, engineering, mathematics), computer science as well as social and cognitive skills. Educational robotics provides teachers and researchers a vehicle which encourages motivating, hands-on activities awakening children's and students' curiosity and interest. Robots are the means for teaching and learning different subjects at different educational levels. (Alimisis, 2012, 2013; Kumar and Meeden, 1998; Eguchi, 2010).

A large number of different educational robotics approaches and projects can be found in current literature. Many of these publications focus on technical aspects but it is crucial to emphasize on the underlying teaching/learning concepts (Alimisis, 2012; Altin and Pedaste, 2013; Sullivan and Moriarty, 2009). A lot of existing approaches define young children and school students as their target audience. The review of literature revealed that, on the contrary, educational robotics approaches with special focus on children aged between three and six years (kindergarten, pre-school) are less widespread. Children have to be prepared for the rapidly changing field of science and technology. Therefore, it is important to start familiarizing children with technology at an early age (Eck et al., 2013; Kandlhofer et al., 2013). In this context efforts must be made to broaden the target audience of educational robotics in order to address also children, students and teachers who are not yet interested in or related to robotics or a similar technical field (Alimisis, 2013).

The review of literature revealed that there are various stories of success, reports and anecdotes by teachers, students and researchers regarding the positive impact of educational robotics. Although such descriptions are important and provide indications of the powerful potential of this educational tool, the necessity and importance of a systematic evaluation is highlighted in current literature (Barker et al., 2012a; Stubbs et al., 2012). As Alimisis (2013) stresses the impact of the educational robotics approach "needs to be validated through research evidence" (p. 68). Nevertheless, relatively few studies investigate this issue resulting in a lack of systematic empirical evaluations. There is a need for quantitative studies applying a standardized evaluation methodology and a reliable experimental design (Alimisis, 2013; Bredenfeld et al., 2010). Furthermore, there is a lack of studies investigating the long-term effects of such pedagogical approaches on students' ways through school, college and later careers (Stubbs et al., 2012; Cole, 2012; Catlin and Blamires, 2010).

With artificial intelligence (AI) gaining importance and becoming part of our daily life it is crucial to familiarize people with fundamental concepts and techniques behind AI (also with regard to future jobs and careers in science and engineering). There is a need to shift from solely *using* towards *understanding* this technology, developing technological 'literacy' (Alimisis, 2013). As the review of related literature revealed, teaching fundamental topics of AI and computer science at school or pre-school level is quite rare at the moment. To go further, teaching those topics independently from specific programming languages or learning tools on different educational levels and adapted for different age groups hardly exists (Burgsteiner et al., 2016b). What current approaches have in common is the relatively narrow focus on specific target- and age-groups. Many existing approaches focus on teaching AI concepts to undergraduate or graduate students at university. Educational approaches which teach selected topics of AI at school level only focus on certain aspects of AI (e.g. history, chat bots, ...) or on certain programming paradigms relevant to AI. Many approaches exist which *use* AI as a technical aid in terms of Artificial Intelligence in Education (AIED; e.g. intelligent tutoring systems, ...). This is in contrast to the context of this thesis of *teaching* fundamental AI topics and concepts ('education in AI').

Taking into account these challenges and open issues the next chapter deals with the design, development and implementation of two innovative educational intervention concepts in the area of educational robotics and education in artificial intelligence.

Finally, Chapter 4 addresses the discussed challenges regarding the lack of empirical evaluations in the area of educational robotics. It describes the design and implementation of a comprehensive evaluation applying a mixed methods research approach which comprises both qualitative and quantitative research methods.

Chapter 3

Concepts for Educational Interventions

This chapter addresses the following research questions (as stated in Chapter 1):

- Qa_1: *What are open issues and challenges in educational robotics (in the context of using robotics as a learning tool)*?
- Qa_2: *What is the current status and what are open issues in teaching fundamental concepts of artificial intelligence at different educational levels ('education in AI')?*
- Qa_3: *Which novel educational intervention concepts are needed to address those challenges (applying, amongst others, educational robotics as a learning tool)?*

Research questions Qb_1 - Qb_3 are addressed in Chapter 4.

3.1. Overview

The literature review in Chapter 2 regarding educational robotics as a learning tool (research question Qa_1) and current approaches of teaching AI/education in AI (research question Qa_2) identified a number of open challenges which could be condensed into the following two major issues:

First, as educational robotics has gained increased attention in the last decades a large number of different educational robotics approaches and projects can be found in current literature. Several conferences and workshops deal with the use of robotics in education (Merdan et al., 2016). Many publications focus on technical aspects of various robotics platforms for education or present local projects. Nevertheless, next to technical aspects there is a need to also emphasize the underlying pedagogical concepts and methodologies (Alimisis, 2012; Altin and Pedaste, 2013; Sullivan and Moriarty, 2009). Furthermore, a lot of educational robotics approaches are aimed at primary/secondary school students. On the contrary, educational robotics with special focus on pre-school children aged between three and six years is less widespread. Children have to be prepared for the rapidly changing field of science and technology. In this context it is important to a) start familiarizing children with technology at an early age and b) also to address people who are not yet technically interested (Alimisis, 2013; Eck et al., 2013; Kandlhofer et al., 2013).

Second, artificial intelligence (AI) plays an increasingly important role in our daily life. People already use different devices, applications, and services which are based on principles of AI. Examples would be intelligent household appliances like autonomous vacuum cleaners or lawn mowers as well as services and smartphone applications like *Google (Maps, Now, ...)*, *Cortana* or *Siri*. In contrast, people hardly know about the concepts and techniques behind those services and computer applications (Cole, 2012). Instead of just using technology people need to understand the fundamental principles behind by developing technical/AI 'literacy' (Alimisis, 2013). This is important not only for future careers in science and engineering but also for fostering people's awareness of opportunities and threats of emerging technologies. As the review of related literature revealed, teaching fundamental topics of AI and computer science at school or pre-school level is quite rare at the moment. To go further, teaching those topics independently from specific programming languages or learning tools on different educational levels and adapted for different age groups hardly exists (Burgsteiner et al., 2016b).

In order to deal with these major issues we developed, implemented, and evaluated two innovative educational intervention concepts. Addressing research question Qa_3 this chapter describes their design and implementation. The concepts have been developed considering pedagogical and didactical aspects applying well-established, proven learning methods and teaching techniques (as discussed in Chapter 2).

The first concept described in Section 3.2 applies a cross-generational approach focusing on kindergarten children and integrating school students up to the age of thirteen as well as senior citizens in order to initiate a vital social process among the different age groups (broadening the target audience). The goal is to familiarize the target audience (in particular pre-school children and school students), with science and technology in a playful way using educational robotics as learning tool.

The second concept discussed in Section 3.3 deals with the development and implementation of a concept to familiarize different age groups on different educational levels (from kindergarten to university) with fundamental topics of artificial intelligence (AI). AI already plays a major role in our daily life and therefore, sound knowledge about AI and the principles of computer science will be of vast importance for future careers in science and engineering. In this context literacy in AI and computer science will become as important as classic literacy (reading/writing). By using an analogy with this process the AI education concept aims at fostering AI literacy. The concept uses educational robotics as a learning tool, along with a broad range of other tools and methods to teach fundamental concepts of artificial intelligence to kindergarten children, school students (primary, middle, secondary/high school) and undergraduate university students.

Both intervention concepts have been conducted and empirically evaluated within the scope of proof-of-concept implementations. Sections 3.2 and 3.3 describe the design, applied methodology and implementation of both concepts while Section 3.4 summarizes both intervention concepts and discusses conclusions, shortcomings, limitations and future work. The evaluation methods and results are described in detail in Section 4.3 of Chapter 4.

3.2. Pre-School Educational Robotics in a Cross-Generational Context

The idea behind the concept of educational robotics in kindergarten is to use the robot as pedagogical tool to familiarize children in pre-school age with science and technology in a playful way (as discussed by Bers (2007)). Science and technology are changing rapidly and young children have to be prepared for this development. Integrating new technology in the education of children between three and six years of age cannot be considered in isolation but must rather be accomplished by applying a multi-dimensional approach. Therefore, we developed a novel concept within the field of educational robotics: Different age groups (kindergarten children, school students (aged from eleven to thirteen) and senior citizens) as well as different scientific and educational institutions (kindergartens, schools, universities) working together on a cross-generational and cross-institutional educational robotics project (Kandlhofer et al., 2014; Eck et al., 2013; Kandlhofer et al., 2013).

We developed, conducted and empirically evaluated a first pilot-project. In general the goals can be summarized as follows:

- developing an educational robotics concept in cooperation with kindergartens, schools and universities (*cross-institutional*) in order to
- introduce pre-school children and in parallel also school students and senior citizens to robotics and computer science (*cross-generational*) as well as
- investigating the learning effects and the medium-term impact (up to eight months) of the project on participating school students, and in addition
- gaining experience and gathering information on how to prepare complex technical topics for a diverse target audience without prior knowledge.

The next sections describe this educational concept and the applied methodology as well as the implementation of a pilot project. While the related literature was already discussed in Section 2.1.2 of Chapter 2, evaluation methods and results can be found in Section 4.3.1 of Chapter 4.

3.2.1. Methodology

The cross-generational educational robotics concept was developed as a joint project between Graz University of Technology (TUG), the University of Teacher Education Styria as well as a kindergarten and a secondary school. The overall structure was based on the teaching approach *Children visit Science (CvS)*. Originally initiated in 2010, CvS is an innovative approach within the context of kindergarten pedagogy. Its basic aim is to provide pre-school children and school students access to different scientific fields and, furthermore, to give an insight into the research sector at different scientific institutions. Initially the CvS approach comprised six educational modules, focusing on different topics such as electrostatics and electricity, bioscience, experimental physics, chemistry, paper manufacturing and criminology. All modules had a strong focus on hands-on activities (e.g. building a power circuit or testing the conductivity of different materials in the electricity module) (IMST, 2011; Hirschmugl-Gaisch et al., 2011). According to the CvS approach the cross-generational educational robotics concept follows the ideas of peer teaching (Whitman and Jonathan, 1988) as part of an education partnership (Textor, 2011). In doing so, school students act as guides explaining and presenting contents to kindergarten children as well as to senior citizens who accompany the kindergarten children. Students slip into the part of a teacher, guiding the children through their way of discovering and experiencing and in parallel learn by teaching others (Frager and Stern, 1970).

One main objective of this educational concept was to prepare contents of the area of robotics and computer science respecting pedagogical and didactical aspects as well as principles of constructionism (educational robotics) (Alimisis (2009); Frangou et al. (2008); Virnes and Sutinen (2009); Romero et al. (2012)). Therefore, university researchers together with kindergarten pedagogues and teachers developed eleven different hands-on activities and educational games applying methods of discovery learning (De Jong and Van Joolingen, 1998; Messner, 2009) and the technique of storytelling (Westlund and Breazeal, 2015; Bers, 2008; IMST, 2011; Masemann and Messer, 2009). Respecting fundamental principles of constructionism children could actively participate, explore, test, and interact with the robots. Furthermore, each activity and educational game states a specific research question or task children have to address.

Thus, the basic structure of the cross-generational educational robotics concept can be summarized in the following way:

(i) researchers, teachers and kindergarten pedagogues develop specific hands-on activities and educational games in the area of robotics/computer science

(ii) school students first get introduced (by researchers and teachers) to fundamental robotics/computer science topics and afterwards to the specific hands-on activities

(iii) kindergarten children and their accompanying grandparents (senior citizens) perform and explore those hands-on activities under the guidance of school students

This approach combines two major benefits. On the one hand students learn about scientific topics not only during the preparation process but also by guiding and explaining the topics to kindergarten children and senior citizens. On the other hand, kindergarten children have the opportunity to learn and gather practical experiences together with students and senior citizens. In this context one important aspect is that pre-school children can actively participate in the hands-on activities. Furthermore, the integration of different age groups and different educational institutions fosters a vital social process between kindergarten children, school students, senior citizens as well as mentors, teachers and staff members of the participating institutions. Therefore, this approach involves a broad range of people with different backgrounds and different interests. By broadening the target audience in this way also people (e.g. children, students, senior citizens, pedagogues) who might not be technically interested or, who have not been engaged in technical subjects before, are addressed. In general the concept of discovering and experiencing represents a valuable pedagogical approach within the area of pre-school education, fostering the learning process of children in a holistic way (IMST, 2011; Hirschmugl-Gaisch et al., 2011).

The robotics/computer science hands-on activities are structured around following major topics:

- introduction, types of robots
- basics of algorithmic thinking and programming (Futschek and Moschitz, 2011)
- human-robot interaction (Goodrich and Schultz, 2007)
- intelligent agents (Russell and Norvig, 2009)
- mapping and object tracking (Grisetti et al., 2005)

3.2.2. Implementation

The cross-generational educational robotics concept was implemented in terms of a scientific project day at a kindergarten. In sum twenty-five kindergarten children aged between four and six years participated. They had been divided into groups of three. Each group of children was accompanied by at least one senior citizen (mostly children's grandparents). Moreover, ten school students aged between eleven and thirteen years of age participated. During this project day each hands-on activity was carried out at a separate area, also referred to as 'experimentation station' where school students explained the activities to kindergarten children and the accompanying senior citizens.

In preparation for their tasks students attended a robotics workshop held by university researchers and teachers. The content was prepared in an age appropriate way based on principles of constructionism and instructionism (Papert, 1993a; Johnson, 2005). Prior to this workshop students did not know any details about the previously developed hands-on activities. The teacher only announced that she is looking for volunteers joining a 'robotics project'. In the course of the workshop students were first introduced to the basic concepts of robotics and computer science. Afterwards they were familiarized with the scientific and technical background of each activity. This was mainly accomplished by applying methods of discovery learning (Ormrod, 1995) (playing educational games which demonstrate the basics of robotics and computer science; interacting with the different robots in order to discover the technical background). Students then could choose an activity they wanted to be responsible for during the project day. Finally, each student got detailed instructions on how to carry out and guide her 'experimentation station'.

To address the major topics described in the previous section following robotics platforms were used:

- the educational robot *Bee-Bot* (Pekarova, 2008)
- the *LEGO Mindstorms NXT 2.0* robotics kit (Kim and Jeon, 2007)
- the humanoid robots *Nao* (Han et al., 2012) and *Hitec RoboNova* (Grunberg et al., 2009)
- the mobile research robot *Pioneer 3-DX* (Zaman et al., 2011)

Figure 3.1 shows the different robotics platforms used during the pilot implementation as well as the excitement of children and students while carrying out robotics hands-on activities. Following a description of the activities for each of the major topics.

Introduction, Types of Robots

By using different robotics platforms (as described above), participants got a better understanding of the variety of robots. For instance, by using the *RoboNova* platform the basics of humanoid robots were demonstrated. Children could control the robot by sending commands via the infrared remote controller. The other children had to watch the robot carefully and afterwards imitate its movements (Figure 3.1a). The research question was: "Is a robot a better dancer than me?"

Basics of Algorithmic Thinking and Programming

For this activity we used the *Bee-Bot* robot, a widely adopted tool within the context of educational robotics for pre-school and early primary school children. It can be controlled according to the principles of the *Logo* programming language (Papert, 1993a). Using the buttons on the back of the robot (forward, backward, rotate left, rotate right) children can enter a sequence of commands. Each forward/backward instruction moves the robot in the corresponding direction whereas each rotation instruction turns the robot by 90 degrees without changing its current position (Pekarova, 2008). Based on this functionality two educational games were developed. The idea behind was to embed the tasks children have to accomplish into a story. In the first game children had to program the robot to follow a certain path on a special square grid mat. The path represented the different production stages in a glass factory (also see Figure 3.1b). The research question for the children was: "Can you teach the Bee-Bot to make glass?". The challenge of the second game was to program the robot moving from a starting point to an endpoint, stopping at certain intermediate positions on a square grid mat with fairy-tale motifs imprinted. The research question for this task was: "Can you tell the story of the bad wolf and the three little piglets whereby the Bee-Bot is acting as the wolf?"

Human-Robot Interaction (HRI)

HRI was of course part of every robotics activity since all the activities and educational games comprised interactions with robots in some way. In order to provide a deeper insight and a more intense experience participants could also interact with the humanoid robot *Nao* (talking to the robot, touching the robot, tracking faces, . . . ; see Figure 3.1c). The research task stated was: "Find out what skills Nao has". The main idea behind this task was to apply a discovery learning-based approach (Ormrod, 1995) (i.e. learning by interacting) in order to familiarize children with the HRI topic.

Intelligent Agents

Several hands-on activities demonstrated the principle of simple reflex agents (as described by Russell and Norvig (2009)) as well as the use and functionality of different sensors (ultrasonic-, light-, sound-, color-sensor). Children could interact with the different robots which were constructed using *LEGO Mindstorms NXT 2.0*. Research tasks included: "Follow the light", "Find and grab the can", "Sort the color bricks", "Follow the noise", "Don't drop from the table", "Avoid collisions"; (see exemplary Figures 3.1d and 3.1e). The concept of intelligent agents is a well suited vehicle to familiarize children with basic concepts of robotics (as well as artificial intelligence) in an age appropriate, understandable way (Burgsteiner et al., 2016b).

Mapping and Object Tracking

This experimentation station dealt with mapping and object tracking using the *Pioneer 3-DX* robot with a *SICK* laser scanner and a *Microsoft Kinect* camera (Figure 3.1f). First the robot autonomously created a map of the kindergarten. Children followed the robot on its way through the building. Afterwards the robot performed an object tracking task using the Kinect camera. Children could actively interact with the robot by moving an orange soccer ball. In parallel a university researcher provided explanations on the functioning of the robot and the basic principles of mapping and object tracking. The research tasks for the children were formulated as follows: "Supporting the robot to explore the building" and "Playing soccer with a real robot". The main idea behind those tasks was to apply methods of social learning. This means learning by direct experience with or observation of models (e.g. people, media, objects, ...). A strong identification with those models promotes learning (Bandura and Walters, 1977; Ormrod, 2007; Bandura, 1988). Therefore, the robot (= the model) explored ('walked through') a familiar environment (the kindergarten) and also played a popular and familiar game (soccer). This consequently led to a stronger identification with the robot.

(a) *RoboNova* humanoid robot (topic: types of robots)

(b) *Bee-Bot* glass factory robot (topic: basics of programming, algorithmic thinking)

(c) *Nao* humanoid robot (topic: human-robot interaction)

(d) *LEGO NXT* robot equipped with ultrasonic sensor (topic: intelligent agents (collision avoidance))

(e) *LEGO NXT* robot equipped with a light sensor (topic: intelligent agents (edge detection))

(f) *Pioneer 3-DX* research robot (topic: mapping, object tracking)

Figure 3.1.: Kindergarten children, school students and senior citizens together carrying out hands-on robotics activities (different robotics/computer science topics using different platforms)

3.3. Education in Artificial Intelligence

The previous section described the development and implementation of a cross-generational educational robotics concept focusing on introducing pre-school children, school students and senior citizens to major topics of robotics applying an educational robotics/computer science approach. Based on this concept and the experiences gained within the pilot implementation we developed an advanced educational concept focusing on familiarizing different age groups with fundamental principles of artificial intelligence (AI) and computer science (Kandlhofer et al., 2016b).

Considering the current technological development, sound knowledge about AI and the principles of computer science will be of vast importance for future careers in science and engineering. Looking towards the near future, jobs will largely be related to AI as it will be the basis of the products where our future wealth will be built on (smart production, internet of things, autonomous driving, robotics, . . .). In this context literacy in AI and computer science will become as important as classic literacy (reading/writing). Research in the area of classic literacy shows that starting to learn those basic skills at an early stage is essential for developing profound abilities (Myberg, 2007; Genlott and Gronlund, 2013). In order to develop AI literacy it is crucial as well to familiarize people with the underlying concepts of AI and computer science as early as possible.

By using an analogy with the development of classic literacy we developed a novel AI education concept for different age groups on different educational levels aiming at fostering AI literacy. Developing reading/writing literacy begins during pre-school years, continues through primary, middle and high school and extends right through university. In kindergarten, children are introduced to letters in a playful way, followed by a more methodological approach in primary school. Each subsequent level of education fortifies already learnt knowledge, introduces new topics, and explores certain topics in depth. Based upon existing knowledge, skills are enhanced and abstraction abilities are fostered (Bereiter, 1980). People develop and improve reading/writing skills during their whole life but as research shows the early childhood years (up to the age of eight) are crucial in classic literacy development. Acquiring profound classic literacy skills also requires continuous learning by consolidating already learnt contents and active interaction with print (Neuman et al., 2000; NAEYC, 2013).

Taking into account this theory and transferring it into AI literacy development, our AI education concept comprises modules for different age groups on different educational levels starting with kindergarten and primary school and continuing with middle school, high school and university (see Figure 3.2).

One look at the reading/writing development shows, that successful teaching builds upon already existing knowledge (Neuman and K.Roskos, 1998). Considering this fact, the modules of the AI education concept build on one another, each module covering basic topics in a greater detail as well as introducing new/advanced topics. For instance, modules for kindergarten/primary school introduce fundamental AI/computer science topics (*graphs and data structures, sorting, problem solving by search*) while subsequent modules for middle/high school cover those topics in more detail but also introduce advanced AI/computer science topics (*automata, intelligent agents, planning, machine learning*; also see definition of AI literacy and contents in Section 3.3.1).

Based on this AI education concept we developed four proof-of-concepts modules focusing on kindergarten, middle school, high school and university. All four modules have already been conducted and empirically evaluated in several pilot projects.

While Section 2.3 of Chapter 2 already discussed related literature, the subsequent Section 3.3.1 describes the applied methodology, defines the term AI literacy and describes the AI education concept

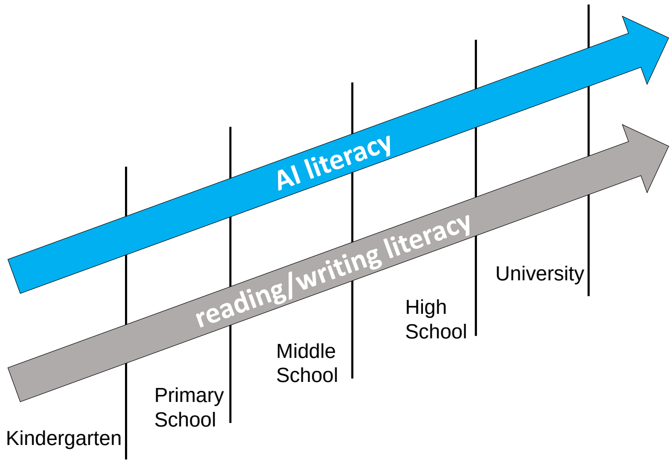


Figure 3.2.: Development of AI literacy in analogy with classic literacy (reading/writing) on different educational levels

in detail (content, structure, learning techniques, tools, stages of AI literacy development). Finally, Section 3.3.2 deals with the description of the proof-of-concept implementation for each module. Evaluation methods and results are presented in detail in Section 4.3.2 of Chapter 4.

3.3.1. Methodology

AI Literacy

In the near future profound knowledge about AI and computer science will be the basis for careers in science and engineering since more and more AI based products and services will emerge. In this context literacy in AI constantly gains importance and will become almost as important as classic literacy (reading/writing literacy). Classic literacy enables people to read and understand new text, instead of learning a text just by heart (Sklar and Parsons, 2002). The same applies to AI literacy: It allows people to understand the techniques and concepts behind AI products, applications, and services instead of just learning how to use certain technologies or current applications.

Our definition of AI literacy comprises following major topics of AI and computer science (Burgsteiner et al., 2016b) (based on the common textbook by Russell and Norvig (2009); also see Figure 3.3)

- **Graphs and data structures** (stack, queue, trees, ...) as well as **basics of computer science** (control statements, paradigms, data representation) and the **definition of a problem** (in the context of AI) form the basis for any task in AI and computer science.
- **Sorting** represents another fundamental concept in AI/computer science (algorithms such as bubble-, merge-, insertion-, selection-, quick-sort, ...).
- **Intelligent agents** such as simple reflex, model-based reflex, goal-based or utility-based agents are suitable vehicles to demonstrate the modelling process of making and executing decisions. The concept of intelligent agents combines many different AI topics which can be imparted to students and children in a suitable and understandable form (for instance, using robots as learning tools).

- **Automata** form the basis for describing systems and behaviors and demonstrate the decision making process in an illustrative fashion.
- **Problem solving by search** is an essential concept in AI and one of the main emphases of AI literacy with numerous areas of application, such as Constraint Satisfaction Problems (CSP), Satisfiability Problems (SAT solving) or planning. Basic algorithms in this context are breadth-first search, depth-first search, and A* search.
- **Classic planning** (modeling problems, making decisions, establishing and evaluating plans) as well as **logic** (understanding logical operators, performing logical reasoning) are important topics in AI (Sklar and Parsons, 2002). Concepts to be considered are, amongst others, state-space planning, forward and backward chaining as well as propositional and predicate logic.
- **Machine learning** is an interesting and very motivating topic for students which gains more and more importance. Contents to be considered are, amongst others, different approaches to learning agents (e.g. logic-based learning, knowledge based systems, reinforcement learning) as well as decision trees and neural networks.

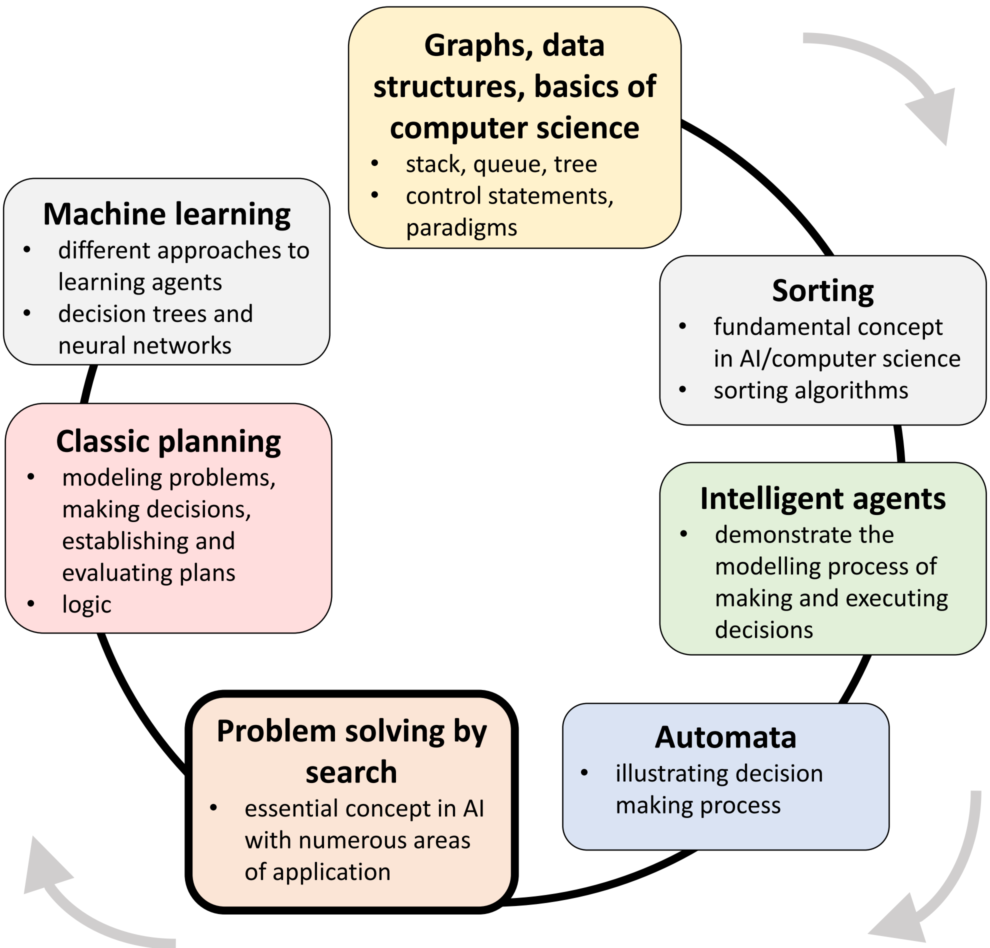


Figure 3.3.: Topics of AI literacy (Burgsteiner et al., 2016a)

Stages of AI Literacy

Neuman et al. (2000); NAEYC (2013) propose a multi-phase view on reading/writing development in order to adapt learning methods and goals in an age-appropriate way:

- *Phase 1 - awareness and exploration*: By exploring the environment children at an early age establish the basis to learn reading and writing. At this stage children are aware that letters represent a meaning. Children are able to identify certain letters, signs and labels.
- *Phase 2 - experimental reading/writing*: Children at kindergarten age start to experiment with reading and writing and, furthermore, they develop a basic understanding of letters. Children are able to compare spoken and written words as well as to write single letters and familiar or often used words.
- *Phase 3 - early reading/writing*: First grade children actually start reading simple stories and writing about topics related to their personal life. They are able to read and retell simple stories, to apply certain strategies for understanding a text (e.g. re-reading, questioning) as well as to identify more and more words by sight.
- *Phase 4 - transitional reading/writing*: At this phase children show an increased fluency in reading and an increased ability to write more complex texts. They are able to use different text forms, to review their own texts and to use reading in order to investigate different topics.
- *Phase 5 - independent and productive reading/writing*: Children improve and extend their reading and writing skills in order to meet various requirements of different audiences. They are able to read fluently, to use advanced strategies in order to identify unknown words, to use an extensive vocabulary as well as to establish links between different texts.

In analogy with this model we define the following stages in the development of AI literacy (also see Figure 3.4):

1. **building awareness and playful exploring AI topics (kindergarten, primary school);**
2. **experimenting and familiarizing with the theory behind certain AI topics and working independently on solving a problem (middle school);**
3. **fostering core AI topics and getting familiar with advanced AI topics; independently acquire and apply knowledge (high school);**
4. **becoming 'fluent' in AI; applying problem solving methods on a higher abstraction level; fostering fundamental understanding of AI topics (university);**

AI Education Concept

By using an analogy with the development of reading/writing literacy we developed an AI education concept aiming at fostering AI literacy. The concept comprises modules for different age groups on different educational levels (kindergarten, primary school, middle school, high school, university; see Figure 3.2). Fundamental (core) AI topics addressed in each module are, amongst others, *graphs and data structures*, *sorting* as well as *problem solving by search*. The modules build on one another, each module covering the core topics in a greater detail as well as introducing new/advanced topics.

Education research has shown the positive impact of hands-on experiences on learning (Sklar and Parsons, 2002; Gruber and Voneche, 1977), hence the modules are largely based on principles of constructionism (Papert, 1993a; Papert and Harel, 1991) comprising a wide range of hands-on activities.

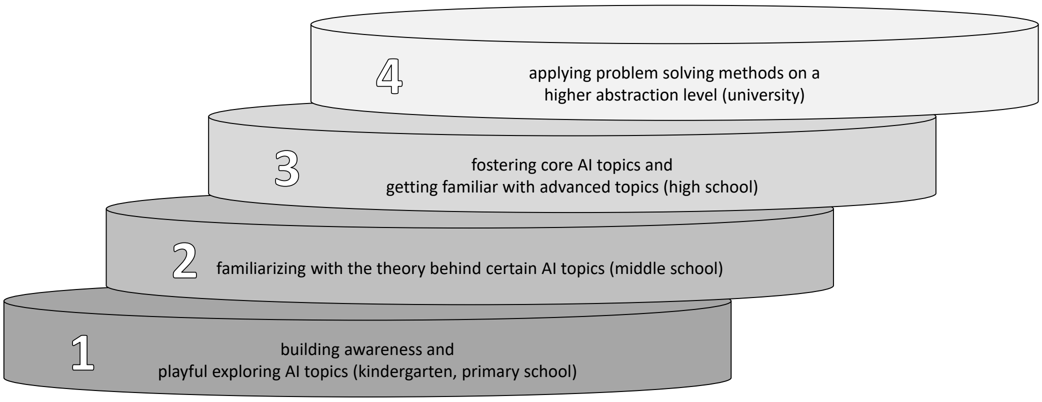


Figure 3.4.: Stages in the development of AI literacy

Each module applies appropriate learning methods and techniques (discovery learning, inquiry learning, collaborative learning, problem-based learning, project-based learning, storytelling, peer teaching; (Virnes and Sutinen, 2009; Romero et al., 2012; Frangou et al., 2008; Masemann and Messer, 2009; Bers, 2008; Westlund and Breazeal, 2015)), respectively combinations of these methods as suggested by Altin and Pedaste (2013) (also see Chapter 2, Section 2.2). Furthermore, in each module a number of different learning tools and platforms are used (educational robotics (Alimisis, 2009; Barker et al., 2012a), computer science unplugged (Bell et al., 1998), educational games, paper-and-pencil exercises (Futschek and Dagiene, 2009)).

In analogy with research in the area of classic literacy the activities in each module are embedded in meaningful, enjoyable experiences. The goal is to familiarize children and school students with AI topics while they experience motivational, interesting and inspirational activities (Johnson, 2005; Stickland, 1998; Snow et al., 1998). The following sections provide an overview of contents, structure and goals of each module.

Kindergarten and Primary School

Research in the area of classic literacy shows that it is essential to start to learn basic reading/writing skills at an early stage (Myberg, 2007; Genlott and Gronlund, 2013). Furthermore, studies show that it is important that children gather experiences with books in order to make connections between printed and spoken word (Denton and West, 2002). In order to develop AI literacy it is crucial as well to a) familiarize children with the basic concepts of AI/computer science as early as possible and b) to let children discover the connection between applications (which use AI) and the underlying concepts.

The idea behind this module is to introduce kindergarten and primary school children (aged between four and eight years) to the core AI/computer science topics in a **playful way** by breaking down complex contents in an age-appropriate fashion (Virnes and Sutinen, 2009; Bers, 2007) (according to stage 1 (see Figure 3.4) defined in Section 3.3.1).

Respecting pedagogical and didactical aspects and based on the experiences gained from the cross-generational educational project described in Section 3.2 we developed different hands-on units where children can actively participate and explore AI/computer science topics (Frangou et al., 2008). We applied methods of discovery- and inquiry-learning (Altin and Pedaste, 2013; Mayer, 2004), the technique of storytelling (Bers, 2008; Masemann and Messer, 2009; Westlund and Breazeal, 2015) as well as the principles of educational robotics (Romero et al., 2012; Alimisis, 2009) and computer science unplugged (Bell et al., 1998). In this context we used different learning tools (robotics platforms like *Bee-Bots* (Pekarova, 2008), *LEGO Mindstorms NXT* (Kim and Jeon, 2007) and *Cubelets* (Correll et al., 2014) robotics kits, but also non-robotics material like standard LEGO bricks).

Following AI/computer science topics are covered in several hands-on units (Kandlhofer et al., 2015) (see section 3.3.2 for a short description of each unit).

- **graphs and data structures**
- **sorting algorithms**
- **problem solving by search**

The hands-on units can be combined modularly, depending on how this module is being implemented in kindergarten/primary schools (Section 3.3.2 describes the pilot implementation).

Middle School

Looking at reading/writing literacy in later years of education, the focus of teaching shifts more towards supporting children to develop independent reasoning and comprehension skills. Children should be encouraged to analyze different topics, formulate questions and organize written answers by giving them challenging tasks (Neuman et al., 2000; NAEYC, 2013).

Applying this knowledge to our AI literacy approach, in this module school students (aged between eleven and thirteen years) take a first look at the theory behind certain AI topics and apply this knowledge afterwards in a practical group project encouraging them to analyze and work independently on solving a specific problem (stage 2 of AI literacy development (see Figure 3.4) defined in Section 3.3.1). Hence, this module comprises theoretical and hands-on elements based on principles of constructionism and instructionism (Papert, 1993a; Johnson, 2005) applying project-based, collaborative learning and problem-solving methods (Altin and Pedaste, 2013). Learning tools used in this module are the educational robotics platform *LEGO Mindstorms NXT* as well as paper-and-pencil and computer science unplugged exercises.

The module fosters core AI topics, in particular graphs and data structures as well as problem solving by search. Furthermore, it introduces the concept of intelligent agents. After completing this module school students should have a basic idea of fundamental data structures and search algorithms and **understand the connection between those AI techniques and common applications which use AI** (e.g. Google Maps). Basically the module is structured as follows:

- raising a guiding research question
- motivation, raising awareness for the topics
- introducing school students to **graphs/trees and data structures** (*stack, queue*)
- introducing students to **search algorithms**, in particular *depth-first (DFS) and breadth-first search (BFS)*
- familiarizing students with **intelligent agents**

- evaluating, comparing and documenting different search strategies/algorithms (random, wall-follow, DFS, BFS)

This module is designed to be implemented in form of a research week/camp or in form of weekly courses (Section 3.3.2 describes a pilot implementation). The modular design allows implementations with different levels of complexity and difficulty (e.g. for school students with or without prior knowledge in AI/robotics/computer science).

High School

In this phase reading/writing abilities are fortified based on already existing knowledge, certain topics are explored in depth and new topics are introduced (Bereiter, 1980). According to this development and in line with our AI literacy concept (stage 3 (see Figure 3.4) as described in Section 3.3.1) the goal of this module is to foster core AI topics by exploring them in a detailed way, introducing advanced AI topics as well as to foster the ability to acquire and apply AI topics independently.

Based on principles of constructionism and constructivism (Papert and Harel, 1991; Alimisis, 2009) school students (aged between 15 and 18 years) actively participate in the learning process. Activities include paper-and-pencil/programming exercises, robot constructions, discussions, group works and home-assignments by applying inquiry- and collaborative learning and problem-solving methods (Altin and Pedaste, 2013).

After completing this module school students should be familiar with all topics of AI literacy as defined in Section 3.3.1. The following list provides an overview of the topics and the structure (units) of this module (Burgsteiner et al., 2016c; Russell and Norvig, 2009; Burgsteiner, 2016):

- **Introduction**: Students are introduced to the AI topic by first discussing the requirements for 'intelligence', by discussing how students would define 'artificial intelligence' as well as by introducing and discussing the Turing test (Shieber, 2004; Burgsteiner et al., 2016c; Burgsteiner, 2016).
- **Automata**: Automata are a good and illustrative way to introduce the process of modelling (describing) systems and behaviors. Furthermore, automata play an important role in research (e.g. model diagnosis, automated testing, ...) and in various other applications. Topics and questions which are addressed: What is a state? How can an automaton transfer from one state to another state? Which different types of automata (deterministic, non-deterministic, timed, input/output) can be distinguished? (Burgsteiner et al., 2016c; Burgsteiner, 2016)
- **Intelligent agents**: After learning about states and state transitions students are introduced to basic structures of agents (i.e. addressing the question of how intelligent behavior could be internally organized and represented). Furthermore, students are introduced to the different types of agents (simple reflex agents, model-based reflex agents, goal-based agents, utility-based agents, learning agents). The concept of intelligent agents combines a wide range of AI topics and it is well suited to explain the modelling process of making and executing decisions (Burgsteiner et al., 2016c; Burgsteiner, 2016).
- **Data structures, graphs, problems**: Basic data structures like stack and queue as well as basics of computer science (control statements, paradigms, data representation, sorting algorithms) are presented and discussed (partly already addressed in the previous units). Based on this knowledge students are introduced to more advanced data structures like graphs and trees (as

these form the basis for solving problems in AI). Another focus is the definition of a problem in the context of AI (states, set of actions, transition model, goal test, cost function) since this forms the basis for any task in AI and computer science (Burgsteiner et al., 2016c; Burgsteiner, 2016).

- **Problem solving by search**: After repeating and discussing how problems in AI can be mapped to graphs, students are introduced to the fundamental search algorithms breadth-first search (BFS), depth-first search (DFS) and A*-search (explaining theory behind, group discussion, paper-and pencil exercises, programming exercises). Solving problems by search is an essential concept in AI and computer science and one of the main emphases of AI literacy with a wide range of different applications (CSP, SAT solving, ...) (Burgsteiner et al., 2016c; Burgsteiner, 2016).
- **Classic planning and logic**: In this unit students are introduced to logic and general planning algorithms. The goal is that students get a basic sense for the topic and that they are then able to apply algorithmic problem solving strategies. The main topics addressed are logical operators, propositional logic, first-order logic, logical reasoning, modeling problems, making decisions and plans, evaluating plans, forward and backward search algorithms (theoretical input, discussion, paper-and-pencil exercises) (Burgsteiner et al., 2016c; Burgsteiner, 2016).
- **Machine learning**: The final unit first deals with discussing principles of machine learning (dynamic knowledge base, learning strategies expanding this knowledge base, unsupervised and supervised learning). Students are then introduced to selected machine learning algorithms (reinforcement learning (Sutton and Barto, 1998), logic-based inference (Levesque, 1986), decision trees (Quinlan, 1986), neural networks (Graupe, 2013)). The selection of approaches discussed is based on the question which machine learning algorithms could be useful in robotics, in particular in junior robotics competitions (e.g. RoboCupJunior) (Burgsteiner et al., 2016c; Burgsteiner, 2016).

Due to its extensive content this module is designed to be implemented on a weekly basis (e.g. as an optional subject with one or two hours per week; see Section 3.3.2 for a pilot implementation). Further details on the concept and topics of this module can be found in Burgsteiner et al. (2016b), Burgsteiner (2016) respectively.

University

In order to follow our analogy to reading/writing literacy, at university level we aim at a more **fundamental understanding of the topics** and the enabling of further developments in the field (stage 4 in the AI literacy development (see Figure 3.4) defined in Section 3.3.1). The former aims at the educational aspect in order to develop a professional career. In the context of writing and reading people will use the written language as a core component of their profession. For instance, at university level people are educated to become teachers, journalists or translators. In order to do so a sound understanding of the concepts and models behind but also methods as well as the properties of all of them are needed.

In the context of AI that means the capability to **describe problems formally** and precisely and on a much **higher abstraction level**. Moreover, also the understanding of properties of problems and the relation and the mapping of different problems is important because it allows to reuse powerful solving methods. Finally, the knowledge about properties of problems such as complexity are relevant in the context of AI. The latter aims at research where fundamental questions are raised that research tries to answer in order to better understand the own field (i.e. better models) or do extend the portfolio of applicable methods. This endeavor can be related to reading/writing with a strong connection to language as well as AI (as part of computer science).

The university module consists of course-based education in the area of theory of computation and AI based on classical textbooks by Russell and Norvig (2009); Sipser (2012). In order to support a better learning we are following the idea of constructionism and use demonstrative hands-on exercises.

3.3.2. Implementations

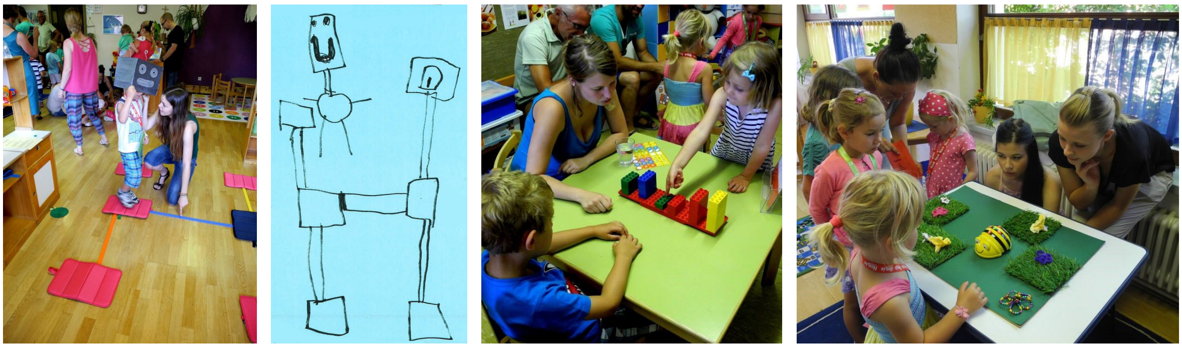
Based on our AI education concept we developed, conducted and evaluated proof-of-concept implementations for each of the modules described in the previous sections. The subsequent sections describe the pilot implementations while the evaluation methodology and results for each module can be found in Section 4.3.2 of Chapter 4

Module 1 - Kindergarten

The first module was implemented in a kindergarten in terms of a scientific project day based on the same principles as the project day described in Section 3.2 (Kandlhofer et al., 2015, 2014). Different units dealing with AI/computer science topics were developed and carried out on separate hands-on areas. According to the concept of peer teaching (Whitman and Jonathan, 1988) students of the school for kindergarten pedagogy hosted and explained the units to the kindergarten children accompanying them through their way of discovering and experiencing. In preparation for their tasks, school students attended several workshops at university where they were introduced to the principles and concepts of AI, computer science and robotics. Furthermore, they were also actively involved in the development of age-appropriate activities for each unit. The following list provides an overview of the different activities, categorized by AI/computer science topics.

- graphs and data structures: programming a Bee-Bot to traverse a graph in order to find a way out of a maze (see Figure 3.5d); navigating a 'human-robot' through a maze (traversing a graph; one child acts as 'programmer', another child acts as 'robot');
- sorting algorithms: sorting LEGO bricks according to the bubble sort algorithm (see Figure 3.5c); children line up in a row and afterwards sort themselves according to their age applying the bubble sort algorithm;
- problem solving by search: children have to traverse a graph from the root (nodes and edges are taped on the floor) to a certain node (where a 'treasure-box' is located): to demonstrate uninformed search, children wear a special helmet were they can only see the next edge of the graph (see Figure 3.5a,b); children 'programme' a LEGO Mindstorms robot to find a treasure box (traversing a graph from the start node to the goal node): the 'programming' is carried out by putting colored stripes in front of the robot's color sensors (blue - turn right, yellow - turn left, green - move forward to next node);

In sum 24 kindergarten children (average age 5 years; 54% female, 46% male) and 10 school students for kindergarten pedagogy (average age 16 years; all female) participated. Figure 3.5 exemplary shows hands-on activities carried out during the pilot implementation.



(a) children traverse a graph (with helmet) to introduce them to uninformed search (the goal is to find the 'treasure box' node)

(b) drawing of a child describing the blind search ('helmet') activity several days afterwards

(c) children applying the bubble sort algorithm to sort LEGO bricks

(d) graphs and problem solving by search using the *Bee-Bot*

Figure 3.5.: Kindergarten children and school students for kindergarten pedagogy discovering AI topics

Module 2 - Middle School

This module was implemented in form of a summer research week (three days, six hours per day) for middle school students at the university's robotics lab. Basically we followed the structure as described in Section 3.3.1. The following list provides an overview of the tasks and activities.

- Raising a guiding research question: *What does AI have to do with graphs, algorithms, and Google Maps?*
- Motivation, raising awareness for the topics: Students had to navigate to a given location on the university campus using Google Maps as well as a conventional map.
- Graphs/trees and data structures (stack, queue): After providing a short theoretical explanation, students were familiarized with the concept of stack/queue by applying educational games/unplugged exercises (e.g. stacking books, queueing toy cars on a one-way road), group discussions (e.g. *What is a tree in computer science and how can problems be mapped to graphs/trees?*), paper-and-pencil exercises (e.g. given the graphical representation of a maze, construct the corresponding graph) and programming exercises (e.g. implementing the push() and pop() operations in a given software framework).
- Introduction to search algorithms (depth-first (DFS), breadth-first search (BFS)): After an introduction to the theoretical basics of DFS and BFS students completed several paper-and-pencil exercises (investigating both algorithms by following pseudo-code steps given a simplified graph). This unit concluded with a group discussion regarding differences and advantages of those basic search algorithms.
- Intelligent agents: Following a short introduction to the different types of intelligent agents (simple reflex, model-based reflex, goal-based) students' task was to construct a robot equipped with light-, color- and RFID-sensors (using LEGO Mindstorms). This robot was finally used to accomplish the subsequent task:

- Autonomous maze-exploring robot: Students had to programme their robots to explore a small maze (= graph; finding the exit = goal node) by applying different search strategies/algorithms (random search, wall-follow search, depth-first search). The maze consisted of lines of black tape (= edges of the graph) whereas intersection points (= nodes of the graph) were uniquely identified with RFID tags. Students had to evaluate, compare and document their findings for each search algorithm (also see Figure 3.6). The summer research week concluded with a presentation of students' achievements and findings.

In sum 24 school students (8% female, 92% male) with an average age of 12 years participated. Participants were familiar with the graphical LEGO programming language but had no prior knowledge in AI. Since most of the students were not familiar with text-based programming we also gave an introduction to NXC (C based programming language for LEGO Mindstorms robots (NXC, 2016)). Furthermore, we provided students with a framework where all basic robot functionalities (sensor reading, motor control, ...) were already implemented. Therefore students could focus on implementing and testing different search strategies (*random, wall-follow, depth-first search*). Due to lack of time we decided to introduce students to the topics *breadth-first search*, and *queue* by unplugged exercises rather than implementing those concepts in NXC. To foster teamwork, students worked in pairs. Respecting students' attention span those technical sessions were embedded in various other activities (games, sports, short soldering exercises, ...). Figure 3.6 provides exemplary pictures of this pilot implementation.

(a) introduction to search algorithms using simplified graphs (paper-and-pencil, unplugged)

(b) introduction to intelligent agents (LEGO robot equipped with sensors)

(c) programming the robot to explore a maze (applying different search algorithms)

Figure 3.6.: Middle school students implementing and testing different search algorithms for a given graph.

Module 3 - High School

We conducted this pilot implementation as an elective course at a representative high school which integrates robotics in the regular curriculum. The course was held weekly by university researchers and comprised seven teaching units. In sum nine high school students with an average age of 16.5 years (1 female, 8 male) voluntarily participated. They all had prior knowledge in robotics (also in terms of participating in junior robotics competitions) but none in AI. In general we followed the structure defined in Section 3.3.1:

- introduction: group discussion (e.g. requirements of intelligence, Turing test, ...); (Burgsteiner et al., 2016c; Burgsteiner, 2016)
- automata: e.g. defining a finite state machine representing the simplified control of a vending machine and students' competition robots; (Burgsteiner et al., 2016c; Burgsteiner, 2016)
- intelligent agents: e.g. building Braitenberg vehicles (Braitenberg, 1984) using *LEGO Mindstorms NXT* robotics kits; (Burgsteiner et al., 2016c; Burgsteiner, 2016)
- graphs, data structures, problems in AI: e.g. programming a robot to explore a small maze and building the corresponding graph; discussing the well-known vacuum world example from Russell and Norvig (2009); (Burgsteiner et al., 2016c; Burgsteiner, 2016)
- problem solving by search: theoretical input, including group discussion; different classroom stations where students have to find out how BFS, DFS and A* work (paper-and-pencil exercises; also see Figure 3.7); discussing the Romanian street map example from Russell and Norvig (2009) and implementing the A* algorithm in C#; (Burgsteiner et al., 2016c; Burgsteiner, 2016)
- classic planning and logic: e.g. demonstrating first-order logic by discussing the King Richard example from Russell and Norvig (2009); solving a planning problem ('block world') with given initial-/goal-state and actions with pre-/post-condition: in order to simulate the 'computer's view' on this problem and to block out students' common sense the whole problem domain is masked (e.g. substituting the goal state *Have(Bananas)* as *Eahv(Nnaaabs)*); (Burgsteiner et al., 2016c; Burgsteiner, 2016)
- machine learning: presenting the theory behind and showing animations/short videos of the different machine learning approaches; discussing which algorithms would be most suitable for students' junior robotics competition robots; (Burgsteiner et al., 2016c; Burgsteiner, 2016)

Some contents were slightly adapted and put in context with students' background and knowledge in robotics and junior robotics competitions (e.g. using search algorithms to improve the performance of students' competition robots). Further details on the implementation of this module can be found in Burgsteiner et al. (2016b), Burgsteiner (2016) respectively. Figure 3.7 shows, as an example, high school students researching different search algorithms based on a given graph.

Module 4 - University

At university level we have conducted a course on basic AI techniques at the bachelor level for several years. Besides topics such as logic or CSP (constraint satisfaction problem) we focused on the abstract description of dynamic systems like robots in order to allow to plan for this systems or to reason about. For this we use the situation calculus (Reiter, 2001). The advantage of this representation is that it has a strong theoretical foundation based on first order logic and leads to elegant descriptions. Moreover, there is the language *Golog* which is based on the calculus and can directly be used to program agents. The problem of the language and its interpreter is that the theory is quite complex and the tools are very clumsy and counterintuitive. Therefore, in the early stage many students failed in finishing their practical assignment. The two main reasons for that was the Golog interpreter that has no clear syntax and the results of a program run was just printed to a text console.

In order to overcome these problems we developed the new program language *YAGI* (Yet Another Golog Interpreter) that is still based on the concept of the situation calculus but has a clearly defined

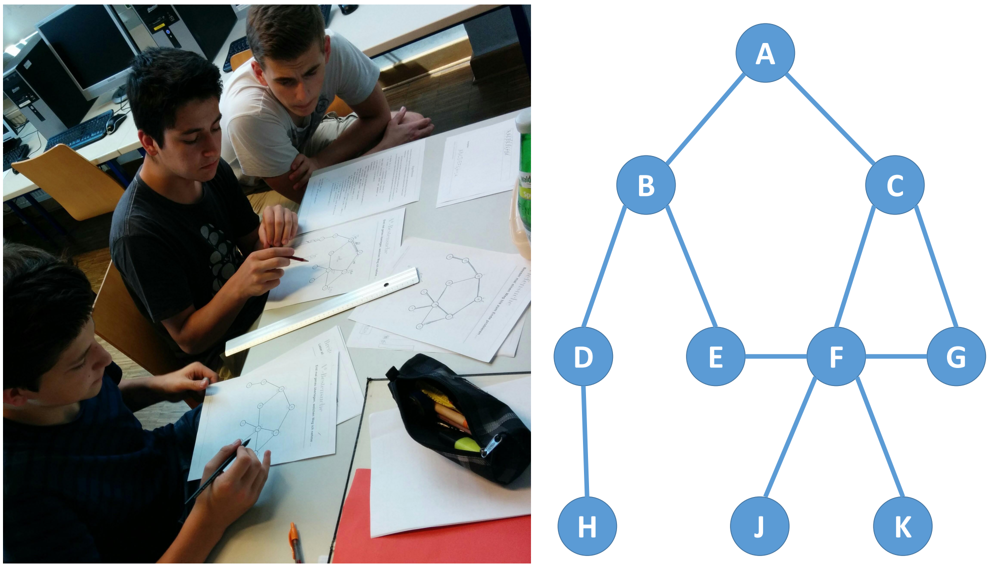


Figure 3.7.: High school students researching the DFS, BFS and A* search algorithm (understanding the algorithm by analyzing source code based on the given graph) (Burgsteiner, 2016)

syntax and semantics and is closer to common programming languages such as C++ (Maier, 2015; Ferrein et al., 2015). Moreover, we developed the general simulation environment ASRAEL (Abstract Simulator for Research and Education in AI) which is based on the game engine *Unity* (Craighead and Murphy, 2007). It allows to control an agent in different environments via a simple socket-based interface. We developed different environments such as the classical wumpus world (Sardina and Vassos, 2005) or a service robot in a kitchen (see Figure 3.8). The simulation can be easily hooked up with different AI systems and allows an appealing and motivating visualization of students' solutions.

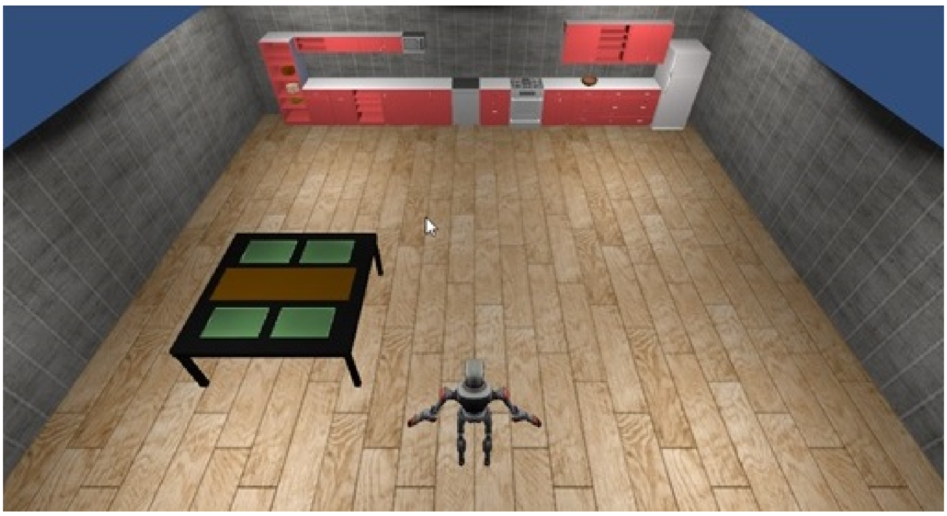


Figure 3.8.: ASRAEL simulation of a service robot in a kitchen (university module).

3.4. Conclusion

Addressing research question Qa_3 (Chapter 1, Section 1.2) this chapter described the methodology (learning methods, goals, structure, content) and proof-of-concept implementations of two innovative educational intervention concepts. Those intervention concepts dealt with the major challenges and open issues regarding educational robotics as a learning tool (research question Qa_1) and education in AI at different educational levels (research question Qa_2) (as discussed in Chapter 2, Section 2.6 as well as in Section 3.1).

Science and technology are developing rapidly. In order prepare children for this development it is important to familiarize them already in kindergarten with science and technology in a playful way. In doing so, the first part of this chapter presented a novel approach for integrating educational robotics in kindergartens. The cross-generational, cross-institutional educational robotics concept combined different robotics platforms and different hands-on activities in order to introduce kindergarten children, school students as well as senior citizens to robotics and computer science. A pilot project was conducted and empirically evaluated. Overall results of an analyses indicate that the defined goals were achieved (for evaluation details see Chapter 4, Section 4.3.1).

Based on the findings and experiences gained from this cross-generational educational robotics concept an advanced AI education concept was developed. AI already plays a major role in our daily life. Profound knowledge about AI and the principles of computer science will be of vast importance for future careers in science and engineering since jobs will largely be related to AI (smart production, internet of things, autonomous driving, robotics, . . .). Nevertheless, teaching fundamental topics of AI and computer science at school or pre-school level hardly exists at the moment. Therefore, in the second part of this chapter an innovative approach of fostering AI literacy by using an analogy with the development of reading/writing literacy was presented. In order to achieve this goal the AI education concept comprises modules for different age groups on different educational levels (kindergarten/primary school, middle school, high school, university). Relevant AI literacy topics, content and structure as well as learning techniques and tools were described. Four proof-of-concept projects were conducted and empirically evaluated focusing on kindergarten, middle school, high school and university. Evaluation results of those pilot implementations for each module indicate that the proposed AI education concept aiming at fostering AI literacy works (for evaluation details see Chapter 4, Section 4.3.2).

The intervention concepts and the pilot implementations presented in this chapter have some limitations and shortcomings and further steps need to be taken. By now no proof-of-concept project was implemented in a primary school (regarding the AI education concept). Therefore, there is no data whether the activities developed for this age group and educational level would work or not. In this context an additional module focusing on primary school children aged between eight and ten years of age has to be implemented and evaluated. The content and topics for middle school students turned out to be too extensive for the short time available. Therefore, this module has to be adapted and could be implemented as part of an elective course in a representative middle school. It has also to be stated that the applied approach of using an analogy with the development of reading/writing literacy (regarding the AI education concept) is only one possibility. Analogies with other literacies (mathematics, science, . . .) might be conceivable as well.

Results and lessons learned from the first proof-of-concept projects form the basis to adapt, improve and extend the intervention concepts, pursuing the long-term goals of establishing science and technology in early years of education and, furthermore, fostering AI literacy.

The next chapter presents a comprehensive empirical evaluation concept (design, methodology, instruments, results) to investigate the impact of educational robotics (education in AI). The next chapter also describes methods, results and limitations of the evaluations conducted in the course of the proof-of-concept implementations of the educational intervention concepts presented in this chapter.

Chapter 4

Empirical Evaluation

Educational robotics has gained increased importance over the last decades. Using robots as a vehicle to interest young people in science and technology and in addition to improve their technical- and social-skills has become a widespread approach in various countries worldwide (TOE, 2013; Kandlhofer et al., 2014; Lammer et al., 2016a). Besides robotics competitions a number of other educational projects and cross-cultural initiatives aim to encourage young people to get involved in science and technology by applying a project-oriented educational robotics approach.

As the review of literature in Chapter 2 revealed one can observe a predominantly positive feedback as well as various stories of success and anecdotes regarding the positive impact of educational robotics. There is the subjective impression by students, teachers, mentors and researchers that this educational approach works well. Although such descriptions are important and provide indications of the powerful potential of educational robotics, it is crucial as well to provide valid information and verifiable data to prove its effectiveness and positive impact. The necessity and importance of a systematic evaluation is stressed in current literature (Barker et al., 2012a). As stated by Cole (2012) there is also a need for investigating the long-term effects of such pedagogical approaches on students' ways through school, college and later careers but relatively few studies investigate this issue (Stubbs et al., 2012). Alimisis (2013) stresses that the impact of the educational robotics approach "needs to be validated through research evidence" (p. 68). Nevertheless, relatively few studies investigate this issue resulting in a lack of systematic empirical evaluations. There is a need for quantitative studies applying a standardized evaluation methodology and a reliable experimental design. Furthermore, hardly any studies exist which focus on the investigation of the impact in terms of the change or improvement of technical- and soft-skills as well as science related attitudes and interests of involved students in an empirical way, covering a wider region, an extended period of time, different age groups and a broad population. (Alimisis, 2013; Barreto and Benitti, 2012; Stubbs et al., 2012; Bredenfeld et al., 2010; Kandlhofer and Steinbauer, 2013).

In order to address these challenges we developed a comprehensive evaluation concept applying a mixed methods research approach (Johnson and Onwuegbuzie, 2004) which comprises both qualitative and quantitative research methods (Kandlhofer and Steinbauer, 2016).

This chapter describes the design and implementation of the entire evaluation concept. Section 2.4 of Chapter 2 already discussed related literature and the theoretical background of empirical evaluation methods as well as particular evaluations and studies conducted in the area of educational robotics. The next section states the relevant main research questions and presents the overall evaluation concept and its components. Sections 4.2, 4.3 and 4.4 describe methodology, instrumentation and implementation of each evaluation component and presents evaluation results and findings. Finally, Section 4.5 summarizes the results and discusses conclusions, shortcomings and potential future work in the context of a comprehensive empirical evaluation of the impact of educational robotics (education in AI, respectively).

4.1. Research Questions and Evaluation Concept

The main purpose of the evaluation concept is to gather valid empirical data and verifiable, solid information regarding the effectiveness as well as the impact of the educational robotics approach on school students of different age. Therefore, the evaluation concept addresses the following detailed research questions (as stated in Chapter 1; research questions Qa_1 - Qa_3 have already been addressed in Chapter 3):

- Qb_1: *What are the motivational factors and inherent values of educational robotics and, furthermore, what is the long-term effect of the involvement in educational robotics activities on the individual career development of school students?*
- Qb_2: *Are the novel educational intervention concepts (cross-generational educational robotics / education in AI) working as expected?*
- Qb_3: *Is there a difference/change in the outcome (compared between before and after participating in educational robotics activities) in terms of technical skills, social aspects and soft skills and science-related attitudes and interests between school students participating in educational robotics activities compared to school students not participating in educational robotics activities?*
  - $\text{Qb}_{3.1}$: *Is there a difference/change in the outcome (compared between before and after participating in educational robotics activities) in terms of technical skills, social aspects and personal interests between young students (up to the age of 12) participating in educational robotics activities compared to young students not participating in educational robotics activities?*
  - $\text{Qb}_{3.2}$: *How do students intending to participate in educational robotics activities differ from students not intending to participate in educational robotics activities in terms of technical skills, social aspects and soft skills, science related attitudes, career and personal interests as well as attitudes towards their teacher?*

In order to deal with those research questions we developed an evaluation concept which relies on a proven, well-grounded methodology respecting general rules of designing evaluations for specific educational programs as discussed in Chapter 2, Section 2.4.1 (Stubbs et al., 2012). Complexity and diversity of the research questions require the use of a broad range of different empirical research techniques and instruments. Therefore, applying a mixed methods research approach, the evaluation concept comprises both qualitative and quantitative research techniques (Johnson and Onwuegbuzie, 2004; Diekmann, 2007; Newman and Benz, 1998). The overall concept is structured as follows (in addition, Figure 4.1 schematically depicts the structure):

- qualitative pre-study addressing research question Qb_1

- qualitative/quantitative evaluation of educational intervention concepts (as described in Chapter 3) addressing research question Qb_2
- quantitative main study addressing research questions Qb_3 and sub-questions $Qb_{3.1}$ and $Qb_{3.2}$

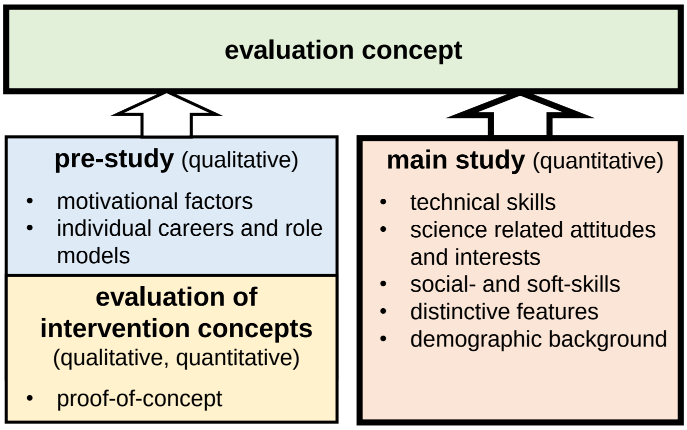


Figure 4.1.: Structure/pillars of the evaluation concept addressing research questions Qb_1 - Qb_3

4.2. Qualitative Pre-Study

As a first step in pursuing the goal of conducting a comprehensive empirical evaluation on the impact of educational robotics on young people a qualitative study has been carried out (research question Qb_1 (Section 4.1)). Therefore, within the scope of this study we aimed at identifying the motivational factors inherent to the educational robotics approach and, furthermore, at the extraction of role models and later careers (long-term aspect) of young people who participated in educational robotics activities. This was accomplished by means of investigating careers and stories of former participants of junior robotics competitions, in particular *RoboCupJunior (RCJ)* (Kandlhofer et al., 2012), (Kandlhofer et al., 2012). The project-based international RCJ initiative has a strong focus on education. School- and undergraduate students up to the age of nineteen are encouraged to get involved in science and engineering. The goal is to improve technical and social skills, to foster teamwork and creativity, as well as to promote international contacts and knowledge exchange (Eguchi et al., 2012). For this pre-study RCJ was chosen due to its long-standing tradition and its big number of participants in the annual national and international competitions as well its well established structures in Austria (a more detailed description of the RoboCupJunior initiative can be found in Chapter 2, Section 2.1.1).

Relatively few studies investigate the effect of robotics programs on students' later careers (Stubbs et al., 2012). Furthermore, most of the available studies seem to look for a proof that a certain educational robotics activity or initiative is successful. Within the scope of this pre-study we applied a different approach. We have decided to regard the perspective that (in this particular case) RCJ as an educational robotics initiative, is successful as a fact, and instead look for the reasons why this is and what the motivational factors (so called 'hooks') behind this initiative are. We see that RCJ fosters not only technical skills, but also management, communication and social skills. Students learn how to handle larger projects, how to work in teams and how to deal with conflicts. We also see how participating in RCJ increases students' self-confidence. Our goal is to find out the reasons for why this is the case and what long-term effect this participation has on students' future careers.

Semi-structured qualitative interviews formed the basis of that evaluation (Wengraf, 2001; Hove and Anda, 2005). We have conducted nine interviews with former RCJ participants. The main goal was to get the stories of their 'RCJ careers' and to find out if their participation in this competition have had any effect on their future development. Especially we wanted to find out if their involvement in this educational robotics activity has raised their interest in technology in general or a technical career in particular. The findings and results as well as the gained expertise and lessons learned from conducting the pre-study formed the basis of the evaluation of intervention concepts (addressing research question Qb_2; Section 4.3) as well as for the development of the quantitative main study (addressing research question Qb_3; Section 4.4).

4.2.1. Methodology

Similar evaluations have also been done in other scientific fields such as sociology, economy, medicine and education in general (e.g. UNICEF (2008), Orpinas et al. (2000), Severson et al. (1997) and Epp (2008)). In these fields there already exists a large amount of knowledge regarding empirical research methods (Borrego et al., 2009; Flick et al., 2004). Therefore, methods applied in those studies and areas were adapted and used for our evaluation attempt. For this pre-study we have conducted nine semi-structured qualitative interviews (Wengraf, 2001) with former RCJ participants. Qualitative research methods have their origin in the field of sociology and anthropology. Conducting interviews is one specific qualitative research technique which is frequently used in the area of psychology, educational science but also empirical software engineering (e.g. conducting case studies). Though, qualitative interviews are rarely used in the field of robotics. Preparing and analyzing semi-structured interviews is a very time consuming and resource demanding data collection technique. However, qualitative interviews provide additional verbal and non-verbal information that could not be obtained by using quantitative methods (for instance, feelings, opinions, moods, facial expressions, discussions, narratives, ...). Furthermore, the open-ended nature provides the interviewer with the possibility to improvise, e.g. by reacting to the interviewee, adding additional questions or delving deeper into certain topics (Hove and Anda, 2005; Stubbs et al., 2012).

The main goal of this qualitative evaluation was to investigate former participants' stories of their 'RCJ careers' and to find out if their participation in RCJ have had any long-term effect on their careers after that. As described by Flick et al. (2004) a list of specific predefined questions acted as a guideline to ensure that important topics were covered during the interview. We put a lot of effort into formulating these questions in an open, none-directional way. The open-ended questions, such as *Do you remember some person, some situation or some activity especially? And why?* not only allowed the discovery of unforeseen information but also enabled the interviewer to deviate from the predefined guideline. Beforehand, interviewees were informed about the general purpose of the interview. The reason for only stating the purpose of the interview at the beginning without providing further information was to avoid influencing or steering the interviewees in a specific direction. Interviewees were also asked to sign an informed consent stating that all collected data were to be treated confidentially, personal information was to be made anonymous and specific statements and stories were to be omitted in future publications and presentations of this data (the latter on request). The informed consent can be found in appendix A.1 (signed consents available upon request). For later analysis all interviews were recorded. As described by Flick et al. (2004) various different methods for analyzing semi-structured qualitative interviews exist. Our approach was to transcribe and afterwards qualitatively analyse the interviews by means of a content analysis in order to identify patterns for RCJ inherent values (Neuendorf, 2002).

Instrumentation

From talking to former RCJ mentors as well as teachers we listed twelve specific questions and several sub-questions to be used if the interviewees not themselves came to talk about all topics we wanted information about. The first questions covered overall information (current educational program, potential work status, background information, ...) as well as information about the first contact with RCJ (when, how, by whom, ...). The second part dealt with questions about the specific activities the interviewee had taken part in, the preparations for a RCJ competition and the competition itself (success, team-members, ...). The third part of the interview encompassed questions regarding positive and negative memories, remarkable situations and/or specific remembered persons during the interviewee's RCJ career. In addition, two specific questions were formulated: *What did you learn?* and *Has RCJ affected somehow what you do today?* We are aware that the two last questions can be seen as too directional. As mentioned in the previous section we wanted to be complete open with our aims in order to allow the discovering of unforeseen information and new insights. After discussing this issue extensively we finally agreed on asking these additional questions only in case the respondents did not already answer them during the interview. Following the entire structure of the applied research instrument.

1. *What are you working/studying/doing today?*
   a) *How do you like that?*
   b) *How did it happen that you are doing that today? What is your educational/working story to where you are today?*
2. *When were you first introduced to RoboCupJunior?*
   a) *What was your impression and what did you know of robots before then?*
   b) *How were you introduced to RoboCupJunior (e.g. school introduction course by RoboCupJunior regional center, teachers in school, ...)?*
3. *What RoboCupJunior activities did you then take part in?*
   a) *Did that change your impression/knowledge of robots? And how?*
4. *What is your overall memory of all your RoboCupJunior activities?*
   a) *What did you learn?*
5. *Do you remember you first RoboCupJunior class?*
   a) *What was your experience then?*
   b) *Did you like everything about it? Or was it something you did not like?*
   c) *What did you like?*
   d) *Do you remember the teacher? Why? What do you remember?*
   e) *Do you remember some situation or some activity especially? And why?*
6. *You then choose to continue with RoboCupJunior, why did you do that?*
7. *From your further RoboCupJunior training, do you remember some person, some situation or some activity especially? And why?*
8. *How do you remember the training you did for the competition?*

   a) *What did you do?*
   b) *What was hard? And what was not so hard?*
   c) *How much time did it take?*
   d) *What was fun about it? Was there something that was not so fun?*
   e) *Was everyone in the team involved?*
   f) *Are you in contact with the others today?*
   g) *Do you know what they do?*
   h) *What was their impression you think?*

9. *And then the actual competition, what is your story there?*
   a) *Where was it? How did you get there?*
   b) *How far in the competition did you get?*
   c) *Did everything work out as it was supposed to?*
   d) *What was fun about it? Was there something that was not so fun?*
   e) *Would everyone in the team tell the same story you think?*
10. *Do you have some bad memories (other than the ones you have already mentioned)?*
11. *Do you have some good memories (other than the ones you have already mentioned)?*
12. *Is it possible to say that your RoboCupJunior activities have affected you long-term somehow? Have they affected somehow what you do today?*

Participants

In order to examine a longer period of time only participants who took part in a RCJ competition before 2009 were contacted. To find such RCJ participants we browsed lists of past national competitions, contacted former teachers, and as well asked schools and organizers of past RCJ events for their help. The people we ended up interviewing in turn provided us with contact information of their former team-mates. It should also be mentioned that all interviewees were immediately willing to participate in this study. The interviews took place between December 2011 and April 2012.

We interviewed nine former RCJ participants (two women, seven men). Five attended the same gymnasium in Graz (hereinafter referred to as *Gymnasium Graz1*), one a different gymnasium, also in Graz (*Gymnasium Graz2*), two a polytechnic high-school in Styria (*Polytechnic Styria*) and one a polytechnic high-school in Lower Austria (*Polytechnic Lower Austria*). At the time of the interviews two of the participants were studying *Telematics* at Graz University of Technology (TUG) (in 4th semester), two *Software Development and Business Management* at TUG (4th and 6th semester), one *Software Information Engineering* at Vienna University of Technology (4th semester), one *Electrical and Audio Engineering* at University of Music and Performing Arts Graz/TUG (6th semester), one *Geomatics Engineering* at TUG (4th semester) and two were studying *Informatics* at TUG (4th, 2nd semester). The nine interviewees were part of five different teams that participated in various national and international competitions from 2008 to 2011. Subsequently we provide a brief introduction of the interviewees and their relationship. In order to ensure anonymity we are using fictive names for both members and teams.

Johanna, *Martin* and *Roland* who all attended *Gymnasium Graz1*, were studying at TUG at the time of the interview. During their RCJ time (2008-2011) they were always part of the same soccer-team (*Team II*). *Verena* and *Simon* attended *Polytechnic Styria* and were studying at TUG as well. At the first competition in 2008 their team (*Team III*) participated in RCJ Rescue. For the 2009 competition they decided to build their own robot from scratch to compete in RCJ Soccer. Members of Team II and Team III know each other from former RCJ competitions. Johanna provided us with contact information to Martin, Roland, Verena and Simon. *Patrick* and *Walter* attended *Gymnasium Graz1* and were studying at TUG at the time of the interview. Their team (*Team I*) took part in four different national and international competitions from 2008 to 2009 (RCJ Soccer). Although they attended the same school like Johanna, Martin and Roland they don't know each other. Together with one friend, *Christian* (*Gymnasium Graz2*, studied at TUG as well) formed *Team IV*. From 2008 to 2010 they competed in RCJ Rescue. There was no relationship between Christian and the other eight interviewees. Finally, *Samuel* took part in various competitions (RCJ Dance) between 2009 and 2010 where he always acted as team captain. He attended *Polytechnic Lower Austria* and was studying at Vienna University of Technology at the time of the interview. Again, there was no relationship to other interviewees. Figure 4.2 outlines interviewees and their relationships, their former RCJ team and school, as well as date and place of the competitions and disciplines they participated in (note: the numbering of teams has no significance). Each circle represents a former RCJ team whereby different frame colors indicate different schools. Touching circles (Team II and III) indicate that their members knew each other and/or did courses together at university at the time of the interview. Arrows pointing from one member to another mean that the 'source-member' provided us with contact details about the 'target-member'.

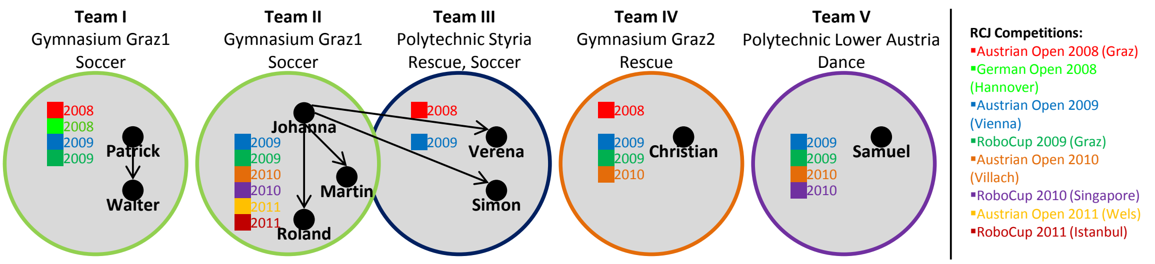


Figure 4.2.: Overview of teams, schools, members, relations, competitions (international and national) as well as disciplines of former RoboCupJunior participants (qualitative pre-study)

4.2.2. Results

All of the interviewees were technically interested (computer science, mathematics, electronics, physics, ...) even before they got involved in educational robotics by means of RCJ. Nevertheless, six of them stated that RCJ was at least one deciding reason for choosing their specific study direction at university. Except Patrick and Samuel none of the interviewees had comprehensive previous experiences in the field of robotics. Before getting in contact with RCJ Patrick already had a LEGO Mindstorms robotics kit and together with a friend he had programmed a chess-robot. Samuel had participated in the *Hexapod* robotics competition (FH Hagenberg, 2010) several times before 2008. Simon stated that he never was very interested in robots before getting involved in RCJ but always enjoyed playing with LEGO. Verena explained that a friend of her told stories about his participation in the Hexapod competition some years before she was introduced to RCJ. Roland only heard about robotics kits using graphical programming languages but he had no practical experience before his first robotics introduction course in school. All nine interviewees were initially introduced to the RCJ initiative by their teachers either by offering optional school subjects and projects or by providing LEGO kits for designing and programming robots during their leisure time.

After analyzing the recorded interviews (as described in section 4.2.1) we identified motivational factors and patterns for RCJ inherent values, which we call *the hooks*. Those hooks could be grouped into three major categories, namely "social experience", "engaged community" and "feelings of success", which will be described in detail in the following subsections.

Social Experience

To take part in a robotics competition like RCJ means many hours of collaborative work. Decisions have to be made, tasks have to be distributed and disputes among the team-members have to be settled. During preparation, the journey to the competition and the actual competition team-members spend a lot of hours together. However, all of the interviewees expressed their positive memories on this. Following a representative quote underpinning this statement.
"Although this was a very time-consuming activity it was the right and a good decision to take part in this robotics activity"[*] - Walter

Interviewees also stressed the special atmosphere and the possibility for socializing during the national and international competitions. Furthermore, competition participants were regarded to be open-minded and helpful, also in sharing their experiences and technical skills among the teams. Johanna mentioned how, unlike the various sports competitions in which she participated as well, the atmosphere at RCJ events is not that competitive, but rather cooperative.
"During school time I also took part in international Judo competitions but I have never seen before such a strongly developed competitive thinking among participants. At RoboCupJunior it is completely different, all the helpfulness and cooperativeness." - Johanna

Patrick enjoyed the long technical discussions with other competitors and the possibility to learn from each other.
"It's good to see that there are a many other people who share the same interests. During the RoboCupJunior competition we learned a lot from other teams." - Patrick

Johanna, Martin and Roland, all members of Team II (*Gymnasium Graz1*) reported that they met every day after school in order to prepare for their first competition. In sum the team took part in six national and international competitions. In the subsequent years they also voluntarily acted as main referees for the national RCJ competitions. At the time of the interviews all three members were studying. They were still friends, met regularly and did common projects together at the university. Similar stories were told by Patrick and Walter. The former members of Team I were still good friends and although their third team-mate was studying at ETH Zurich they managed to meet and discuss their common RCJ experiences several times a year.

Interviewees also mentioned negative memories. For instance, Simon reported various problems within Team III (communication problems, two members were kicked out, the robot did not work at the day of the competition). In contrast though, his team-mate Verena, who acted as project leader, did

[*] All citations were translated to English as all interviews were originally conducted in German.

not mention these issues explicitly. The story she told was much more positive compared to Simon's. Despite their different perspectives at the time of the interviews they were still in touch and were also doing some courses together at the university.

Samuel took part in four RCJ and various other robotics competitions. He talked about his experiences of being a team-captain, about how hard it was to motivate other team members and to delegate work. He also mentioned the problems arising when working together with good friends and described the difficult situation when another team-mate wanted to become captain as well. However, this did not turn him down but instead motivated him to compete again, to recruit new members and to improve his abilities in order to become a better team-leader. After graduating from school Samuel decided to become mentor for RCJ teams at his former school.

In summary, the social experiences described by the interviewees can be categorized into the following components: friendship (meeting after school for preparation, still good friends, working together at university), project management (dealing with problems among members, motivating team-mates, being a captain) and competitions (cooperative atmosphere, discussion with other teams, socializing with students from other countries). We don't claim that the participation in this educational robotics activity is the only reason why people stayed in touch or why interviewees improved their social skills, but all of these examples and stories show that there definitely is a strong social aspect within RCJ: Interviewees worked together preparing *for RCJ*, they took part in *RCJ competitions*, they dealt with controversial issues *within a RCJ team* and they experienced the special atmosphere during a *RCJ tournament*.

Engaged Community

The interviews revealed that the schools can be considered as important part of the engaged community around educational robotics, especially RCJ. The *Gymnasium Graz1* is perhaps the best example of an "engaged community school". It is a very committed school within the RCJ community in Austria. The school integrated educational robotics into the regular curriculum. Furthermore, it provides financial and infrastructural support to student teams. Every year several teams from this school take part in national and international competitions and achieve respectable placements. The school established its robotics courses in 2007 (Patrick's and Walter's class was the first to participate in those courses).

As previously mentioned all interviewees were initially introduced to RCJ by their teachers. There were exclusively positive statements regarding those teachers. Half of the interviewees indicated their former teacher as the most influential person during their RCJ career.
"We had a very dedicated computer science teacher. We learned a lot and he was also the reason why we initially participated in RoboCupJunior." - Verena

As another part of the engaged community we have identified academics/researchers and members of the organizational staff. For Christian the most remarkable person was a specific member of the organizational staff who also acted as trainer and judge in several competitions. Three interviewees indicated a particular university professor as the most memorable person during their RCJ career. They stressed his helpfulness in general, his support during competitions and the good cooperation between him and their former teachers.
"This professor even tried to help us fixing a specific problem at the day of competition." - Simon

Finally, parents need to be mentioned as part of the engaged community. The interviews revealed that parents often provided financial support (e.g. for travelling) and acted as role models. For instance, the fact that his father studied Mechanical Engineering led Walter to choose a technical study as well. Moreover, Verena's father was the main sponsor and supporter of her team. He provided all required hardware to build the robot.

Besides all the positive stories, the interviewees also brought up several negative memories and issues. Samuel, for instance, complained about the lack of coordination between different schools and also the lack of support when organizing journeys to competitions (e.g. flights to the international RoboCup competitions). Although Christian spoke in high terms of his former computer science teacher (*"helpful, enthusiastic, dedicated"*) he criticised the school as such. Initially, he explained, the school was neither interested in Christian's team nor provided any support (for example they were not allowed to use the computer lab). But after the team made it to the finals at RoboCup 2009 this success was communicated as a great achievement of the school. Similarly, Christian and Samuel complained that they were given little support by their school administration (at least the beginning of their RCJ career).

We can see that students need to be supported by an engaged community. But as it appears, difficulties described might have been part of the hook itself. Students developed self-confidence, they felt proud of themselves by succeeding to handle the problems and facing the challenges. This shows that the support provided has to be well balanced so that students get the chance to manage problems and difficulties on their own.

Feelings of Success

Since RCJ and other comparable initiatives are competitions, it is of course also about victories and good placings. But even (from an objective point of view) the placings or performances were not on a top-level, it is the subjective feeling of students that matters. During the interviews we heard various different stories of success. Both Johanna's and Patrick's teams achieved first and second places at national competitions. In addition, to those measurable successes, Patrick mentioned a specific situation during their first participation in 2008. The robot crashed one day before the competition started, thus his team had to work the whole night to fix the problem. It was a great success for them to get the robot moving again and to be able to take part in the competition even if they did not compete very well.
Another example would be Verena: Despite the fact that the robot did not work at the day of the competition she was very proud of their achievement to even build such a complex soccer robot. She also presented this robot at the interview (see Figure 4.3).
Samuel provided a detailed explanation of his robotics activities. Together with some friends he founded the first RCJ team at his school, promoted RCJ in the following years and also gave robotics presentations to students years after he competed in RCJ. For him it was a big success that his achievements and activities have helped to establish RCJ in his old school.
Concluding a representative quote by Martin. His team came in third at RoboCup 2009, which was indeed quite a remarkable placing, and asked for the most memorable success he replied without thinking:
"When we scored our first goal, it was the 1:0, we were overjoyed." - Martin

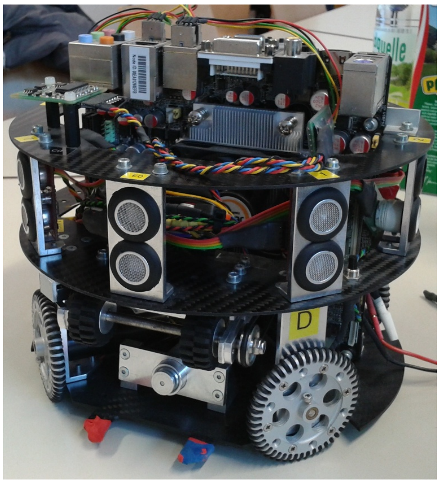


Figure 4.3.: Feelings of success: A RoboCupJunior soccer robot presented by one student during the interview

4.2.3. Summary and Discussion

In this qualitative pre-study we aimed at revealing the values inherent to the educational robotics approach through the example of RoboCupJunior (RCJ). We focused on the extraction of role models and later careers of former participants who attended different schools in Austria and took part in various national and international RCJ competitions between 2008 and 2011. Semi-structured qualitative interviews formed the basis of that evaluation. We conducted nine interviews aiming at identifying the motivational factors ('hooks') that attracted participants as well as investigating their 'RCJ careers'. We did not want to find evidence for RCJ being successful in how it fosters technical, management and other soft skills; we took that as a proven fact and basis for our work. Instead of gathering quantitative performance data we wanted to gather and analyze qualitative data to gain insights in the reoccurring motivational factors.

It is important to point out that this pre-study presents results of nine interviews. The group of interviewees is not representative in any way. We are aware that nine qualitative interviews just provide first hints and preliminary insights to identify the inherent values of an educational robotics approach like RCJ. Nevertheless, as stated by Stubbs et al. (2012) even a small sample size may provide valuable information for this kind of research questions.

All of the respondents did have a positive opinion towards educational robotics and RCJ and were interested in robotics also after their participation in RCJ. However, it is crucial as well to investigate also negative examples (e.g. students who were not influenced by their involvement in educational robotics activities in their future careers, and/or have negative attitudes towards educational robotics/RCJ).

It is not sufficient to only know that an educational robotics approach like RCJ is successful for students and undergraduates, but why. There is also a need for more long-term evaluation in the area of educational robotics in order to improve pedagogical approaches. In this regard a series of follow-up studies, such as ethnographic studies of the teachers, content-related analysis of the teaching material and a long-term shadowing study of selected students from different age ranges need to be conducted. These follow-up studies would also ease the limitations of the study presented in this section, such as the small number of interviewees, which all had successful RCJ experiences. Moreover, it would be interesting to see if the now observed trend that students keep their social network, which they established through the RCJ initiative, for their later career as science and technology student, is reported also by other students.

Looking at the findings of this first evaluation we can say that all interviewees were enthusiastically talking about their robotics activities within the context of RCJ. Many of them competed for years and later all of them continued in science and engineering studies. Furthermore, many former team members were still friends and worked together at university or meet in leisure time. Even if none of the teams reached top placements at the competitions they were proud of their achievements. With regard to research question Qb_1 results of this pre-study show that RCJ as an educational robotics approach generates three important motivational factors (inherent values, so called 'the hooks') namely the *social experience* (friends, teamwork and international contacts), the *engaged community* (schools, motivating teachers, academics and family) and the *feelings of success* (personal development, competition placements and positive memories). Regarding the nine interviewees there is an obvious positive relationship between their educational robotics/RCJ experiences and their later careers. Several of them kept involved in RCJ, either as mentor or judge. All of them pursued science and engineering related studies at different Austrian universities. Two also continued in the major level of RoboCup, playing a leading role in a successful RoboCup Rescue team. Furthermore, both of them already finished their bachelor and master theses in the area of robotics and entered the professional life or started a Ph.D. respectively.

The findings and results as well as the gained expertise and lessons learned from this pre-study also form the basis for a) the evaluation of intervention concepts (addressing research question Qb_2 as discussed in the following section) and b) build the foundation for the development of the quantitative main study (addressing research question Qb_3 as described in Section 4.4). Finally, the findings of this pre-study are also used to improve and extend the support actions for schools and students (as presented in Chapter 2, Section 2.1) provided by the university in order to attract more students to engineering and scientific education. Furthermore, we are as well convinced that the 'hooks' also could be applied on other topics and teaching activities.

4.3. Evaluation of Intervention Concepts

Chapter 3 described the development and implementation two novel educational intervention concepts.The first concept (Section 3.2) focused on a cross-generational aspect (kindergarten children, school students, senior citizens) in order to familiarize the target audience, in particular pre-school children and school students, with science and technology using different robotics platforms as pedagogical tools. The second concept (Section 3.3) dealt with the development and implementation of a concept to familiarize different age groups on different educational levels (from kindergarten to university) with fundamental topics of artificial intelligence (AI).

Addressing research question Qb_2 (Section 4.1) this evaluation investigates whether those intervention concepts work as expected and whether the goals of each concept were achieved during the pilot implementations. In general the applied evaluation methodology follows a qualitative approach but comprises quantitative elements as well.

4.3.1. Pre-School Educational Robotics in a Cross-Generational Context

The main focus of this evaluation was on the investigation of the learning effects and the medium-term impact of the pilot project on participating school students and kindergarten children (the pilot project was implemented in terms of a scientific project day). We conducted semi-structured qualitative interviews with school students who guided the hands-on activities during the pilot implementation in order to collect empirical data as well as to get positive and negative feedback. To obtain information about the medium-term impact and the learning effects the interviews took place around six months after the project day. The interviews were conducted directly at the school. Seven out of ten school students voluntarily agreed on participating in this study. In addition, to gather further qualitative data we applied passive and active techniques of participant observation.

Methodology

We applied the qualitative research technique of semi-structured interviewing as described in Section 4.2.1. Based on the observations made during the pilot implementation and discussions with teachers and pedagogues a set of questions, acting as a guideline during the interview, was designed. It was essential that those questions were formulated in an open-ended, non-directional way in order to avoid influencing interviewees' answers (Flick et al., 2004).

The introductory questions dealt with background information (grade, favorite school subject, ...), information about the specific task performed at the project day as well as prior knowledge or experiences in the field of robotics. The main part dealt with students' experiences during the project day (working with kindergarten children, acting as guide, conducting and explaining activities, memorable situations) followed by questions asking for improvement suggestions and further experiences in the field of robotics made after the project day. The final question posed (only in case the interviewees did not already provide an answer) dealt with lessons learned from the students' point of view. Following an overview of the guiding questions[†].

1. *Which grade do you attend?*
    a) *What is your favorite subject in school?*
2. *What was your task during the project day?*
    a) *Why did you choose this task?*
3. *What did you know of robots before you participated in this project?*
4. *Please describe your experiences during the project.*
    a) *Did everything work out as it was supposed to (conducting and explaining activities, acting as a guide)?*
5. *How was the cooperation with the kindergarten children?*
    a) *Where the children interested in the activities? Did they actively participate?*
6. *How was the cooperation with the senior citizens?*
7. *Do you remember some situation or some activity especially? And why?*

[†]All questions were translated to English since all interviews were originally conducted in German.

8. *What would you change on the next robotics project?*
9. *Did you make any experiences in the field of robotics after the project?*
10. *What did you learn within the scope of this robotics project?*

For later analyses all interviews were audio recorded. For the analysis of qualitative data various different techniques could be applied (as described in Section 4.2.1). Our approach was to transcribe all recorded interviews, to summarize inherent quantitative data and finally to perform a content analysis (Neuendorf, 2002). Prior to the interview, students were asked for their permission to record the conversation. Furthermore, students' parents were asked to sign informed consents describing the main purpose and the procedure of the interview as well as stating legal and ethical aspects (for a template consent see appendix A.2; signed consents available upon request). All collected data was treated confidentially and personal information was made anonymous.

In order to collect qualitative data directly at the robotics day, techniques of participant observation were applied (Jorgensen, 1989). We used both passive as well as active participation methods (field notes, informal interviews, discussions). In addition, we also took pictures and videotaped the experiments. Considering ethical and legal aspects all collected data was treated confidentially. Beforehand parents were informed and asked for their permission to take pictures and to videotape experiments.

Findings

We interviewed seven students (four girls, three boys) aged from eleven to thirteen at the time of the interview. They all had basic knowledge of computers since the school provides one hour of computer science every two weeks. Three students stated that they had previous experience with robot toys, one boy reported that he once watched a friend working with a LEGO Mindstorms robot and one girl already attended a LEGO Mindstorms robotics workshop in primary school. The other two students never had anything to do with robotics.

As described in Chapter 3, Section 3.2 students participated in a preparation workshop. Basically they could decide themselves which activity to guide during the project day. Most students chose activities which seem to fit their personal interests and talents. For instance, one student interested in sports and physical education insisted on guiding a robot-dance experimentation station. Another student, who is a very talented speaker, decided for the Bee-Bot station where it was her task to retell a fairy tale while providing explanations on how to program the robot. Only one student reported that his robot was *"too complicated to handle"* and questions asked by visitors were *"too tricky"*. Asked for the topic and name of his station, the student had to think for a while until he could remember. It finally turned out that this student's task was assigned by the teacher instead of chosen voluntarily.

Students also talked about their most memorable situations and experiences. One student, for instance, highlighted the special situation when he was controlling the humanoid dancing robot in front of a big audience. Similarly, two students talked about the joy of slipping into the part of a teacher, *"explaining things to little kids"*. Another student mentioned the great feeling of success when she illustrated the functioning of the robot to a girl from Romania which did not speak German at all[‡]. Two students also remembered negative experiences (issues with a troubled kindergarten child; difficult technical questions by one visitor; being afraid to provide explanations in English).

[‡]In this context it is important to mention that the native language of the participants (students, children, teachers, senior citizens) was German since the project day took place in Austria.

One aim of this qualitative evaluation was to find out what interviewees actually think about lessons learned and knowledge gained. Following a brief overview of students' statements:

- kindergarten children understood the functioning of the different robots very fast
- robotics is fascinating but it is much harder than expected that robots actually do what programmers want them to do
- many different robotics platforms and types of robots exist
- constructing and programming of robots mean a lot of work
- teamwork is important if you want to construct and program a robot
- the robotics project was an opportunity to improve English and presentation skills
- programs have to be written first and afterwards transferred to the robot

In sum all seven students were enthusiastic about their participation in the robotics project. Suggestions for improvement included the integration of one or two *"bigger robots with arms and legs or tracks"*. The overall feedback was mainly positive although interviewees also mentioned some problems and challenges during the robotics day (e.g. jamming robot gearwheels, unexpected robot behavior, being nervous while speaking in front of an audience, providing explanations in English, tricky questions, troubles with difficult children). However, students pointed out the 'positive feeling' after handling these issues successfully (either on their own or by asking for assistance). During the interviews they still talked about 'their' robot and 'their' experimentation station, even half a year later. Based on those statements and on the observations made during the interviews it could be concluded that students, despite problems and some negative experiences, were satisfied and felt proud of their achievements and that they identified with the chosen task and robots.

The interviews also revealed that the cross-generational concept worked out well. Although one of the interviewees complained about very complicated questions asked by senior citizens all other students said that is was great fun to carry out robotics experiments together with pre-school children and their grandparents. Kindergarten children were fascinated by the robots, asked a lot and even tried to programme robots (especially the Bee-Bot) on their own. This shows that robotics was the perfect common topic for all involved age groups and that it has great potential to bring together kindergarten children, school students and senior citizens. This is supported by findings of videos, pictures and field notes analysis.

Students' statements and stories told indicate that both students and kindergarten children gained various technical and social skills during the robotics project. Furthermore, it is also worth mentioning that three months after the project all ten students who guided the experiments, decided to attend an advanced robotics workshop at university. In addition, the robotics project formed the basis for follow-up activities at the kindergarten (educational games, Bee-Bot exercises,... guided by kindergarten pedagogues) in order to deepen what children have seen and experienced.

Next to this qualitative evaluation we also obtained qualitative feedback from kindergarten pedagogues, grandparents, parents and pre-school children. In sum the feedback was mainly positive. For instance, some parents reported that both children and their grandparents were motivated to build robots on their own after participating in the robotics project day. One teacher told about a child with special needs which also participated in the robotics day. The day after both the child's occupational therapist and its psychologist noticed a significant improvement of its behavior. In addition, kindergarten pedagogues reported that children were very enthusiastic about their first 'robotics experience'. Months later, they were still talking about the robots, asking *"when they would return"*.

4.3.2. Education in Artificial Intelligence

The aim of this evaluation was to gather empirical data to investigate whether the overall AI education concept (as described in Chapter 3, Section 3.3) works and whether each of the modules (kindergarten, middle school, high school, university) achieved its goals within the context of first proof-of-concept implementations.

Methodology

To evaluate the modules with respect to the diverse target audience (age group, educational level) mainly qualitative but also quantitative reliable research methods were applied (Diekmann, 2007). In order to collect qualitative data we applied techniques of participant observation using both passive and active participation methods such as field notes, discussions and informal interviews (Jorgensen, 1989) but also interpretation of children's drawings (Anning and Ring, 2004). Furthermore, we applied the technique of conducting semi-structured interviews using a set of predefined questions as guideline (Hove and Anda, 2005) as described in Section 4.2.1. A content analysis (Neuendorf, 2002) was performed after transcribing all recorded interviews and summarizing inherent quantitative data. In addition, we also took pictures and made videos during each pilot implementation. Applying a grounded theory approach we collected and afterwards analyzed the collected qualitative data using open and selective coding (Virnes and Sutinen, 2009; Corbin and Strauss, 2014). In terms of quantitative evaluation we applied paper-and-pencil questionnaires (3- and 5-point Likert scale, open ended and multiple choice questions (MCQ)), self- and foreign-evaluation of acquired skills (Mabe and West, 1982) as well as feedback questionnaires. The questions were selected in order to provide feedback on content, structure, teaching style and presentation of topics. For each module and each age group appropriate evaluation methods were applied. Considering ethical and legal aspects all collected data were treated confidentially and personal information was made anonymous (Kandlhofer et al., 2016b; Burgsteiner et al., 2016c).

Findings

This sub-section describes the evaluation implementation and results separately for each pilot module (kindergarten, middle school, high school, university). In addition, the table in Figure 4.4 provides an overview of goals and topics of each module in relation to the evaluation results. For a detailed description of goals, topics and implementation of the modules please refer to Chapter 3, Sections 3.3.1 and 3.3.2).

Module 1 - Kindergarten This module was implemented in a kindergarten in terms of a scientific project. Analysis of collected data (mainly qualitative) indicate that our goal of introducing kindergarten children to fundamental AI/computer science topics in a playful way worked well. Video data, pictures and observations (field notes) during the project day indicate that children a) joyfully explored the different units and b) understood the (simplified) AI concepts and carried out most of the activities in each unit correctly. Qualitative interviews with pedagogy school students and kindergarten pedagogues support these observations. For instance, after a short explanation/demonstration kindergarten children were able to sort LEGO bricks using the bubble sort algorithm. Some of the children were even able to explain the algorithm to other children afterwards (see Figure 3.5c).

In addition, we asked the children several days after the project day to draw pictures of their most memorable unit. Interpreting drawings is a well-known approach to assess the learning success of young children (Anning and Ring, 2004). It turned out that children draw pictures of robots traversing graphs and finding ways out of labyrinths. For instance, Figure 3.5a shows a child traversing a graph applying a blind search approach in order to find a certain goal node (where a 'treasure box' was located). This child's drawing (Figure 3.5b) several days afterwards clearly depicts the graph, the 'robot' as well as the goal node with the 'treasure box'. The findings of the drawing interpretations underpin the results of the qualitative data analysis.

Module 2 - Middle School This module was implemented in form of a summer research week (three days, six hours per day) for middle school students at the university's robotics lab. To evaluate this module on a broad basis we collected data from several sources applying various evaluation techniques:

- assessing students' prior knowledge (group discussion)
- foreign-evaluation of skills (13 item MCQ post-questionnaire; e.g. *"What are the characteristics of depth-first search?"*)
- field notes (participant observation)
- pictures and videos taken during the week
- students' feedback and self-evaluation post-questionnaire (3-point Likert scale; e.g. *"How would you rate your knowledge about search algorithms?"*)
- students' solutions of the tasks (implemented programs)
- students' documentations (results of their experiments investigating different search algorithms / strategies)
- students' final presentation of their work at the end of the week

Summarizing the results of the data analysis the objectives of this module have partly been met. On the one hand students got a basic understanding of graphs, trees and data structures (stack, queue) as well as of different search strategies and their characteristics (pros, cons). This is documented by the post-questionnaire, observations, students' documentations, program code and final presentations. According to the feedback questionnaire and our observations, students were enthusiastic and liked the tasks, which they described as challenging but not too difficult. On the other hand it turned out that students had problems to understand the connection between the basic AI concepts and their application (e.g. in navigation systems, or *Google Maps*). The reason might be that, due to a lack of programming experience and a lack of time, students were too focused on the programming task rather than making connections and seeing the overall picture. Therefore, we either have to reduce the programming effort as well as the amount of topics addressed or we have to provide more time (e.g. by increasing the number of days/hours available for working on the tasks).

Module 3 - High School We conducted this pilot implementation as an elective course (seven units; two hours per week) at a representative high school. The evaluation of this pilot implementation was done applying following research techniques:

- self-evaluation of skills post-questionnaire (3-point Likert scale; e.g. *"I am able to explain the principles of the A* search algorithm"*)

- feedback questionnaire on teaching style and structure of the units (open ended and 5-point Likert scale questions; e.g. *"Contents were prepared and explained in a clear and understandable manner"*)
- collecting qualitative data by means of participant observation and by taking pictures and field notes during each teaching unit
- semi-structured qualitative interviews with each of the high school students (structured around the topics *background* (technical/educational background, prior knowledge), *motivation* (reasons for voluntarily participating in the project), *expectations* (prior and after the project), memorable experiences (AI topics covered, situations, lessons learned) as well as general *feedback*; respecting legal aspects students signed informed consents to give their approval for the interview - see appendix A.3 (signed consents available upon request))

Summarizing the evaluation results, the pilot implementation succeeded in familiarizing high school students with a broad range of fundamental AI topics. Results indicate that students got a well-founded understanding of almost all AI literacy topics (as defined in Section 3.3.1 of Chapter 3) except for some sub-topics (architectures for agents, propositional logic). Here additional input or help would be necessary. According to students' self-evaluation they had a very positive feeling about their gained knowledge.

Although students had partly different expectations prior to the course they finally were motivated and enjoyed learning and applying fundamental AI techniques. Their main motives for participating in the project were interest in robotics, computers and AI as well as the possibility to prepare for science studies at university. In sum they provided overall positive ratings on structure and teaching style of the course. Finally, students will benefit from the acquired content in future (e.g. participating in robotics competitions, writing final high school theses, starting engineer or science studies at university) (Burgsteiner et al., 2016b; Burgsteiner, 2016).

Module 4 - University At university level we have conducted a course on basic AI techniques at the bachelor level for several years. Usually there are around hundred students attending this course every year. Due to a quite complex theory and clumsy, counterintuitive tools, in previous years many students failed in finishing their practical assignment. By using motivational hands-on exercises (controlling an agent in an environment and a teaching vehicle that is much handier but still focuses on the basic concepts of the situation calculus) almost all students now successfully complete the course. Based on students' practical assignments (correctness, completeness, ...) and discussions during and after the lectures it can be stated that students have a deeper understanding of AI topics on a higher abstraction level by successfully completing this course.

4.3.3. Summary and Discussion

Addressing the main research question Qb_2 (Section 4.1) this evaluation investigated two newly developed intervention concepts (cross-generational educational robotics and education in artificial intelligence as described in Chapter 3).

The evaluation of the first concept dealing with pre-school educational robotics in a cross-generational context comprised semi-structured qualitative interviews as well as passive and active participant observations, informal interviews, field notes and discussions. Qualitative data showed that kindergarten

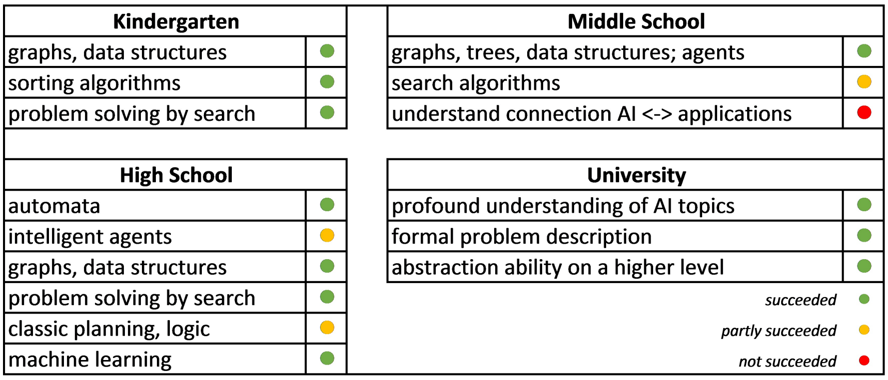


Figure 4.4.: Overview of goals and topics covered in each module in relation to evaluation results (regarding success in reaching the goals of each module)

children were familiarized with science and technology in a playful and sustainable way (follow-up activities in kindergarten, children talking and asking questions about the robots months afterwards), were actively involved in the hands-on activities (e.g. programming the Bee-Bot, interacting with the robots, asking and being excited about the robots) and interacted with school students and senior citizens in the sense of an education partnership. The analyses of the semi-structured interviews with school students revealed that both students and kindergarten children gained various technical and social skills during the robotics project (e.g. learning basics of programming and robotics, improving English and presentation skills, recognition of the difficulty of programming robots and the necessity of applying teamwork, discovering that children understand the functioning of robots quite fast, ...). Students, despite problems and some negative experiences, were satisfied and felt proud of their achievements and they identified with 'their' task and 'their' robot during the project day. The results of this investigation indicate that using robots as a pedagogical tool by applying a cross-generational, cross-institutional approach could be one successful way to introduce pre-school children and in parallel also school students and senior citizens to robotics and computer science.

The evaluation of the second concept focusing on education in artificial intelligence on different age- and educational levels comprised qualitative (participant observation, field notes, discussions, informal and semi-structured interviews, drawing interpretations) but also quantitative research methods (open ended and multiple choice questions, self- and foreign-evaluation of acquired skills, feedback questionnaires). Evaluation results of the pilot implementations for each module indicate that the proposed AI education concept aiming at fostering AI literacy works (also see the overview table in Figure 4.4). The proof-of-concept implementation in a representative kindergarten (in form of a project day) showed that children (average age 5 years) explored fundamental AI topics in a playful way and understood the (simplified) AI concepts. The module for middle school students (average age 12 years) was implemented as a research week at university. Results of this pilot project indicate that, on the one hand, students got a basic understanding (theory plus practical implementation) of basic AI/computer science topics but, on the other hand, had problems to understand the connection between the basic AI concepts and their application in real life (e.g. in navigation systems). The content and topics turned out to be too extensive for the short time available. The module for high school students (average age 16.5 years) was implemented as a weekly elective course in a representative high school. Results show that after completing the course students were familiar with a broad range of fundamental AI topics and got a well-founded understanding of all AI literacy topics. At university level a course on basic AI techniques was conducted for several years. By applying new learning tools and motivational hands-on exercises almost all students now successfully complete the course.

Summarizing the evaluation results after analyzing all gathered data we can conclude that the novel intervention concepts presented in Chapter 3 are working as expected. Within the context of first proof-of-concept implementations we showed that both intervention concepts achieved almost all of their goals (referring to research question Qb_2). Nevertheless, due to the relatively small sample of participants in the pilot implementation of each intervention concept, evaluation results only provide preliminary insights and first hints. In order provide additional, sound underlying data documenting the success of both concepts, further implementations and more detailed quantitative evaluations in different kindergartens, schools and universities are necessary. Certain modules of the AI education concept (i.e. university) also require a more detailed evaluation (questionnaire, self-evaluation, quantitative feedback). To gather valid long-term data we would also have to follow a group of students participating in the entire program (from kindergarten to university).

After addressing research question Qb_1 in the previous section and research question Qb_2 in this section the next section focuses on investigating the main research question Qb_3 (Section 4.1) by describing and discussing the development, implementation and results of an extensive study to evaluate the impact of educational robotics on students in a quantitative way.

4.4. Quantitative Main Study

Addressing the main research question Qb_3 (see Section 4.1) the basic aim of this quantitative research is to evaluate the impact of educational robotics on students' technical- and social-skills and the impact on students' attitudes and interests towards science and technology. The conducted study relies on a well-grounded empirical methodology encompassing pre- and post-tests using a quasi-experimental two-group design. This means the study comprises *experimental-group* and *control-group* as well as two measurement points (in commonly literature referred to as *pre-test* and *post-test* (Diekmann, 2007; Barreto and Benitti, 2012; Bortz and Döring, 2006; Trochim et al., 2015)). At each measurement point study participants completed a multiple choice questionnaire. The assessment instrument was a student questionnaire based on different already proven assessment tools and survey instruments which have been validated and/or applied and tested in previous studies, theses and investigations (Nugent et al., 2010; Jomento-Cruz, 2010; Dagienė and Futschek, 2008; University of Waterloo, 2013; Austrian Computer Society (OCG), 2013; OECD, 2006; Clark, 2004; Fraser, 1981; Hansen and McNeal, 1997).

Basically the quantitative main study was divided into two stages (stage I, stage II). Stage I addressing main research question Qb_3, covered a period of approximately eight months and comprised students from different types of secondary schools in various Austrian regions. Robotics in education, and RoboCupJunior (RCJ) in particular, is well established in Austria (see Chapter 2, Section 2.1.1). A large number of schools have integrated robotics in their curriculum and participate in national and international RCJ competitions on a regular basis (Hofmann and Steinbauer, 2010; Kandlhofer and Steinbauer, 2013). In order to obtain results also in an international context the same study was carried out simultaneously in a selected school in Sweden. Pre-tests started in autumn 2013, post-tests were completed in June 2014. Using sound statistical methods data were analyzed around 14 different topics (so called 'sub-scales') arranged in three main categories (so called 'main-scales') related to technical- and soft-skills as well as attitudes and interests towards science and social aspects.

After applying the overall evaluation design and instrumentation within the context of stage I, stage II of the quantitative main study, addressing sub-questions $Qb_{3.1}$ and $Qb_{3.2}$ started in autumn 2014. On the one hand stage II of the study encompassed the evaluation of the impact of educational robotics on young school students up to the age of twelve (sub-research question $Qb_{3.1}$). Therefore, another evaluation instrument focusing on those students was compiled and a pilot study was conducted in two selected middle schools.

On the other hand stage II focused on the investigation of distinctive features between experimental- and control-group students (sub-research question $Qb_{3.2}$). It comprised participants from different types of secondary schools in eight different countries worldwide (Europe, Asia, Australia). Therefore, based on the findings and lessons learned from stage I of the study, the assessment instrument was adapted, extended and translated into the respective languages.

By applying this widespread, mid-term approach we aim to gather solid and valuable empirical data on the impact of educational robotics on participating students on a large geographical- and age-scale. Finally, the evaluation concept and instrumentation developed for this quantitative main study can be applied to evaluate other initiatives and projects as well (Kandlhofer and Steinbauer, 2016).

4.4.1. Methodology

Research Questions and Hypotheses

The main purpose of this study was to investigate the impact of educational robotics on young students' technical and social skills. Furthermore, the study intended to determine the effects of educational robotics activities on students' attitudes and interests towards science, technology and social aspects. In this context we aimed to determine differences between students participating in robotics activities compared to students not participating in robotics activities. In doing so, the study investigated the following main research question Q_3 and its two sub-research questions $Qb_{3.1}$ and $Qb_{3.2}$:

- Qb_3: *Is there a difference/change in the outcome (compared between before and after participating in educational robotics activities) in terms of technical skills, social aspects and soft skills and science-related attitudes and interests between school students participating in educational robotics activities compared to school students not participating in educational robotics activities?*
  - $Qb_{3.1}$: *Is there a difference/change in the outcome (compared between before and after participating in educational robotics activities) in terms of technical skills, social aspects and personal interests between young students (up to the age of 12) participating in educational robotics activities compared to young students not participating in educational robotics activities?*
  - $Qb_{3.2}$: *How do students intending to participate in educational robotics activities differ from students not intending to participate in educational robotics activities in terms of technical skills, social aspects and soft skills, science related attitudes, career and personal interests as well as attitudes towards their teacher?*

Based on this research questions the following two main hypotheses (H_1, H_2) and four sub-research hypotheses (H_3 - H_6) were deduced and investigated within the scope of this quantitative study:

* ***$H_{1\ Qb3}$*** : Educational robotics has a significant positive impact on students' performance in different separate topics regarding technical- and soft-skills and social-aspects as well as on students' attitudes and interests towards science.

* ***$H_{2\ Qb3}$*** : Educational robotics has a significant positive impact on students' performance (technical-, soft-skills) and attitudes and interests (towards science, social-aspects) regarding a group of related topics. §

- ***$H_{3\ Qb3.1}$***: Educational robotics has a significant positive impact on young school students' performance regarding technical skills and on their attitudes towards social aspects.

- ***$H_{4\ Qb3.1}$***: Educational robotics has a significant impact on the change of young school students' personal interests.

- ***$H_{5\ Qb3.2}$***: Significant distinctive features exist between students intending to participate in educational robotics activities and students not intending to participate in educational robotics activities in terms of technical skills, social aspects and soft skills and science related attitudes.

- ***$H_{6\ Qb3.2}$***: Significant distinctive features exist between students intending to participate in educational robotics activities and students not intending to participate in educational robotics activities in terms of career interests, personal interests as well as attitudes towards their teacher.

Study Design and Research Approach

The study relied on a quasi-experimental two-group design including pre- and post-tests (Barreto and Benitti, 2012; Diekmann, 2007; Bortz and Döring, 2006; Kandlhofer and Steinbauer, 2013; Griffith, 2005; Trochim et al., 2015). Study participants were divided into experimental group (EG) and control group (CG). The EG consisted of students who participated in robotics activities for the first time whereas the CG comprised students who actually did not participate in those robotics activities. Students in EG and CG shared comparable demographic attributes (e.g. age, school level, social and educational background). Students in CG attended comparable subjects and activities (e.g. they participated in regular computer science courses)

For this study we cooperated with schools and educational institutions that regularly take part in annual national or international junior robotics competitions (e.g. RoboCupJunior (RCJ), FIRST Lego League (FLL), ...) or offer regular robotics courses or elective subjects during the semester. In this context the RoboCup initiative (RoboCup, 2016) eased the access to schools and mentors in order to recruit participants. National RCJ representatives as well as schools, mentors and teachers were contacted via email, Skype, newsletter, mailing lists but also in person and directly at robotics competitions (a sample information sheet for attracting schools/educational institutions can be found in appendix A.4).

Teachers at each participating school were finally asked to recruit students for EG and CG matching following criteria:

- **experimental group EG**: Students preparing for a junior robotics competition or attending a robotics course, a robotics elective, a robotics project or a regular robotics club (collectively referred to as 'robotics activities') for the first time.

§ *Group of related topics* means content-related topics; for instance a group of topics related to programming, mathematics and robotics, a group of topics related to attitudes towards science and a group of topics related to social aspects;

- **control group CG**: Students from the same school and around the same age (ideally also from the same class) as students from EG but currently not participating (also not participated in the past) in any of these robotics activities.

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 were compared between EG and CG. The instrument used in this regard was a multiple choice questionnaire comprising different already proven survey assessment tools (details see following Sections). At each school responsible teachers organized and monitored the study conducting. To ensure the same conditions across all participating schools a step-by-step manual, containing detailed instructions regarding preparation, recruiting, implementation and next steps, was provided to those teachers prior to the start of the study. The manual was translated into multiple languages, the English version can be found in appendix A.5 (versions in different languages available upon request).

Table 4.1 schematically depicts the study design. To measure study participants' base level both experimental- and control-group (EG, CG) did the pre-test (O_1, O_3) in autumn (t_1), right before the intervention for EG (robotics activities during the semester; indicated as X) started. Post-tests for EG and CG (O_2, O_4) were conduced approximately eight months after the pre-tests (by middle of the following year). In addition, Figure 4.5 graphically illustrates the overall study approach.

	$\mathbf{t}_1$		$\mathbf{t}_2$	$t_{[1,2]}$...*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)*

Table 4.1.: Study design

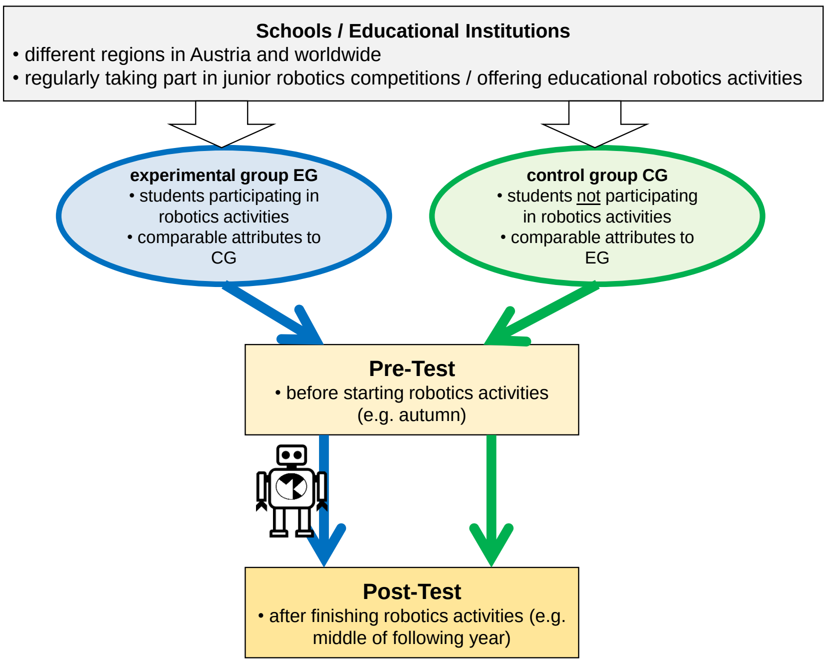


Figure 4.5.: Overall study approach

The overall evaluation design and the applied survey instruments were initially presented and discussed at the *Workshop on Educational Robotics* (Kandlhofer and Steinbauer, 2013) within the scope of the RoboCup Symposium in July 2013. The feedback from experts in the field of educational robotics and national RoboCupJunior representatives was considered at the development of the detailed study design. Preliminary findings, first experiences as well as the applied survey instruments were presented and discussed at the international conference *Robotics in Education (RiE)* in June 2014 (Kandlhofer and Steinbauer, 2014). This feedback was considered in the adaptation of the survey instruments for stage II of the study.

Respecting legal and ethical requirements all collected information was treated confidentially and personal data was made anonymous for further investigations and publications. Participating students, their parents as well as school administrations and/or mentors were asked to sign informed consents stating the purpose and explaining the procedure prior to the start of the study. Again, all documents were translated into multiple languages (the English versions can be found in appendix A.6; the signed consents as well as versions in different languages are available upon request). Finally, the whole study approach was reviewed and approved by the Commission for Scientific Integrity and Ethics at Graz University of Technology (see appendix A.7).

Study Stages

In general this quantitative study was divided into two main stages, entitled **Stage I** and **Stage II**. Stage I, which addresses main research question Qb_3 (hypotheses H_1, H_2), comprised students from different types of secondary schools in Austria and one selected school in Sweden. Pre-tests started in autumn 2013, post-tests were completed in June 2014. The overall evaluation design and instruments were applied within the context of stage I of the study.

Stage II, addressing sub-research questions $Qb_{3.1}$ and $Qb_{3.2}$ (hypotheses H_3 - H_6) started in autumn 2014 and was completed in June 2015. It encompassed the evaluation of the impact of educational robotics on young school students (sub-research question $Qb_{3.1}$) as well as the investigation of distinctive features between experimental- and control-group students (sub-research question $Qb_{3.2}$). School students of selected middle schools as well as secondary schools in different countries worldwide participated in stage II of the quantitative study. Based on the findings and lessons learned from stage I, assessment instruments were adapted and extended for stage II.

The following sections describe instrumentations, statistical analyses and results with respect to stage I and stage II.

4.4.2. Instrumentation Stage I

The main instrument for assessing technical and social skills as well as science and technology related attitudes and interests (addressing **main research question Qb_3, hypotheses H_1, H_2**; Section 4.4.1) was a 129 item student questionnaire separated in several sub-sections (also referred to as ’sub-scales’). This questionnaire combined different standardized assessment tools as well as survey instruments which have been validated and/or applied and tested in previous studies and theses (Nugent et al., 2010; Jomento-Cruz, 2010; Dagienė and Futschek, 2008; University of Waterloo, 2013; Austrian Computer Society (OCG), 2013; OECD, 2006; Clark, 2004; Fraser, 1981; Hansen and McNeal, 1997). 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 (see appendix

A.11). In addition to the skill-/attitude-sections the questionnaire contained several items (partly multiple choice, partly open-ended questions) dealing with demographic background information of study participants as well as a feedback part in the concluding section.

The process of developing the questionnaire was done in cooperation with experts in the field of psychology and sociology respecting general rules of questionnaire-designing (Schreiner and Sjoberg, 2004; Diekmann, 2007; Bortz and Döring, 2006; Bühner, M., 2011). The instrument ran through reliability analyses and several refinement- and improvement-steps (review by experts in educational robotics; review and discussion within the scope of the *Workshop on Educational Robotics* (Kandlhofer and Steinbauer, 2013) and the conference on *Robotics in Education* (Kandlhofer and Steinbauer, 2014); review by pedagogues and teachers as well as experts in robotics; test run with high school students).

In order to conduct the survey in different countries, the questionnaire (initially in English) was translated by native speakers, working together with national RCJ representatives. To allow a convenient data collection from geographically distributed study participants the on-line survey tool *SurveyMonkey* (Symonds, 2011) was used. Therefore, teachers and mentors responsible for conducting the study at the different locations got a link to the questionnaire several days prior to the pre- and post-tests.

The questionnaire, comprising instruments with multiple choice (MCQ) and Likert-scale questions Diekmann (2007); Griffith (2005), was structured around the main sections *Demographic and background information*, *Technical skills*, *Science related attitudes and interests*, *Social- and soft-skills* and *Feedback*. Reliability analyses of applied instruments showed high Cronbach's Alpha reliabilities (technical skills: 0.85; science related attitudes/interests: 0.94; social-/soft skills: 0.89) (Bortz and Döring, 2006; Biddix, 2016). Each main section of the questionnaire was divided into several subsections where questions were sorted in ascending order of difficulty level (Kandlhofer and Steinbauer, 2014). The entire questionnaire (English version) can be found in appendix A.8, further versions in German, Swedish and Slovene are available upon request. Following an overview of the applied questionnaire (main sections are numbered I-V, sub-sections are itemized using dots):

I **Demographic and background information** (14 items; MCQ/open-ended questions)

- **student alias**: information for matching pre- and post-test and ensuring anonymity (*"Create a 'new' word using following rules: Write down the first two letters of your mother's first name, write down the first two letters of your first name, write down the first two letters of your father's first name, write down the last two numbers of the year of your birth"*)
- **group classification**: experimental group, control group
- **confounding factors**: previous knowledge in robotics and programming (questions regarding previous involvements in robotics activities and experiences with graphical and/or textual programming languages)
- **statistical/background information**: age, gender, school, language, grade-level, prior knowledge in robotics/programming

II **Technical skills** (37 items; MCQ)

- **T_1 general programming/robotics** (*4-H Robotics Questionnaire* (Nugent et al., 2010)): basic knowledge of robotics and general programming; analyzing programs; finding mistakes and providing solutions; (e.g. *"What is a computer program?"; "What helps a robot to explore its environment?"*)

- T_2 **computer science** (*Beaver Computing Challenge* (Dagienė and Futschek, 2008; University of Waterloo, 2013; Austrian Computer Society (OCG), 2013)): keeping track of states; fundamentals of algorithms; abstraction; encoding; pointers and references; linking; (e.g. following an algorithm and analyzing different solutions by answering a 'boat navigation' question: *"Which of the following routes to the goal avoids the islands using the smallest number of steps?"*)
- T_3 **textual programming** (*Programming Skills MCQ* (Clark, 2004)): tracing/analyzing code; loops; ability to write programs; (e.g. *"What is the value of variable 'm' after the code fragment above is executed?"*)
- T_4 **mathematics/scientific investigation** (*4-H Robotics Questionnaire, PISA released items, science questionnaire* (Nugent et al., 2010; Jomento-Cruz, 2010; OECD, 2006)): fraction/ratio; converting units; uncertainty/likelihood; controlling scientific experiments; constructing/interpreting graphical representations; relationship between input and output; comparing graphs; (e.g. *"According to the distance vs. time graph above, which conclusions about the car's motion is supported?"; "Which math formula would help you know how far a car would go if the wheel (diameter 38 cm) turned one time?"*)

III **Science related attitudes and interests** (50 items; 5-point Likert scale questions; *TOSRA** (Fraser, 1981))

- A_1 **attitude to scientific inquiry** (e.g. *"I would prefer to find out why something happens by doing an experiment than by being told."*)
- A_2 **adoption of scientific attitudes** (e.g. *"I like to listen to people whose opinions are different from mine."*)
- A_3 **enjoyment of science lessons** (e.g. *"I look forward to science lessons."*)
- A_4 **leisure interest in science** (e.g. *"I would like to be given a science book or a piece of scientific equipment as a present."*)
- A_5 **career interest in science** (e.g. *"A job as a scientist would be interesting."*)

IV **Social- and soft-skills** (23 items; 4-and 5-point Likert scale questions)

- S_1 **self-efficacy in robotics** (*4-H Robotics Questionnaire* (Nugent et al., 2010)): 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.")*
- S_2 **problem solving** (*4-H Robotics Questionnaire* (Nugent et al., 2010)): self-evaluation regarding problem solving approaches (e.g. *"I use a step by step process to solve problems.")*
- S_3 **teamwork attitudes** (*4-H Robotics Questionnaire* (Nugent et al., 2010)): 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."*)
- S_4 **social skills** (*Social Skill Scale* (Hansen and McNeal, 1997)): ability to get along with other people (e.g. *"If I want my friends to go along with me, I know what to say to them.")*
- S_5 **goal-setting skills** (*Goal Setting Skill Scale* (Hansen and McNeal, 1997)): directing an effort to achieve a desired result (e.g. *"Once I set a goal, I do not give up until I achieve it."*)

V **Feedback** (5 items; MCQ/Likert scale, open-ended)

- overall feedback on the questionnaire: difficulty, length, clarity, further comments; (e.g.*"Rate the overall difficulty of the questions."*)

TOSRA (Test of Science-Related Attitudes): The multidimensional instrument was developed by Fraser (1981). It has been extensively tested and applied in various different studies in the field of science education research (Welch, 2010; Jewell, 2011). 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."; "A job as a scientist would be interesting"*) whereby each sub-scale can be scored separately.

4.4.3. Instrumentation Stage II

Sub-research question $Qb_{3.1}$ (hypotheses H_3, H_4) (Section 4.4.1): This question dealt with the evaluation of the impact of educational robotics on young school students (up to the age of 12). Stage I of the study revealed that the 129 item student questionnaire was too long and too difficult for school students of that age. Therefore, a 19 item assessment instrument based on already applied/tested instruments (Dagienė and Futschek, 2008; University of Waterloo, 2013; Austrian Computer Society (OCG), 2013; Hansen and McNeal, 1997; OECD, 2009) was compiled. In addition, the questionnaire contained several items (multiple choice, open-ended questions) dealing with demographic background information of study participants as well as a feedback part in the concluding section. The whole questionnaire was reviewed by pedagogues and teachers and pilot tests with middle school students were conducted.

The instrument comprised MCQ and Likert-scale questions and was structured around the main sections *Demographic and background information*, *Technical skills* (computer science), *Social skills*, *Personal interests* and *Feedback*. Questions were sorted in ascending order of difficulty level. The entire questionnaire (English version) can be found in appendix A.9, the German version is available upon request. Following an overview of the applied questionnaire:

I **Demographic and background information** (6 items; MCQ/open-ended questions)

- student alias, group classification, confounding factors, background and statistical information

II **Technical skills** (5 items; MCQ)

- **T_m computer science** (*Beaver Computing Challenge* (Dagienė and Futschek, 2008; University of Waterloo, 2013; Austrian Computer Society (OCG), 2013)): concepts of data structures (graphs, trees), automata, principles of algorithms and programming languages;

III **Social skills** (5 items; 4-point Likert scale questions)

- **S_m social skills** (*Social Skill Scale* (Hansen and McNeal, 1997)): ability to get along with other people (e.g. *"If I want my friends to go along with me, I know what to say to them."*)

IV **Personal interests** (5-point Likert scale questions)

- **I_m personal interests** (*PISA Pupil Questionnaire* (OECD, 2009)): Students rate their personal interest regarding nine different categories (e.g. *"Working with machines or technical equipment", "Investigating how things work", "Learning a foreign language", . . .*)

V **Feedback** (2 items; MCQ/Likert scale, open-ended)

- feedback on difficulty, further comments;

Sub-research question $Qb_{3.2}$ (hypotheses H_5, H_6) (Section 4.4.1): The instrument for assessing distinctive features between experimental- and control-group students (secondary school) was a slightly adapted version of the student questionnaire applied in stage I. Due to the findings of stage I some parts of the questionnaire were adapted and shortened. In particular, several sub-scales of the TOSRA section were omitted since the analyses of the feedback of stage I showed that this section comprised too many questions and therefore completing the questionnaire took too long. In return, new sections dealing with students' career and personal interests as well as their attitudes towards their teachers were added. In sum the questionnaire comprised 90 items. The entire questionnaire (English version) can be found in appendix A.10, further versions in German, Chinese, Japanese, Croatian and Slovene were compiled and are available upon request. Following an overview of the main- (numbered I-VI) and sub-sections (itemized using dots). For a detailed explanation of the topics/contents please refer to the description of the instrumentation applied in stage I (section 4.4.2).

I **Demographic and background information** (14 items; MCQ/open-ended questions)

- student alias, group classification, confounding factors, background and statistical information

II **Technical skills** (35 items; MCQ)

- **T_1 general programming/robotics** (*4-H Robotics Questionnaire* (Nugent et al., 2010))
- **T_2 textual programming** (*Programming Skills MCQ* (Clark, 2004))
- **T_3 computer science** (*Beaver Computing Challenge* (Dagienė and Futschek, 2008; University of Waterloo, 2013; Austrian Computer Society (OCG), 2013))
- **T_4 mathematics/scientific investigation** (*4-H Robotics Questionnaire, PISA released items, science questionnaire* (Nugent et al., 2010; Jomento-Cruz, 2010; OECD, 2006))

III **Science related attitudes and interests** (10 items; 5-point Likert scale questions; *TOSRA* (Fraser, 1981))

- **A_1 attitude to scientific inquiry**

IV **Social- and soft-skills** (23 items; 4-and 5-point Likert scale questions)

- **S_1 self-efficacy in robotics** (*4-H Robotics Questionnaire* (Nugent et al., 2010))
- **S_2 problem solving** (*4-H Robotics Questionnaire* (Nugent et al., 2010))
- **S_3 teamwork attitudes** (*4-H Robotics Questionnaire* (Nugent et al., 2010))
- **S_4 social skills** (*Social Skill Scale* (Hansen and McNeal, 1997))
- **S_5 goal-setting skills** (*Goal Setting Skill Scale* (Hansen and McNeal, 1997))

V **Career-, personal-interests and attitudes towards teacher** (3 items; 4- and 5-point Likert scale questions)

- **I_1 career interests** (based on *Career Scale* by Griffith (2005)): Students rate their interest (5-point Likert) in different fields regarding possible future careers (e.g. engineering, entertainment, media, computers, science, law, ...)

- I_2 **personal interests** (*PISA Pupil Questionnaire* (OECD, 2009)): Students rate their personal interest regarding different activities (using 5-point Likert: e.g. *"Working with machines or technical equipment", "Investigating how things work", ...*)
- I_3 **attitudes towards the teacher** (*Student-Teacher Quality Scale* (Gruehn, 2000)): The scale measures the motivation ability in education (using 4-point Likert: e.g. *"Our teacher ...often organizes the lessons in an exciting way."*)

VI **Feedback** (5 items; MCQ/Likert scale, open-ended)

- overall feedback on the questionnaire: difficulty, length, clarity, further comments;

4.4.4. Statistical Methods

Stage I The analysis addressing **main research question *Qb*$_3$ (hypotheses H_1, H_2**) (see Section 4.4.1) was done applying *repeated-measures MANOVA* (multivariate analysis of variance) (Mayers, 2013; Meyers et al., 2013; O'Brian and Kaiser, 1985; Delisle et al., 2010). Repeated-measures MANOVA is a well-grounded statistical procedure which investigates the outcomes from several dependent variables *dV* (measured over multiple time points) across two or more independent variables *iV*. MANOVA was chosen because the research question focused on whether the change in the outcome differed in the two groups (experimental- and control-group) between two measurement points (pre-, post-test) (*time*group interaction*).

Within the context of this study we analyzed the gathered data as follows: Type of group (iV_1; experimental group, control group) and time point (iV_2; pre-test, post-test) were used as the two independent variables. Scores of the different sub-scales were used as dependent variables $dV_1..dV_{14}$. Repeated measures MANOVA was used to analyze univariate effects (significant differences for each of the sub-scales separately) as well as multivariate effects (significant differences for the main categories).

The level of significance (p-value) was analyzed for the established alpha level of 0.05 (this means that a value of $p < 0.05$ was considered statistically significant). In order to ensure that assumptions for MANOVA have been met, following steps were taken: ensuring correlation between dependent variables (correlation should be between -0.40 and 0.90); ensuring between-group homogeneity of variance across groups for dependent variables using Levene's test (significance should be greater than 0.05); ensuring homogeneity of variance-covariance matrices using Box's M test (significance should be greater than 0.001) (Mayers, 2013). In addition to MANOVA a correlation analysis (Bortz and Döring, 2006) was applied to measure the relationship between dependent variables.

The gathered data were analyzed around the following 14 different sub-scales:

- T_1 general programming/robotics, T_2 computer science, T_3 textual programming, T_4 mathematics/scientific investigation;
- A_1 attitude to scientific inquiry, A_2 adoption of scientific attitudes, A_3 enjoyment of science lessons, A_4 leisure interest in science, A_5 career interest in science;
- S_1 self-efficacy in robotics, S_2 problem solving, S_3 teamwork attitudes, S_4 social skills, S_5 goal-setting skills;

Those sub-scales were grouped into the following three main categories in order to investigate multivariate effects:

- *technical skills* (T_1 - T_4)
- *science related attitudes/interests* (A_1 - A_5)
- *social aspects/soft skills* (S_1 - S_5)

In addition to MANOVA a correlation analysis calculating *Pearson's correlation coefficient r* (Bortz and Döring, 2006) was applied to measure the relationship between dependent variables. This statistical analysis was applied in order to reveal relevant highly significant ($0.3 < r < 0.82; p < 0.01$) linear correlations between the different sub-scales.

The entire statistical analysis (in stage I and II) was done using the standard software package *SPSS* (Ho, 2006; Eckstein, 2013).

Stage II **Sub-research question $Qb_{3.1}$ (hypotheses H_3, H_4)**: *Repeated-measures MANOVA* (as described above) was used to analyze the change in the outcome of young school students in experimental- and control-group (EG, CG) between pre- and post-test regarding technical- and social-skills (independent variables: iV_1 (EG, CG); iV_2 (pre-test, post-test); dependent variables: dV_1 (mean of technical skills T_m); dV_2 (mean of social skills S_m)).

Analyses of covariance (ANCOVA) was used to determine whether the post-test means of the personal interest scales (dependent variables) for the two groups (EG, CG) differed significantly when the influence of correlated variables (pre-test means of personal interest scales) was controlled. ANCOVA is a well-grounded statistical method which explores outcomes in consideration of additional variables (so called 'covariates') which may have an influence on this outcome. It is commonly used in pre/post designs whereby pre-test scores serve as covariates (Mayers, 2013; Welch, 2010). Following configuration has been used in this analysis: independent variable iV (EG, CG); dependent variables $dV_1..dV_9$ (post-test means of interest scales); covariates $cV_1..cV_9$ (pre-test means of interest scales). The level of significance (p-value) was analyzed for the established alpha level of 0.05. Analyses in order to ensure that the homogeneity of slopes assumption have been met were conducted for each of the dependent variables.

Sub-research question $Qb_{3.2}$ (hypotheses H_5, H_6): *One-way multivariate analyses of variance (MANOVA)* was applied to determine differences between EG and CG in terms of technical skills, science related attitudes and social aspects/soft skills. One-way MANOVA is used when there are two or more dependent variables and one independent variable (Mayers, 2013). Since this sub-research question focuses on determining differences of students before actually starting an intervention, type of group was used as single independent variable iV (EG, CG). Scores of the different sub-scales were used as dependent variables $dV_1..dV_{10}$. The gathered data were analyzed around the following 10 different sub-scales:

- T_1 general programming/robotics, T_2 textual programming, T_3 computer science, T_4 mathematics/scientific investigation;
- A_1 attitude to scientific inquiry
- S_1 self-efficacy in robotics, S_2 problem solving, S_3 teamwork attitudes, S_4 social skills, S_5 goal-setting skills;

Those sub-scales were grouped into the following two main categories for the investigation of multivariate effects:

- *technical skills* (T_1 - T_4)

- *science related attitudes and soft skills* (A_1, S_1 - S_5)

One-way MANOVA was also applied to determine differences between EG and CG (independent variable iV) in terms of career and personal interests and in terms of attitudes towards teachers. The data was analyzed around the following three main categories

- I_1 career interests (dependent variables $dV_1..dV_{12}$: means of 12 career sub-scales)
- I_2 personal interests ($dV_1..dV_9$: means of 9 interests sub-scales)
- I_3 attitudes towards the teacher ($dV_1..dV_5$: means of 5 teacher sub-scales)

In addition, a correlation analysis calculating *Pearson's correlation coefficient r* was applied to investigate possible relations between technical- and soft-skill means and attitudes towards the teacher. This analysis was applied in order to reveal relevant statistically highly significant ($0.2 < r < 0.8; p < 0.01$) linear correlations.

4.4.5. Results Stage I (main research question *Qb*$_3$)

Participants and Interventions

In total 148 students who completed the pre-test also completed the post-test (40% female, 57% male, 3% not stated; experimental group EG: 66 students, control group CG: 82 students). Initially 242 students completed the pre-test which results in a participation rate of 61.2% (students aged between 9 and 11 who did the pre-test skipped the post-test due to the high degree of difficulty of the questions). The mean age of students was 14.9 years (81.8% aged 12-16, 18.2% aged 17-19). Students came from nine different schools of different types whereby eight schools were located in different urban, suburban and rural regions across Austria and one school was located in an urban region in Sweden. Types of schools ranged from secondary polytechnic, secondary modern school, secondary school of higher education in economy and tourism as well as high schools and junior high schools. Figure 4.6 provides an overview of participants' demographic background.

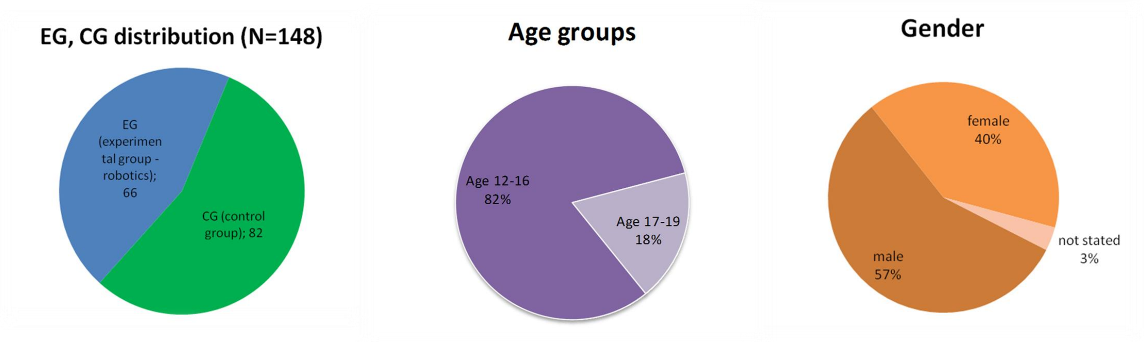


Figure 4.6.: Stage I study participants: EG/CG distribution, age groups and gender distribution

The intervention (referred to as 'robotics activities'; see Section 4.4.1) mainly comprised activities in order to prepare for a national RoboCupJunior (RCJ) competition (around 85% of students in EG). In this context students in EG attended weekly robotics courses, elective subjects or projects at school. There the focus was on building and programming robots for the RCJ disciplines *Dance* (58.9%), *Rescue* (28.6%), *Soccer*(8.9%) and *CoSpace*(3.6%) (for a more detailed description of all disciplines please refer to Chapter 2, Section 2.1.1). The remaining 15% of students in the experimental group participated in weekly robotics elective subjects at school where they were introduced to robotics and programming using the LEGO Mindstorms NXT platform (Kim and Jeon, 2007).

Students in the control group (CG) were from the same class/the same school level as students in the experimental group. Students in CG attended comparable subjects and activities, i.e. they participated in regular computer science courses (on average one hour a week), in computer science electives and/or elective courses in media informatics, physics, chemistry or arts. The learning activities of the control group slightly differed between the different participating schools. In principle those activities comprised working with current application software (e.g. word-/image-processing software), creating web-sites (using Javascript), getting familiar with computer hardware and software, doing online research as well as preparing and presenting reports using new media resources (e.g. tablets, PowerPoint presentations, email). Furthermore, 32.9% of the students in CG were also concerned with textual programming (20.7%; using for example C#, C++,...) and/or graphical programming (12.2%; using for example Scratch,...) mainly by attending computer science electives.

Mean Scores

A comparison of mean scores for each sub-scale indicated that students in the experimental group (EG) basically had higher pre- and post-test scores compared to students in the control group (CG). Figure 4.7 provides an overview of pre- and post-test mean scores (scaled to 100%) for all 14 sub-scales, separated by group (light blue bars indicate pre-test scores of EG, dark blue bars indicate post-test scores of EG; light green bars indicate pre-test scores of CG, dark green bars indicate post-test scores of CG). Depending on the sub-scale EG and CG showed different rates of improvement between pre- and post-test.

Univariate and Multivariate Outcomes

According to Mayers (2013) and Delisle et al. (2010) repeated measures MANOVA was used to determine statistically significant differences (intervention effects) between experimental- and control-group (EG, CG) and between pre- and post-test. In this context univariate as well as multivariate outcomes were analyzed (independent variables *iV*: group (EG/CG), time point (pre-/post-test); dependent variables *dV*: scores of 14 sub-scales).

Univariate analyses were performed in order to investigate statistically significant changes for each of the 14 sub-scales separately. The interaction between time point and group was statistically significant (indicating a positive intervention effect) for the following three sub-scales:

- **T_4 mathematics and scientific investigation** ($F_{1,146}$=5.595, p=0.019). Topics covered by this sub-scale (multiple choice questions): fraction and ratio, converting units, uncertainty and likelihood, controlling scientific experiments, constructing and interpreting graphical representations, relationship of input and output, comparing graphs of acceleration and deceleration (Nugent et al., 2010; Jomento-Cruz, 2010; OECD, 2006). Figure 4.8 shows the pre- and post-test mean scores (scaled to 1.0) of EG and CG (left image) as well as the improvement between pre- and post-test of EG and CG (right image). Students in EG (robotics group) had higher pre-

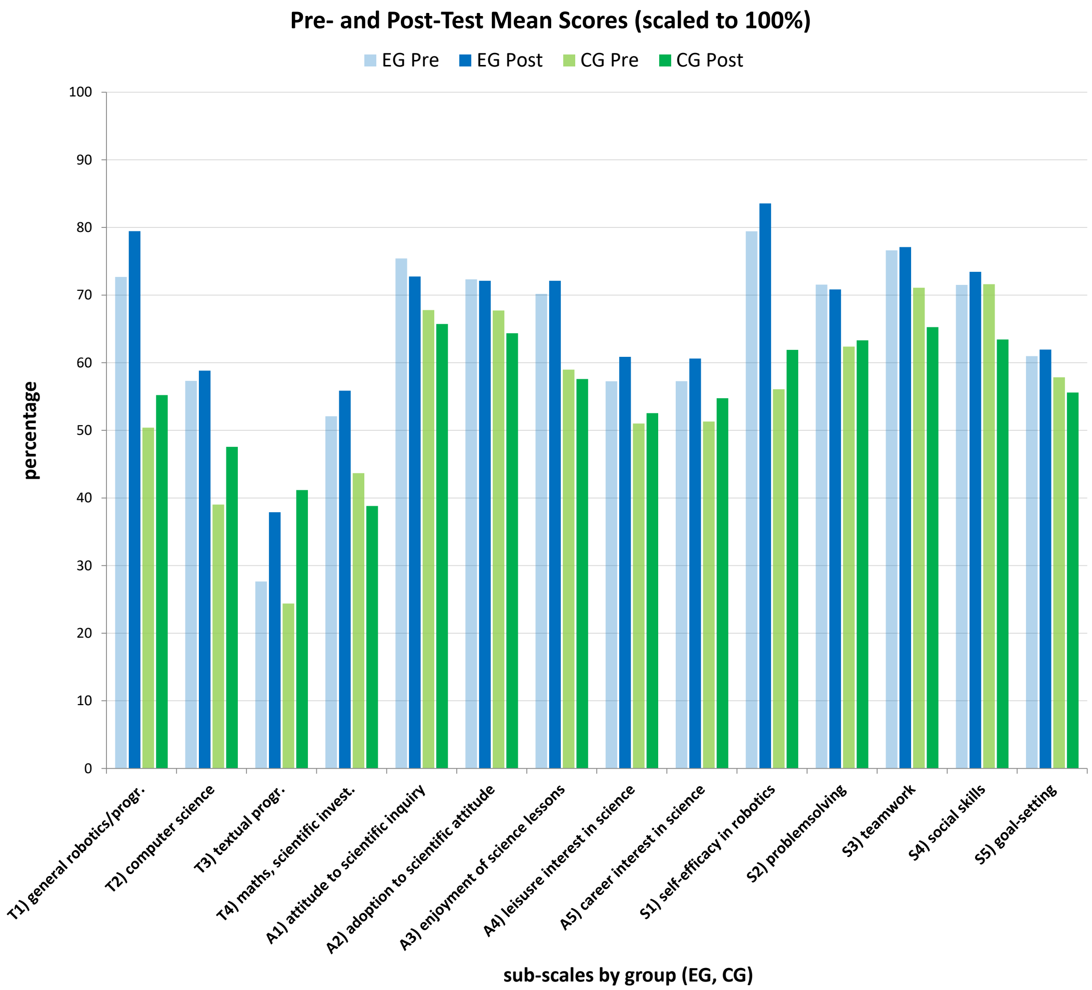


Figure 4.7.: Stage I: Mean scores for all 14 sub-scales separated by EG, CG (scaled to 100%)

and post-test mean scores compared to students in CG. Furthermore, students in EG showed an improvement whereas students in CG showed a decline between pre- and post-test (detailed output of repeated measures MANOVA analysis for this sub-scale available upon request)

- S_3 **teamwork attitudes** ($F_{1,134}$=4.463, p=0.036). The scale focused on students' attitudes regarding working together with other people (5-point Likert scale questions: 1..strongly disagree, 2..disagree, 3..uncertain, 4..agree, 5..strongly agree) (Nugent et al., 2010). A comparison of pre- and post-test attitude means (scaled to 5.0) indicated that students in EG had higher pre- and post-test means compared to students in CG (Figure 4.9, left image). Students in EG showed a more positive attitude regarding teamwork at the post-test (towards 'agree') than at the pre-test. In contrary, students in CG showed a less positive attitude (towards 'uncertain') at the post-test than at the pre-test (Figure 4.9, right image) (detailed output of repeated measures MANOVA analysis for this sub-scale available upon request)
- S_4 **social skills** ($F_{1,134}$=9.708, p=0.002). The scale focused on students' ability to get along with other people (4-point Likert scale questions: 0..strongly disagree, 1..disagree, 2..agree,

3..strongly agree) (Hansen and McNeal, 1997). A comparison of pre- and post-test attitude means (scaled to 3.0) indicated that students in EG had slightly lower pre-test means but higher post-test means compared to students in CG (Figure 4.10, left image). Students in EG showed a more positive attitude at the post-test than at the pre-test (from 'agree' tending to 'strongly agree'). Students in CG showed a less positive attitude (from 'agree' tending to 'disagree') at the post-test than at the pre-test (Figure 4.10, right image) (detailed output of repeated measures MANOVA analysis for this sub-scale available upon request)

Multivariate analyses of the three main-scales (sub-scales grouped by related topics) showed significant multivariate effects for the interaction between time point and group for two of the main-scales. This indicates a significant difference (=positive intervention effect) between EG and CG for the following main-scales:

- **technical skills** ($F_{4,143}$=2.701, p=0.033). Sub-scales grouped within this main-scale: T_1 general programming/robotics, T_2 computer science, T_3 textual programming, T_4 mathematics/scientific investigation;
- **social aspects/soft skills** ($F_{5,130}$=3.403, p=0.006). Sub-scales grouped within this main-scale: S_1 self-efficacy in robotics, S_2 problem solving, S_3 teamwork attitudes, S_4 social skills, S_5 goal-setting skills;

The diagram in Figure 4.11 shows the summarized mean scores (scaled to 100%) of all three main-scales (*technical skills*, *science related attitudes and interests, social aspects/soft skills*). Main-scales for which significant differences were found during the multivariate analyses are highlighted in red.

The table in Figure 4.12 provides an overview of statistically significant results of univariate and multivariate MANOVA analyses.

Correlations

Correlation analysis calculating *Pearson's correlation coefficient r* (Bortz and Döring, 2006) revealed a number of highly significant (strong/moderate) positive relations between various sub-scales. This means that students who show high scores in one sub-scale also show high scores in the related sub-scale (in this context it is important to mention that a correlation analysis measures linear correlations, not causal relationships). Relevant highly significant relations ($0.3 < r < 0.82; p < 0.01$) were found between 39 sub-scales for experimental group (EG), compared to only 18 sub-scales for control group (CG). The diagrams in Figure 4.13 provide an overview of all highly significant (strong/moderate) relationships between sub-scales for EG and CG (highlighted in blue, green respectively). It can be seen that there are various relevant positive correlations which only occur for students involved in robotics activities (EG). For instance, (amongst others), between the following sub-scales:

- computer science (T_2) and textual programming (T_3)
- general programming/robotics (T_1) and self-efficacy in robotics (S_1)
- general programming/robotics (T_1) and problem-solving (S_2)
- general programming/robotics (T_1) and teamwork (S_3)
- adoption of scientific attitudes (A_2) and general programming/robotics (T_1)

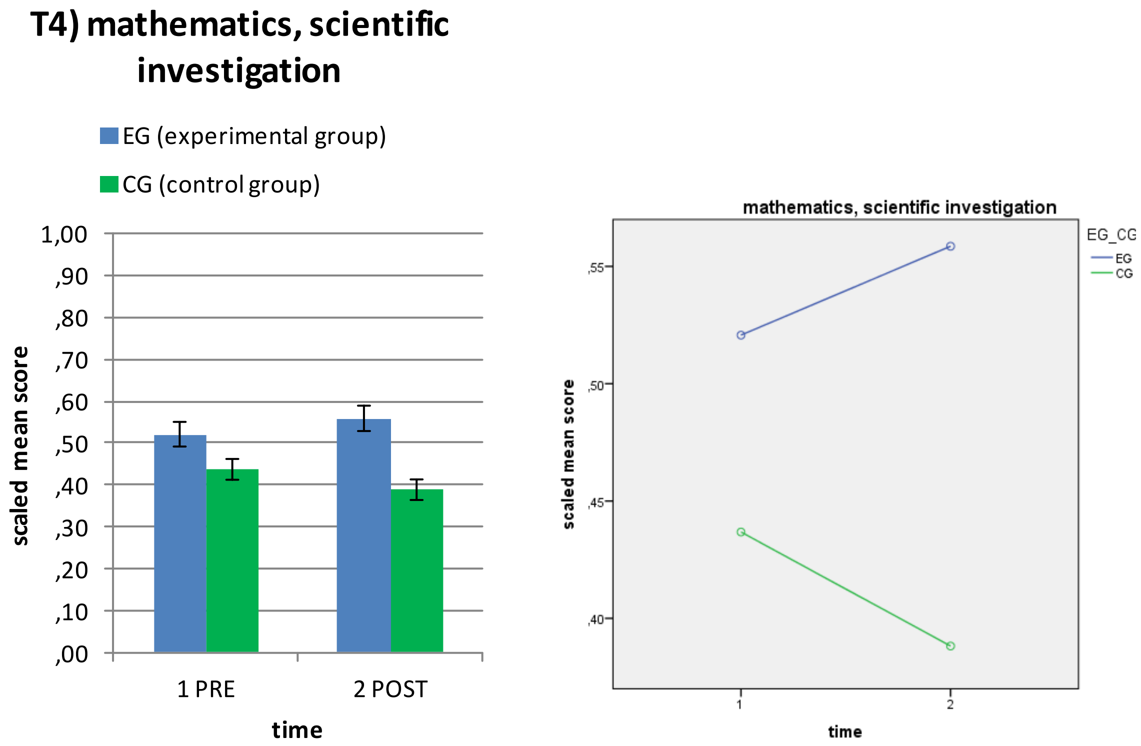


Figure 4.8.: Stage I: Mean scores of EG, CG at pre- and post-test (scaled to 1.0; left image); increase/decrease of mean scores between pre- and post-test (right image)

- enjoyment of science lessons (A_3) and general programming/robotics (T_1)
- ...

Detailed results of the correlation analysis are available upon request.

4.4.6. Results Stage II (sub-research question $Qb_{3.1}$)

Participants

The evaluation of the impact of educational robotics on young school students (hypotheses H_3, H_4; see Section 4.4.1) comprised 132 students (mean age 11.1 years) who completed both pre- and post-test (23% female, 70% male, 7% not stated; experimental group EG: 53 students, control group CG: 79 students; see Figure 4.14). Initially 150 students completed the pre-test which results in a participation rate of 88%. Students came from two different middle schools located in urban and suburban regions in Austria.

Students in the experimental group participated in weekly elective robotics courses at school. The intervention mainly comprised introductory robotics and programming activities using the LEGO Mindstorms NXT/EV3 platform as well as the NXT-G/EV3 graphical programming language. Within the context of this courses students prepared for participating in a certain robotics competition for

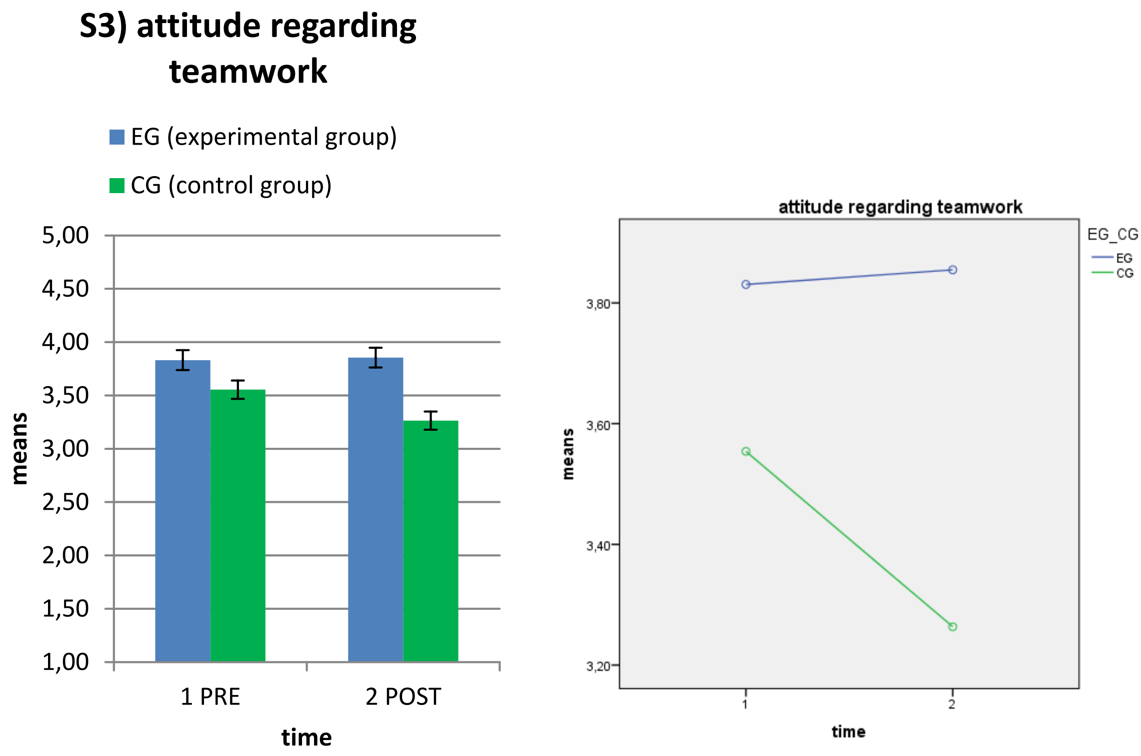


Figure 4.9.: Stage I: Attitude means of EG, CG at pre- and post-test (left image); change of means between pre- and post-test (right image) (scaled to 5.0; 5-point Likert scale; (5=strongly agree, 1=strongly disagree))

young students. This competition focuses on simplified *RoboCupJunior Rescue* tasks (e.g. following lines, avoiding obstacles, ...). Students in the control group came from the same class, respectively the same school level as students in the experimental group. They attended regular science lessons but did not participate in the robotics courses. In general the regular computer science lessons comprises basics of web development (*HTML*), basics of programming (*C#*) as well as the use of application software (*Microsoft Office*).

Technical and Social Skills

Regarding technical skills a comparison of mean scores indicated that students in the experimental group (EG) basically had higher pre- and post-test means compared to students in the control group (CG). Both groups improved between pre- and post-test. Regarding social skills both groups showed similar results with almost no change between pre- and post-test.

Repeated measures MANOVA was used to determine statistically significant changes (intervention effects) between EG and CG as well as between pre- and post-test for technical skills and social skills. Though, students in EG showed higher scores in the technical skill-scale, results of univariate and multivariate analyses did not show statistically significant changes (intervention effects) for either technical nor social skill-scales for the established alpha level of 0.05. Figure 4.15 provides an

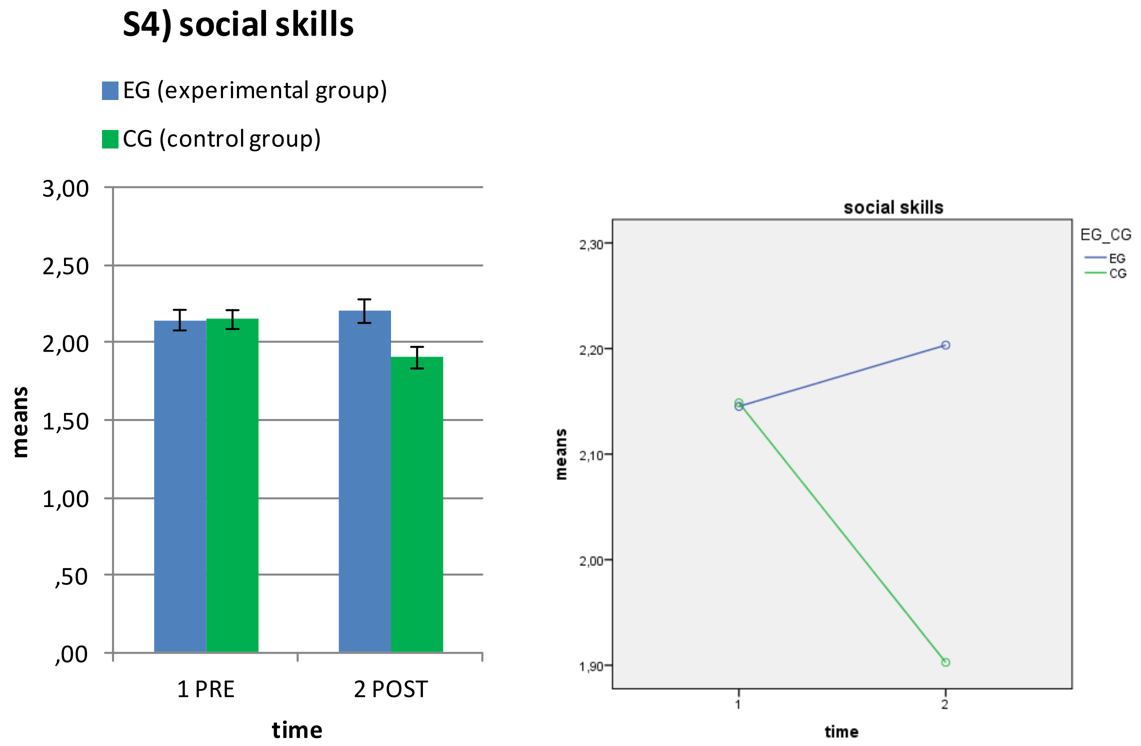


Figure 4.10.: Stage I: Attitude means of EG, CG at pre- and post-test (left image); change of means between pre- and post-test (right image) (scaled to 3.0; 4-point Likert scale; (3=strongly agree, 0=strongly disagree))

overview of pre- and post-test mean scores for technical and social skills (scaled to 100%).

Personal Interests

The applied interest scale comprised nine categories: *Working with machines or technical equipment; investigating how things work; doing things where creativity and imagination are important; adding new parts to a computer; joining an acting or music group; learning a foreign language; establishing contacts or starting a conversation with other people; developing a computer program; drawing or painting pictures*.

A comparison of pre- and post-test means (ranging from 1..very uninterested to 5..very interested) revealed that students in EG basically had higher means in the technical categories whereas students in CG showed higher means in the artistic categories. As described in Section 4.4.4 analyses of covariance (ANCOVA) was used determine which personal interests significantly differ between EG and CG right after the intervention (Welch, 2010) (using post-test scores of each category as dependent variable and pre-test scores of each category as covariate). Statistically significant differences (indicating greater interest of EG students) were found for the following categories:

- **investigating how things work** ($F_{1,127}$=5.998, p=0.016)
- **adding new parts to a computer** ($F_{1,122}$=9.952, p=0.002)

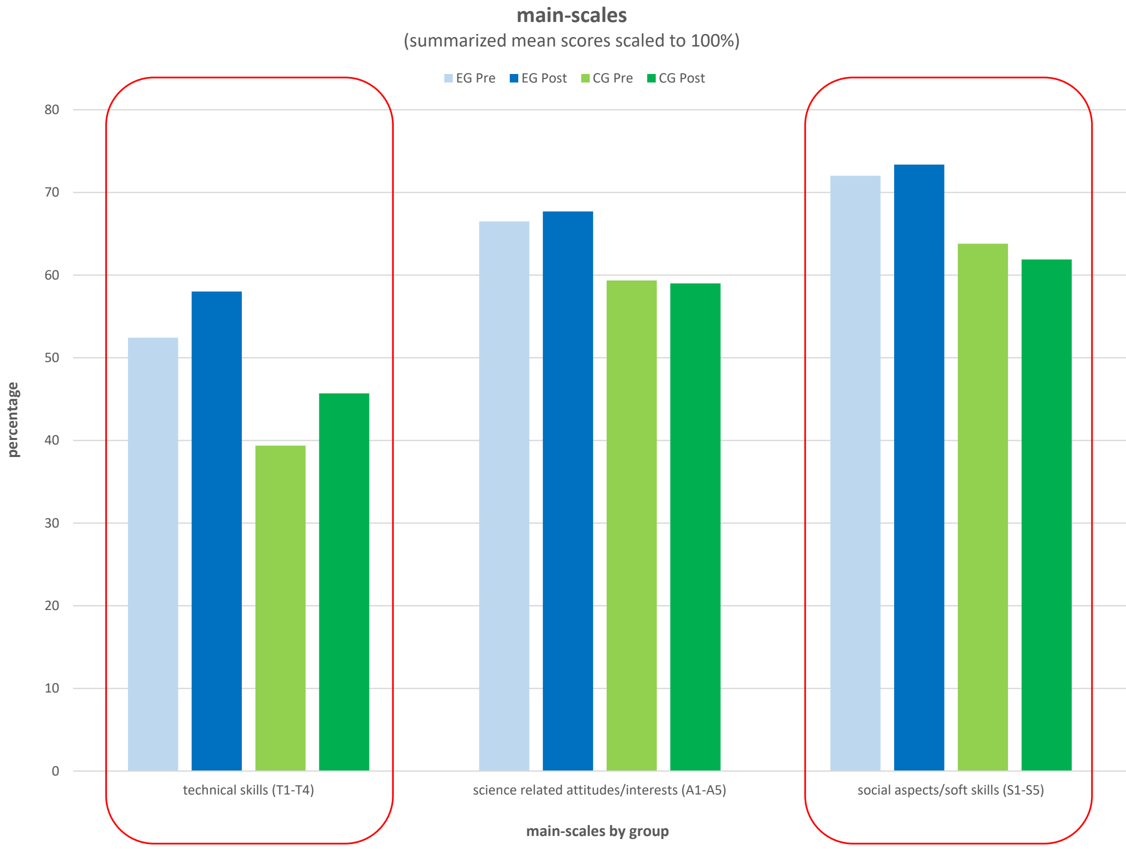


Figure 4.11.: Stage I: Summarized mean scores of all three main-scales (thematically grouped sub-scales). Main-scales with significant differences (according to multivariate analyses) are highlighted in red.

- **developing a computer program** ($F_{1,123}$=8.029, p=0.005)

Figure 4.16 provides an overview of pre- and post-test means for all nine categories with significant differences highlighted.

4.4.7. Results Stage II (sub-research question $Qb_{3.2}$)

Participants

Investigating hypotheses H_5 and H_6 (see Section 4.4.1), 200 students (EG 173, CG 27 students) from eight different countries (Europe, Asia, Australia) and around 20 different schools/educational institutions worldwide participated in the study. In order to investigate distinctive features between students who are about to participate in robotics activities (experimental group EG) and students who are not (control group CG), pre-tests have been administered and results have been analyzed[¶]. The average

[¶]To gather further insight also post-tests have been scheduled. Due to non-participation of a vast majority of students in the post-test as well as several non-matching student IDs between the two measurement points, a valid post-test analysis could not be performed.

MANOVA univariate/multivariate tests - significant intervention effects

			I	II
main-scales	sub-scales		univariate interaction (*time point x group*)	multivariate interaction (time point x group)
Technical skills	T_1	general programming and robotics		✓
	T_2	computer science		
	T_3	textual programming		
	T_4	mathematics and scientific investigation	✓	
Science related attitudes and interests	A_1	attitude to scientific inquiry		
	A_2	adoption of scientific attitudes		
	A_3	enjoyment of science lessons		
	A_4	leisure interest in science		
	A_5	career interest in science		
Social aspects and soft skills	S_1	self-efficacy in robotics		✓
	S_2	self-assessment in problem solving		
	S_3	teamwork	✓	
	S_4	social skills	✓	
	S_5	goal setting		

Figure 4.12.: Stage I: Overview of results of MANOVA analyses (green check-marks indicate statistically significant effects (=positive intervention effect))

age of participants was 13.9 years with a gender distribution of 13% female and 78% male (9% not stated). Figure 4.17 provides an overview of participants' demographic background.

The majority of students in EG participated in robotics activities 'at school' (around 80%) followed by 'at home' (around 11%) and 'in a club' (around 9%). Around 76% of students in EG intended to participate in a robotics competition (*RoboCupJunior* 72.6%, *FIRST Lego League/Robotics Competition* 19.9%, *RoboCup Rescue* 4.8%, *Botball* 2%, *Robotika H* 0.7%). Students in CG mainly participated in regular computer science courses and/or computer science electives at school.

Technical skills, science related attitudes and social aspects/soft skills

Mean Scores: A comparison of pre-test mean scores for each of the 10 sub-scales indicated that students in the experimental group (EG) basically had same mean scores compared to students in the control group (CG) regarding technical skills with marginal differences in the sub-scales *general robotics/programming, computer science, textual programming and mathematics/scientific investigation*. Conversely, in the attitude/soft skill related sub-scales students in EG showed higher means compared to students in CG. Figure 4.18 provides an overview of mean scores (pre-test; scaled to 100%) for all 10 sub-scales, separated by group.

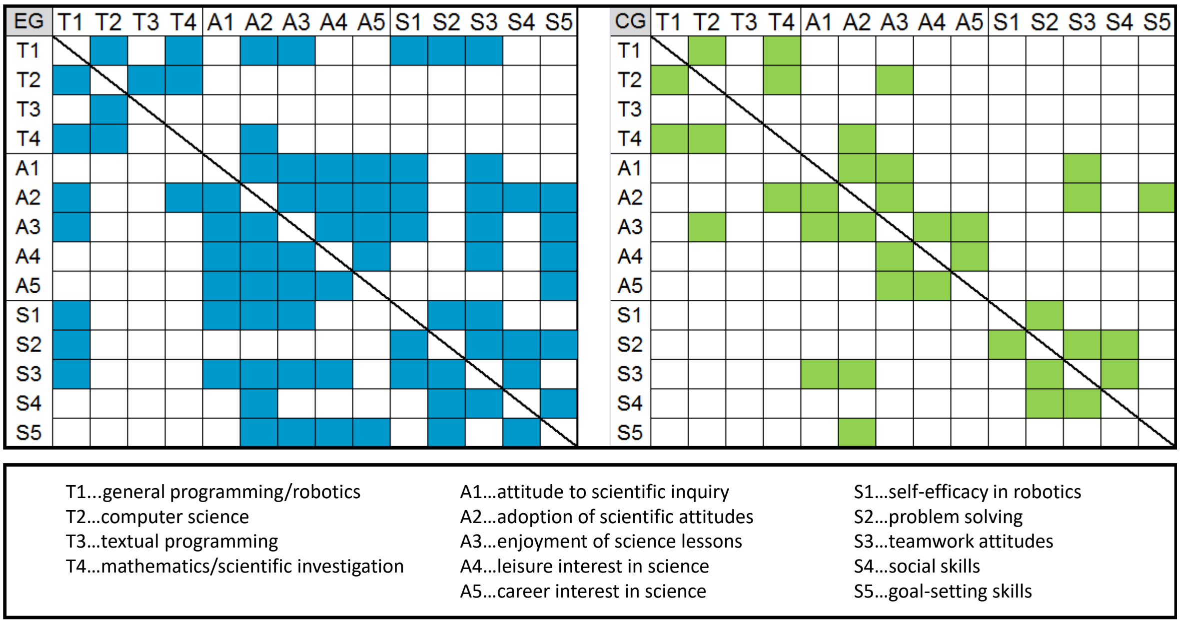


Figure 4.13.: Stage I: Highly significant correlations between sub-scales for experimental group EG (blue; left diagram) and control group CG (green; right diagram)

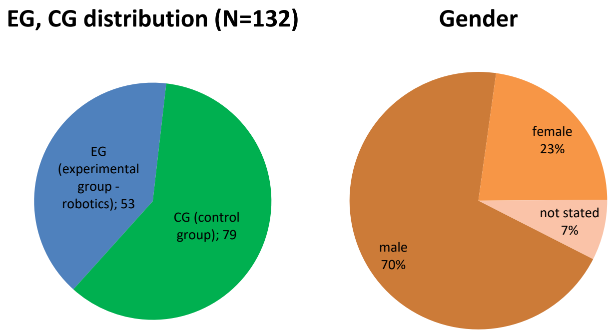


Figure 4.14.: Stage II (impact on young school students): study participants, EG/CG and gender distribution

Univariate and Multivariate Outcomes: One-way MANOVA (as described in Section 4.4.4) was used to determine statistically significant differences ('distinctive features') between EG and CG.

Univariate analyses were performed in order to investigate statistically significant differences for each of the 10 sub-scales separately. Significant differences were found for the following three sub-scales (indicating statistically significant higher means for students in EG):

- S_1 **self-efficacy in robotics** ($F_{1,159}$=22.947, p<0.001). The scale focused on students' self-confidence in solving robotics tasks (5-point Likert scale questions: 1..strongly disagree, 2..disagree, 3..uncertain, 4..agree, 5..strongly agree) (Nugent et al., 2010).
- S_2 **problem solving** ($F_{1,159}$=5.375, p=0.022). Here the focus was on students' self-evaluation regarding problem solving approaches using 5-point Likert scale questions (Nugent et al., 2010).

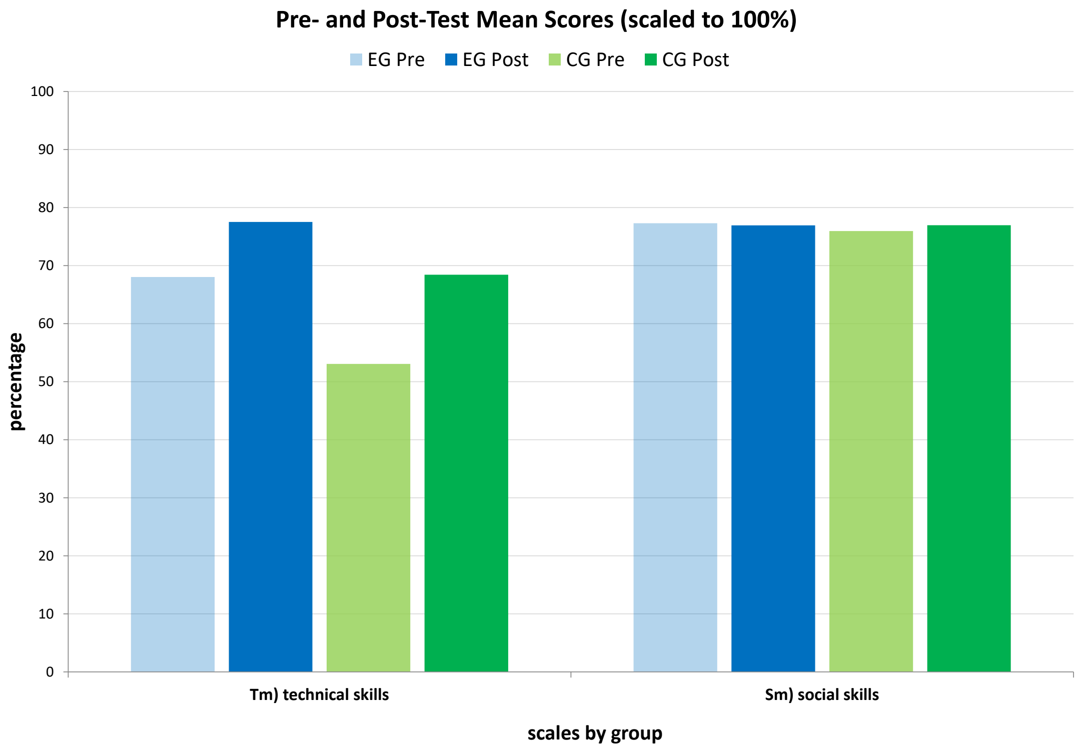


Figure 4.15.: Stage II (impact on young school students): Pre- and post-test mean scores for technical and social skills separated by EG, CG (scaled to 100%)

- S_3 **teamwork attitudes** ($F_{1,159}$=7.157, p=0.008). The scale focused on students' attitudes regarding working together with other people (5-point Likert scale questions) (Nugent et al., 2010).

Figure 4.19 shows the results (scaled to 5.0) of all three significant sub-scales.

Multivariate analyses of the two main-scales (sub-scales grouped by related topics) *technical skills* and *science related attitudes and soft skills* showed significant multivariate effects between EG and CG for *science related attitudes and soft skills* ($F_{6,154}$=4.905, p<0.001; sub-scales grouped within this main-scale: A_1 attitude to scientific inquiry, S_1 self-efficacy in robotics, S_2 problem solving, S_3 teamwork attitudes, S_4 social skills, S_5 goal-setting skills). The diagram in Figure 4.20 shows the summarized mean scores (scaled to 100%) of the two main-scales whereas significant differences found in the context of the multivariate analyses are highlighted in red.

Career-, Personal-Interests and Attitudes Towards the Teacher

Univariate and Multivariate Outcomes: One-way MANOVA (as described in Section 4.4.4) was used to determine statistically significant differences (distinctive features) between EG and CG regarding career interests, attitudes towards the teacher and personal interests. In this context univariate as well as multivariate outcomes were analyzed.

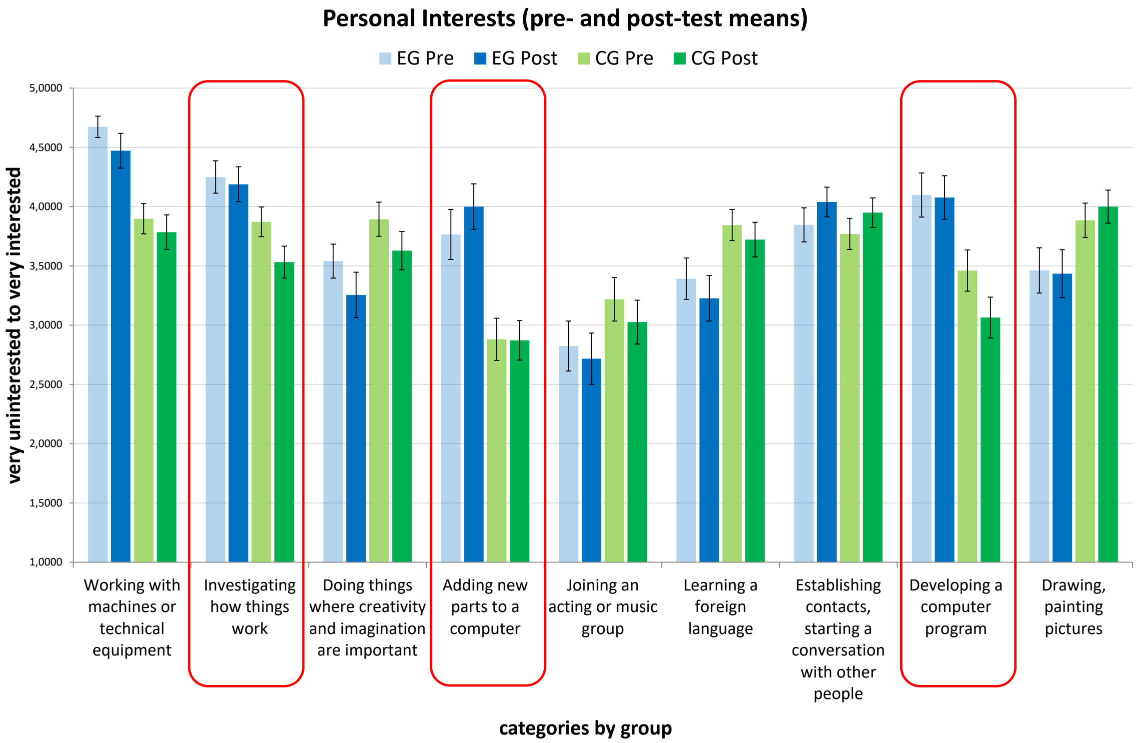


Figure 4.16.: Stage II (impact on young school students): Pre- and post-test means regarding personal interests (scaled to 5.0; 5-point Likert-scale (5=very interested, 1=very uninterested); statistically significant differences are highlighted in red)

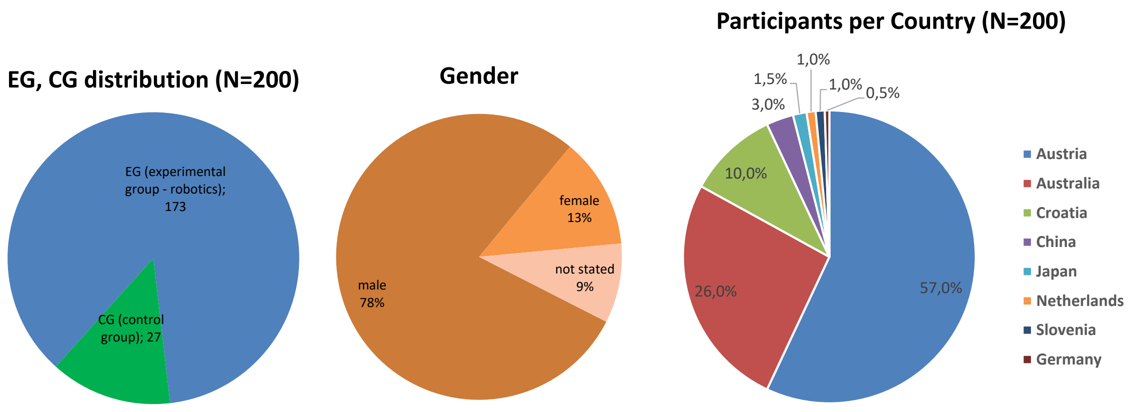


Figure 4.17.: Stage II (distinctive features between EG/CG): study participants, EG/CG and gender distribution; participants per country

- **I_1 career interests**: A comparison of pre-test means for each of the 11 career categories indicated that students in the control group (CG) had higher means in the technical categories

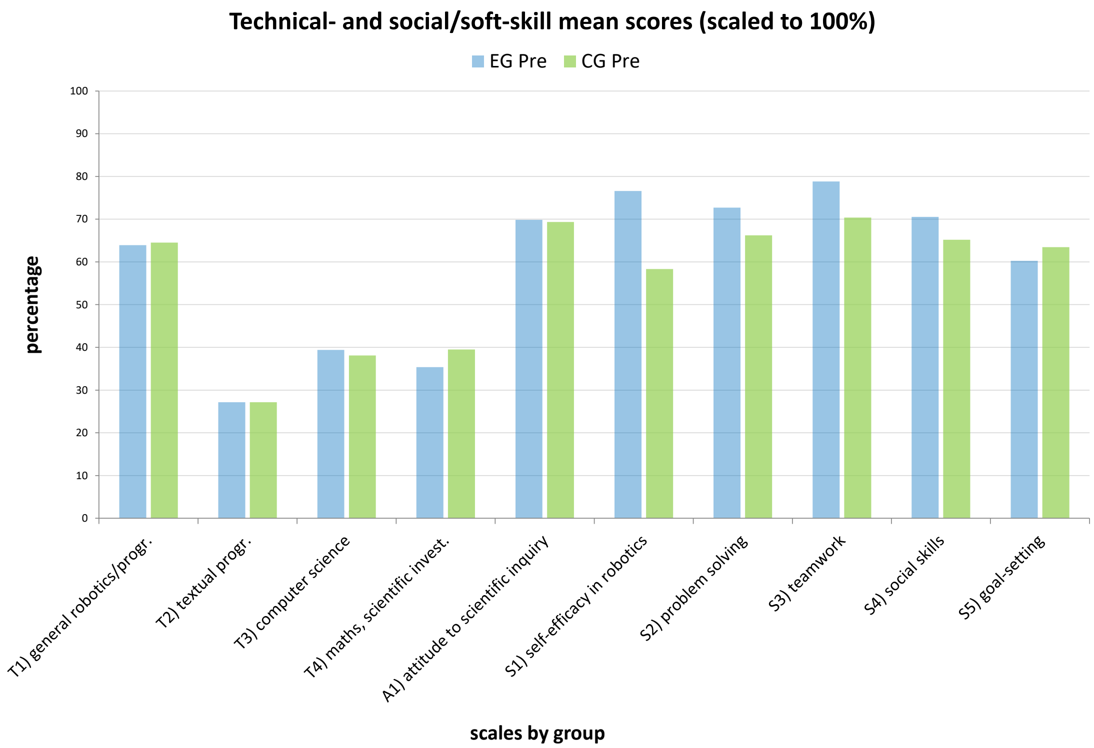


Figure 4.18.: Stage II (distinctive features between EG/CG): EG/CG pre-test mean scores for all 10 sub-scales regarding technical skills, science related attitudes and social aspects/soft skills (scaled to 100%)

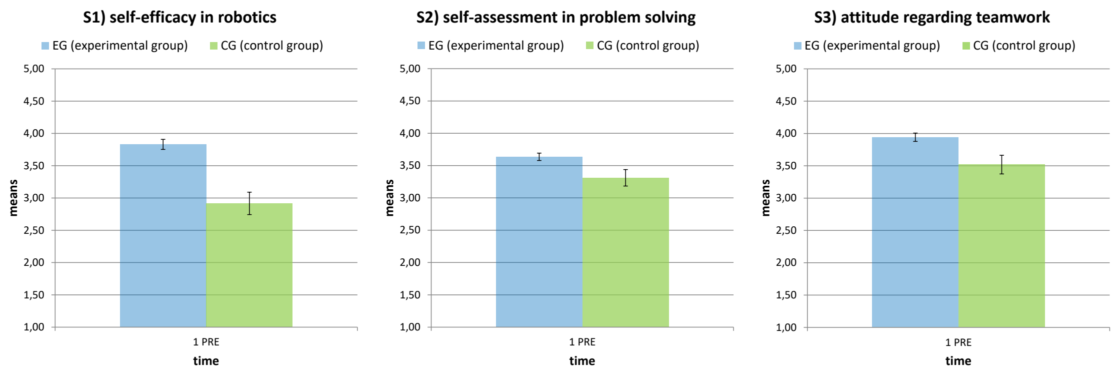


Figure 4.19.: Stage II (distinctive features between EG/CG): Statistically significant different pre-test means of EG and CG scaled to 5.0 (5=strongly agree, 1=strongly disagree)

compared to students in the experimental group (EG).

Univariate analyses of the 11 career categories revealed statistically significant differences (significant higher means for CG) regarding

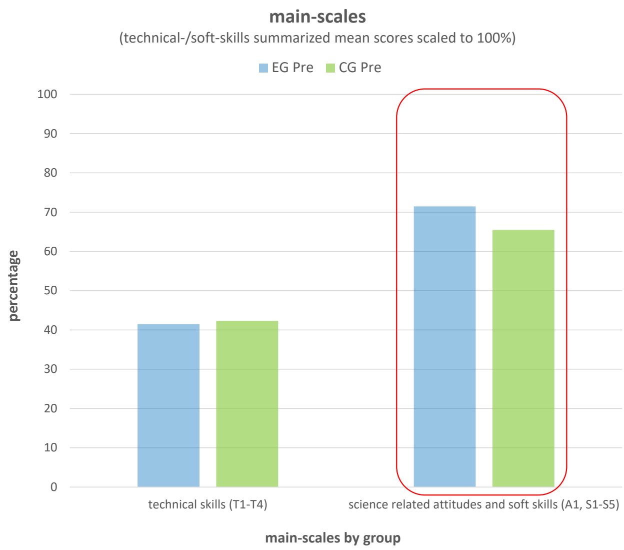


Figure 4.20.: Stage II (distinctive features between EG/CG): Summarized mean scores (scale to 100%) of all two main-scales (thematically grouped sub-scales). Main-scales with significant differences (according to multivariate analyses) are highlighted in red.

'engineering' ($F_{1,89}$=8.808, p=0.004) and
'computers' ($F_{1,89}$=6.804, p=0.011),
respectively significant higher means for EG regarding
'law' ($F_{1,89}$=4.623, p=0.034).
Figure 4.21 provides an overview of pre-test means for all 11 career categories with significant differences highlighted.

- I_2 **personal interests**: A comparison of pre-test means indicated that students in CG basically had higher means in the nine personal interest categories compared to students in EG.

  Univariate analyses of the nine personal interest categories revealed statistically significant differences (significant higher means for CG) regarding
  'working with machines or technical equipment' ($F_{1,147}$=7.796, p=0.006).
  Figure 4.22 provides an overview of pre-test means for all nine categories with significant differences highlighted.

- I_3 **attitudes towards the teacher**: A comparison of pre-test means indicated that students in EG had more positive attitudes (higher means) in all of the five teacher-attitude categories compared to students in CG.

  Univariate analyses of the five teacher categories revealed statistically significant differences (significant higher agreement means of EG students) regarding following four categories:
  '...often organizes the lessons in an exciting way' ($F_{1,156}$=9.079, p=0.003);
  '...can make even dry learning content really interesting' ($F_{1,156}$=13.094, p<0.001);
  '...sometimes really can enthuse pupils' ($F_{1,156}$=5.650, p=0.019);
  '...supports pupils implementing their own projects' ($F_{1,156}$=4.304, p=0.04);
  Figure 4.23 provides an overview of pre-test means for all five teacher categories with signifi-

cant differences highlighted.

Multivariate analyses of the main categories I_1, I_2, I_3 revealed statistically significant multivariate effects (distinctive features) regarding

- I_2 *personal interests* ($F_{9,139}$=1.945, p=0.05) and
- I_3 *attitudes towards the teacher* ($F_{5,152}$=3.412, p=0.006).

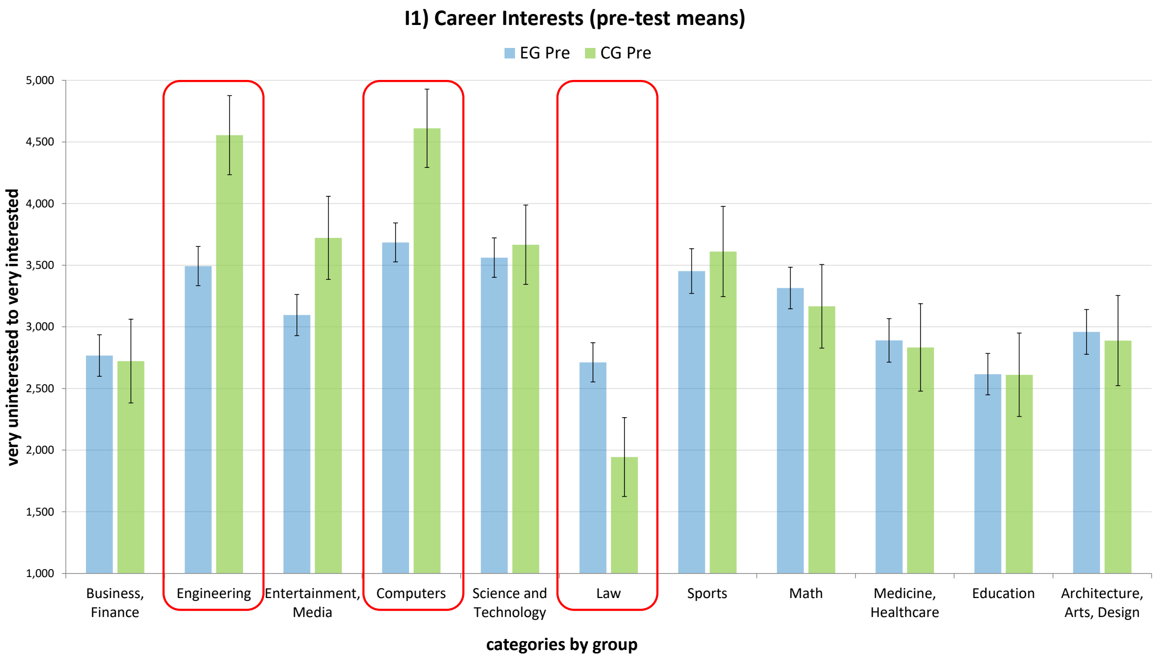


Figure 4.21.: Stage II (distinctive features between EG/CG): Pre-test means regarding career interests (scaled to 5.0; 5-point Likert-scale (5=very interested, 1=very uninterested); statistically significant differences are highlighted in red)

Correlations: Correlation analysis (Bortz and Döring, 2006) was applied to investigate relations between technical- and soft-skill means and attitudes towards the teacher. The analysis revealed a number of highly significant (strong/moderate) positive relations for students in the experimental group (EG). This means that students who show high scores in one sub-scale also show high scores in the related sub-scale (important: correlation analysis measures linear correlations, not causal relationships). Relevant highly significant relations ($0.2 < r < 0.8; p < 0.01$) were found between 57 sub-scales for EG compared to only 6 sub-scales for CG. The diagrams in Figure 4.24 provide an overview of all highly significant (strong/moderate) relationships between sub-scales for EG and CG (highlighted in blue, green respectively). It can be seen that there are various relevant positive correlations which only occur for students involved in robotics activities (EG). For instance, (amongst others), between the following sub-scales:

- computer science (T_3) and '...can make even dry learning content really interesting' (I_3B), '...supports pupils implementing their own projects' (I_3D) as well as '...inspires pupils for science/technology' (I_3E)

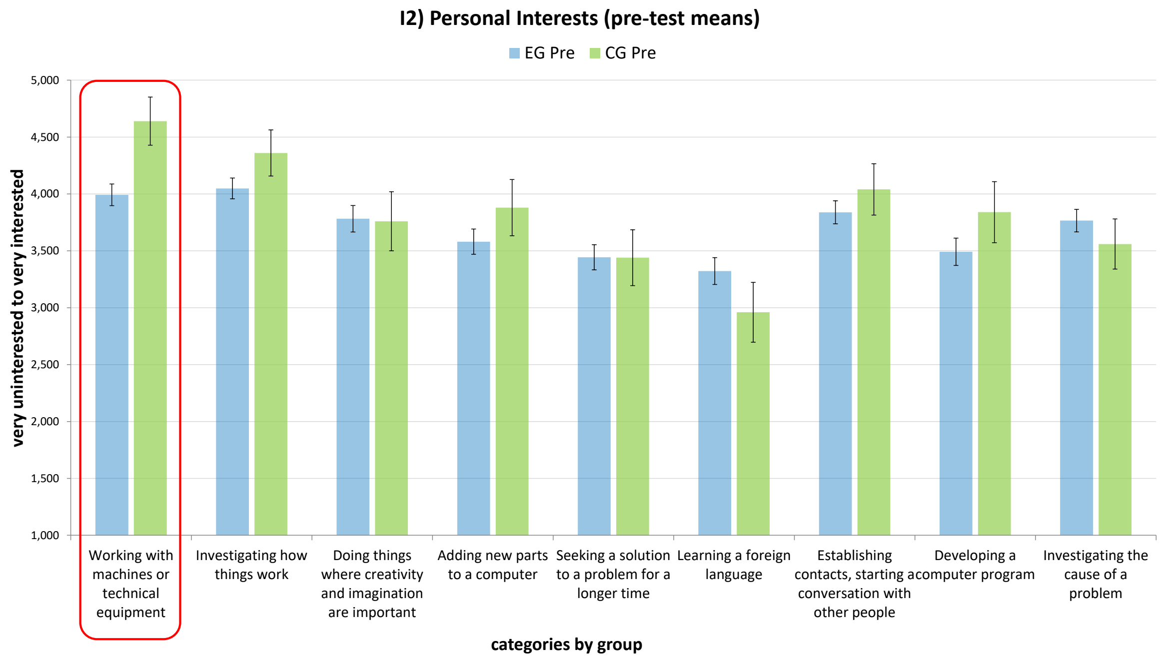


Figure 4.22.: Stage II (distinctive features between EG/CG): Pre-test means regarding personal interests (scaled to 5.0; 5-point Likert-scale (5=very interested, 1=very uninterested); statistically significant differences are highlighted in red)

- problem-solving (S_2) and all teacher related sub-scales (I_3A - I_3E)
- general programming/robotics (T_1) and textual programming (T_2), computer science (T_3), mathematics/scientific investigation (T_4), attitude to scientific inquiry (A_1), self-efficacy in robotics (S_1) as well as problem-solving (S_2)
- computer science (T_3) and textual programming (T_2), mathematics/scientific investigation (T_4), attitude to scientific inquiry (A_1), self-efficacy in robotics (S_1), problem-solving (S_2) as well as goal-setting skills (S_5)
- ...

4.4.8. Discussion of Results, Summary and Conclusions

Addressing the main research question Qb_3 and its sub-questions $Qb_{3.1}$ and $Qb_{3.2}$ (see Section 4.4.1) this section dealt with the extensive quantitative evaluation of the impact of educational robotics. Regarding the impact of educational robotics on students' technical-, social and soft skills as well as attitudes and interests towards science and technology (stage I of the quantitative study; main research question Qb_3) a widespread, mid-term approach was applied, aiming to gather solid and valuable empirical data on a larger geographical scale. Using a well-proven methodology a quasi-experimental two-group design (experimental- and control-group) conducting pre- and post-surveys (also referred to as pre- and post-tests) was set up. A multiple-choice questionnaire, based on different already applied and tested tools, was used as assessment instrument (Nugent et al., 2010; Jomento-Cruz, 2010;

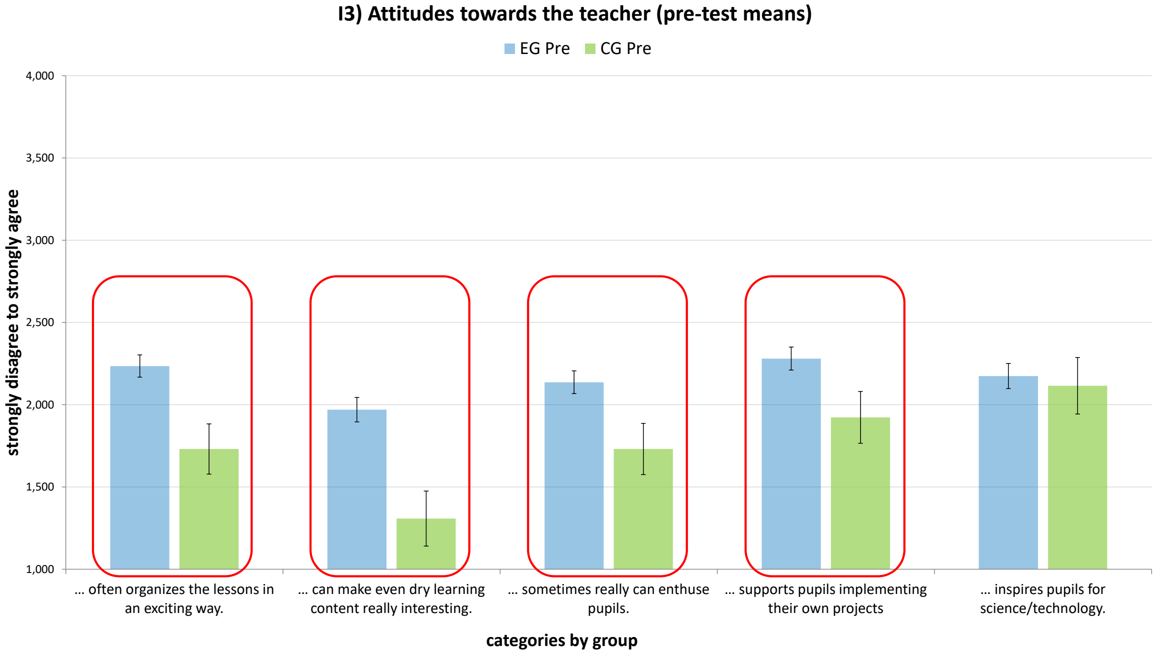


Figure 4.23.: Stage II (distinctive features between EG/CG): Pre-test means regarding attitudes towards the teacher (scaled to 4.0; 4-point Likert-scale (4=strongly agree, 1=strongly disagree); statistically significant differences are highlighted in red)

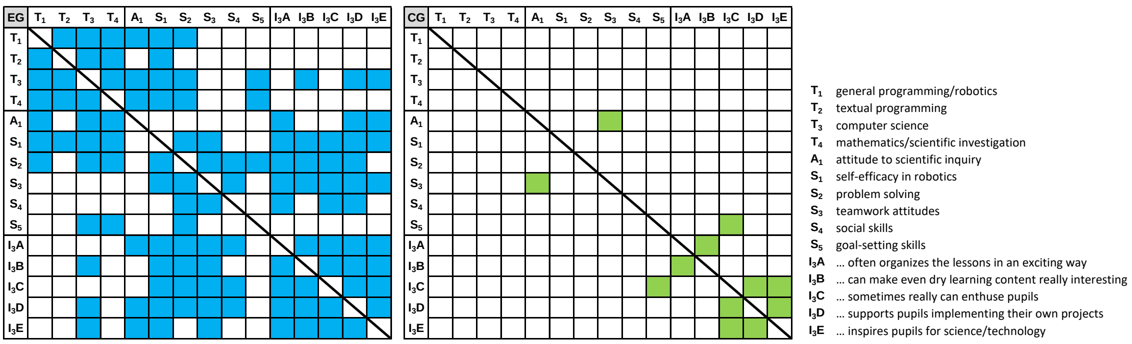


Figure 4.24.: Stage II (distinctive features between EG/CG): Highly significant correlations between sub-scales for experimental group EG (blue; left diagram) and control group CG (green; right diagram)

Dagienė and Futschek, 2008; University of Waterloo, 2013; Austrian Computer Society (OCG), 2013; OECD, 2006; Clark, 2004; Fraser, 1981; Hansen and McNeal, 1997). The study covered a period of approximately eight months (autumn 2013 - mid 2014) and comprised 148 pupils from 9 different schools in Austria and Sweden.

Stage II of the quantitative main study (autumn 2014 - mid 2015) addressed sub-research questions $Qb_{3.1}$ and $Qb_{3.2}$. On the one side, the focus was on the evaluation of the impact of educational robotics on young school students up to the age of twelve. Therefore, a questionnaire for young school students was compiled, tested and a pilot study with 132 young students (average age 11.1 years) was conducted in two selected middle schools in Austria. On the other side, stage II focused on the investigation of distinctive features between experimental- and control-group students comprising 200 participants from different types of secondary schools in eight different countries worldwide. Therefore, based on the findings and lessons learned from stage I of the study, the assessment instrument was adapted, extended and translated into the respective languages.

Using well-grounded statistical methods (Martin, 2007; Huck et al., 1974; Mayers, 2013; Meyers et al., 2013; O'Brian and Kaiser, 1985; Delisle et al., 2010), the gathered data were analyzed around different sub-scales related to technical- and soft-skills, social aspects, attitudes and interests towards science, personal and career interests as well as attitudes towards the teacher.

Main research question Qb_3, hypotheses $H_{1\ Qb3}$ and $H_{2\ Qb3}$ (Section 4.4.1): Looking at the results, it appears that students in the experimental group (EG) had higher scores at the base-level (pre-test) than students in the control group (CG) in various sub-scales (see Figure 4.7). This suggests that students who are already interested in science and technology decide to participate in robotics activities. Analyzing scores of pre- and post-tests it could be seen that both groups showed significant improvements in several sub-scales.

Statistically significant intervention effects (p-value <= 0.05) were found for the three sub-scales *mathematics and scientific investigation, teamwork* as well as *social skills* (see Figures 4.8, 4.9, 4.10), showing a significant positive impact of robotics activities on those topics. These findings indicate that educational robotics has a significant positive impact on some separate sub-scales but does not have a significant positive impact on each of the 14 sub-scales. Therefore, the results do not completely support hypothesis $H_{1\ Qb3}$ of educational robotics having a significant positive impact on all of the sub-scales (dealing with technical-,soft-skills, social-aspects and students' attitudes and interests towards science) separately.

Analyses of the three main-scales *technical skills*, *science related attitudes and interests* and *social aspects/soft skills* revealed statistically significant positive intervention effects for both *technical skills* and *social aspects/soft skills* (see Figure 4.11). Additional correlation analyses showed a large number of highly significant positive relations between various sub-scales for students participating in robotics activities (EG). For instance, there were strong positive relations between computer science and textual programming, between general programming/robotics and various other sub-scales (mathematics/scientific investigation, adoption/enjoyment of science, self-efficacy in robotics, problem solving, teamwork) as well as between attitude related and soft skill related sub-scales (see Figure 4.13) which only occurred for students in EG. All together, these findings support hypothesis $H_{2\ Qb3}$ of educational robotics having a positive impact on a group of content-related topics.

Sub-research question $Qb_{3.1}$, hypotheses $H_{3\ Qb3.1}$ and $H_{4\ Qb3.1}$ (Section 4.4.1): Looking at the results, it appears that students in EG had higher scores in the technical skill scale than students in CG (at both pre- and post-test). Both groups showed almost equal improvement rates between the two measurement points. Though there was an improvement of technical skills, no statistically significant differences were found between EG and CG. Regarding the results of the social skill scale, both groups had almost the same (relatively high) mean scores at pre- and post-test with almost no change between the two measurement points (see Figure 4.15). Statistical analyses did not reveal significant differences between EG and CG and between pre- and post-test. Therefore, hypothesis $H_{3\ Qb3.1}$ of educational robotics having a statistically significant positive impact on young school students' performance regarding technical skills and on their attitudes towards social aspects has to be rejected.

The analysis of the personal interest scale showed that basically, students in EG had higher mean scores in the technical and social related categories whereas students in CG had higher mean scores in the artistic/foreign languages categories (see Figure 4.16). Some categories also show decreasing rates between pre- and post-test which might be due to already relatively high pre-test means. Statistically significant differences were found for the interest-categories *investigating how things work*, *adding new parts to a computer* and *developing a computer program*. These findings partly support hypothesis $H_{4\ Qb3.1}$ of educational robotics having a significant impact on the change of young school students' personal interests. In sum, results of the interest analyses suggest that the involvement in robotics activities, above all, has a strong impact on the change of young school students' technical related interests.

The results of this investigation suggest that young students (up to the age of 12) who are already interested in technical topics and who already have a basic technical understanding, participate in robotics activities. It shows that there is a strong interest and motivation of talented, technology-oriented young school students to participate in robotics activities. This underpins the findings of stage I of the quantitative main study.

Sub-research question $Qb_{3.2}$, hypotheses $H_{5\ Qb3.1}$ and $H_{6\ Qb3.1}$ (Section 4.4.1): Findings of this investigation are discussed bearing in mind the limitations of not having valid post-test data (due to high drop-out rate and non-matching participant IDs between pre- and post-test) as well as a not well-balanced experimental-/control-group distribution (EG 173, CG 27 students).

The results of the study (pre-test data) investigating how students (secondary school) intending to participate in educational robotics activities differ from students not intending to participate in educational robotics activities in terms of technical skills, social aspects and soft skills, science related attitudes, career and personal interests as well as attitudes towards their teacher, showed the following picture: Students in EG and CG, on one hand, basically had the same mean scores in the sub-scales related to technical skills. On the other hand, in the attitude/soft skill related sub-scales students in EG showed higher means with statistically significant differences regarding *self-efficacy in robotics*, *problem solving* and *teamwork attitudes* (see Figures 4.18 and 4.19). In addition, multivariate analyses of the two main scales *technical skills* (grouped sub-scales T_1 - T_4) and *science related attitudes and soft skills* (grouped sub-scales A_1, S_1 - S_5) revealed statistically significant differences only for the main scale *science related attitudes and soft skills* (see Figure 4.20).

Considering these results, the first part of hypothesis $H_{5\ Qb3.1}$ regarding the existence of significant distinctive features (in terms of technical skills) between students intending to participate in educational robotics activities (EG) and students not intending to participate (CG) has to be rejected. On the contrary, the investigation revealed significant distinctive features in terms of social aspects, soft skills and science related attitudes which supports the second part of hypothesis $H_{5\ Qb3.1}$. In sum, findings suggest that students who are about to participate in robotics (EG) tend to have more positive attitudes towards science and social-/soft-skill related topics. This shows that those students are highly committed and have high expectations regarding their involvement in robotics activities. On the other side, there was no indication that students in EG differ significantly from CG students regarding their technical skills before participating in robotics activities. These contradictions to the findings of stage I and stage II of the quantitative main study (middle and secondary school students having higher pre-test mean scores in technical scales) might be due to the broad geographical scale and the diversity/inhomogeneity of the sample (participants from different schools, countries and cultures in Europe, Asia and Australia) as well as to the aforementioned limitations of this particular experimental setting.

The analysis investigating distinctive features in terms of career interests revealed statistically significant higher means of students in CG regarding the categories *'engineering'* and *'computers'*, respectively significant higher means for EG regarding *'law'* (see Figure 4.21). In addition, analysis of the personal interest scale revealed significant higher means of students in CG regarding *'working with machines or technical equipment'* (see Figure 4.22). In general, CG students showed slightly higher means (p-value > 0.05) in the technical categories while students in EG showed slightly higher means in soft skill categories (e.g. 'learning a foreign language'). These results were unexpected, since findings of our previous studies would suggest that students intending to participate in robotics activities (EG) would be more interested in technical career fields and would have higher means in personal interest categories related to technical aspects. On the other side, this shows that students intending to participate in robotics have a diverse set of interests, not limited to certain technical aspects and categories. Again, aforementioned factors and limitations have to be kept in mind in view of these findings.

Regarding attitudes towards the teacher analyses revealed that students in EG had higher means in all of the five teacher-attitude categories with statistically significant differences in four out of five categories (e.g. 'our teacher often organizes the lessons in an exciting way', 'our teacher can make even dry learning content really interesting', . . . ; see Figure 4.23). Students who are about to participate in educational robotics activities (EG) have a far more positive opinion towards their teachers compared to control group students (CG). Additional correlation analysis revealed a number of highly significant positive relations between technical- and soft-skill means and attitudes towards the teacher for students in EG. Figure 4.24 shows that there are various relevant positive correlations which only occur for EG students (e.g. between 'problem-solving' and all teacher related sub-scales, . . .). Teachers offering robotics activities or integrating robotics in the regular curriculum spend a lot of time and effort in the preparation of lessons and the support of students (e.g. by acting as mentor at robotics competitions during leisure time) and therefore, are perceived by students in positive terms. This highlights the crucial role and enormous importance of the teacher in the context of educational robotics.

In sum, distinctive features between experimental- and control-group students were found for several scales related to career-, personal-interests and attitudes towards the teacher. Multivariate effects were found for the main scales *personal interests* (nine grouped interest categories) and *attitudes towards the teacher* (five grouped teacher categories). These findings support hypothesis $H_{6\ Qb3.1}$ stating that significant distinctive features exist between students intending to participate in educational robotics activities and students not intending to participate in educational robotics activities in terms of career interests, personal interests as well as attitudes towards their teacher.

Results and findings of our study were partly confirmed by previous studies (as discussed in Chapter 2). For instance, the studies of Melchior et al. (2005, 2004); Petersen et al. (2007) also found positive effects on teamwork and social skills. Miller et al. (2008) reported measurable improvement of students' teamwork and communication skills as well as their self-esteem. In his dissertation Griffith (2005) showed that science related attitudes did not change significantly between pre- and post-test. Lindh and Holgersson (2005) found statistical evidence of improvements regarding mathematics and problem solving skills for a sub-group of study participants. Nugent et al. (2012) reported extremely high pre-test attitude scores of the experimental group. The authors argued that this ceiling effect makes it difficult to improve at the post-test. None of the related studies and theses found significant improvements for all of the investigated topics. Alimisis (2013) also discussed the great necessity to address students who are not yet interested in science and technology. Demo et al. (2012) also stressed the crucial role of the teacher regarding the success of educational robotics (by means of a positive impact on students' learning). Other studies came to slightly different findings and conclusions compared to our evaluation. For instance, Nugent et al. (2014) reported only a minor impact on mathematics knowledge. Welch (2010) found a significant positive impact on four out of seven different categories regarding science related attitudes and interests. Varied study designs, different settings, interventions and applied methods as well as the demographic background of study participants might be sources of different results and findings.

4.4.9. Confounding Factors and Limitations

Empirical studies in general face the challenge of considering and eliminating possible confounding factors which can have an influence on study results. We are aware that the quasi-experimental evaluation design applied in this quantitative main study has limitations and shortcomings (Diekmann, 2007; Bortz and Döring, 2006; Schreiner and Sjoberg, 2004; Stubbs et al., 2012). In the following we will discuss particular limitations of the evaluation design as well as countermeasures taken in order to address those challenges as far as possible.

Due to the broad scope and geographical scale of this evaluation with participants from different schools/educational institutions in different countries in Europe, Australia and Asia a randomized assignment of study participants to either experimental group (EG) or control group (CG) was not feasible. Assigning participants randomly provides a higher probability that there are less differences between EG and CG at the initial measurement point. Such differences might concern, for instance, different prior knowledge or experiences of study participants as well as different educational and demographic background. Therefore, by applying a randomized participant assignment, differences found at the final measurement point are attributable to the intervention with a higher degree of certainty. In order to address these issues we developed an evaluation design using pre- and post-tests by assessing the initial situation at the pre-test and analyzing the results after the intervention (post-test) using the pre-test results as base level. A prerequisite of this study was that students in EG and CG share comparable demographic attributes (e.g. age, school level, social and educational background) and that students in CG attend comparable subjects and activities (e.g. participating in regular computer science courses). Teachers at each participating school were asked to recruit students for EG and CG matching a set of specific criteria (see Section 4.4.1). The study instruments applied comprised items assessing prior knowledge of participants regarding technical skills (robotics, programming knowledge, . . . ; see Section 4.4.2).

By applying a pre- and post-test design one have to be aware of potential learning effects. Basically this means that study participants remember the correct answers from the pre-test while doing the post-test. We faced this challenge by establishing an eight-month time gap between the two measurement points. Furthermore, we changed the order of multiple-choice answers of each question from pre-test to post-test.

The validity of answers depends on the honesty and motivation of study participants. This applies particularly to questions related to attitudes and interests where it is important that participants answer questions truthfully. Though critical it is extremely difficult to ensure this prerequisite. Therefore, we addressed this issue on several levels. First, we provided an incentive for the study participants (i.e. by participating in a prize draw). Second, we provided a detailed explanation of purpose and process of this evaluation in order to raise participants' awareness for the importance of their conscientious cooperation in this study. Third, we checked the data for obvious faked or invalid answers (e.g. relevant comments made in the feedback section, ...) and did not include them in the statistical analysis.

The applied study instruments (questionnaires) as well as further documents (informed consents, step-by-step manual for teacher, information material) where originally created in English and afterwards translated into different languages. Translating the study instrument and additional documents is a sensitive process with various sources of errors. Cultural differences, different school systems, different meaning of terms, etc. have to be considered. In order to avoid those errors as far as possible all instruments and documents were translated by native speakers.

The quantitative main study comprised a large geographical area as well as a broad diversity and inhomogeneity of the participants (students from different countries and cultures in Europe, Asia and Australia; different social and educational background of students; different schools of different types; different conditions in each participating school, ...). Due to the broad scale of the study the activities in experimental- and control-groups slightly differed across the different participating schools/institutions. All those aspects affect the study implementation and its results. Various counter measures were taken to address these issues. In order to ensure similar assessment situations in each participating institution we provided detailed information for teachers and pedagogues who were responsible for recruiting students and for conducting the study at their institution (e.g. step-by-step manual, additional documents explaining the process of the study, personal contact as well as correspondence using email, Skype and telephone). In addition, we only recruited students matching certain criteria (as described above and in Section 4.4.1). The majority of students in the experimental group either prepared for RoboCupJunior or participated in educational robotics activities on a weekly basis as part of elective subjects in school. This ensures a more uniform and comparable set of intervention activities across participating schools/institutions.

In the context of stage I of the study we did not measure the influence of the teacher (quality of teaching, didactic and pedagogical skills, relationship to students, ...) and the impact of her/his teaching approach on students' attitudes or performance. The teacher represents one of the most influential confounding factors. In order to face this shortcoming stage II comprised a section dealing with students' attitudes towards the teacher. Nevertheless, further and more detailed investigation of teachers' influence is needed.

Stage II of the study (regarding secondary school students) faced the problem of not having enough valid post-test data. This issue was due to a high drop-out rate and non-matching participant IDs between pre- and post-test. Furthermore, the analyzed pre-test data showed a not well-balanced experimental-/control-group distribution (EG 173, CG 27 students) which limits the significance and validity of the results. Furthermore, additional validity tests and reliability analyses are needed regarding the instruments applied for assessing technical skills of young school students (stage II, sub-research question $Qb_{3.1}$).

The results regarding science related attitudes and social aspects/soft skills are based on self-assessment questionnaires, reflecting students' subjective view and opinion. Other assessment instruments (e.g. knowledge tests,...) might lead to different results (e.g. for problem-solving- and soft-skills). This also applies for the instruments assessing technical skills. Furthermore, it might also be possible that the applied instruments were not sensitive enough to measure all significant changes.

By applying the described counter measures we focused on minimizing the confounding factors and addressing the limitations as far as possible. Nevertheless, results and findings of this quantitative main study have to be considered bearing in mind all the limitations, shortcomings and flaws discussed in this section. It is also important to mention that this first study provides some initial evidence on the impact of educational robotics but further investigation is needed to underpin the results.

4.4.10. Future Work

Future work comprises steps in order to ease the limitations and shortcomings (as discussed in the previous section) such as a more detailed investigation of teachers' influence on students' skills and attitudes in the context of educational robotics.

The assessment instruments for secondary school students have to be shortened further in order to avoid a high drop-out rate at post-test due to high complexity and high expenditure of time for completing the questionnaire. Based on the findings of this study the assessment instrument for young school students has to be adapted and translated and further evaluations at different middle schools in different countries have to be conducted in order to underpin/support results of this first investigation.

The results regarding science related attitudes and social aspects/soft skills are based on self-assessment questionnaires, reflecting students' subjective view and opinion. Other assessment instruments like knowledge tests, problem-solving skill tests, psychological testing procedures (as applied by Wulf (2012); see Chapter 2, Section 2.1.2) or critical thinking assessments (Stein et al., 2007) would provide important additional insights and might also lead to different results. Therefore, it would be of great value to conduct the study using different assessment instruments and to compare the results in order to find possible differences/similarities.

The evaluation design described in this chapter is one first attempt to address the extremely complex question concerning the impact of educational robotics. The large body of gathered data might also be analyzed with respect to different aspects and research questions (e.g. gender, social or regional aspects, . . .).

It is important to mention that this study provides some initial evidence on the impact of educational robotics but further investigation is needed to underpin or disprove the results. In this context a further development of the applied evaluation design would be conceivable in order to conduct an in-depth analysis of the impact of educational robotics on certain subject areas and, furthermore, to address certain limitations of the current study (influence of the teacher, slightly different intervention activities in experimental- and control-groups across different participating schools, . . .):

- selecting a subject area (e.g. mathematics, physics, computer science, . . .) to be investigated
- preparing topics of that area in three different ways (3-group design):
  - using an educational robotics approach (=experimental group)
  - using a different computer-aided/technical teaching approach (e.g. tablets, smart-phones, game-based, . . . ; =control group 1)
  - using a conventional teaching approach (=control group 2)

- all three approaches are taught by a single teacher
- applying pre- and post-test (before and right after the intervention) as well as a follow-up test (several months after the intervention in order to determine mid-/long-term effects)

4.5. Summary and Conclusion

Using robots as a vehicle to interest young people in science and technology and in addition to improve their technical- and social-skills has become a widespread approach in the last decades. There is a predominantly positive feedback from students, teachers, mentors, parents and other stakeholders involved in educational robotics activities. Despite these subjective impressions and anecdotes it is crucial to conduct objective evaluations in order to provide valid information and verifiable data to prove its effectiveness and positive impact. This chapter described the design (methodology, instrumentation), implementation, analysis and results of a comprehensive empirical evaluation applying a mixed methods research approach comprising qualitative and quantitative research methods.

Addressing the main research questions as discussed in Section 4.1 we developed an evaluation concept which relies on a proven, well-grounded methodology. The overall concept is based on three pillars, namely the qualitative pre-study addressing research question Qb_1, the qualitative/quantitative evaluation of intervention concepts[‖] addressing research question Qb_2 and the quantitative main study addressing research questions Qb_3 and its sub-research questions $Qb_{3.1}$ and $Qb_{3.2}$ (see Figure 4.1). The following summarizes methodology, results, limitations and open issues (future work) of each pillar.

The qualitative pre-study (Section 4.2) addressed research question Qb_1: *"What are the motivational factors and inherent values of educational robotics and, furthermore, what is the long-term effect of the involvement in educational robotics activities on the individual career development of school students?"*

Therefore, this study aimed at revealing values inherent to the educational robotics approach by the example of RoboCupJunior (RCJ). The focus was on the extraction of role models and later careers of former RCJ participants who participated in various national and international RCJ competitions between 2008 and 2011. It is not sufficient to only know that an educational robotics approach like RCJ is successful, but also why. In this context semi-structured qualitative interviews aiming at identifying reoccurring motivational factors that 'hooked' participants and investigating their 'RCJ careers' formed the basis of this evaluation.

The pre-study comprised results of nine interviews whereas the group of interviewees is not representative in any way. The aim was to provide first hints and preliminary insights in order to identify the inherent values of an educational robotics approach like RCJ. All of the respondents did have a positive opinion towards educational robotics and RCJ in particular. However, it is crucial as well to investigate also negative examples (e.g. students who were not influenced by their involvement in educational robotics activities in their future careers, and/or have negative attitudes towards educational robotics/RCJ). There is also a need for more long-term evaluations in the area of educational robotics in order to improve pedagogical approaches. In this regard a series of follow-up studies, such

[‖]The description of the cross-generational educational robotics/education in AI intervention concepts can be found in Chapter 3 as ethnographic studies of the teachers, content-related analysis of the teaching material and a long-term shadowing study of selected students from different age ranges need to be conducted. Those follow-up studies should also ease the limitations of this qualitative pre-study, such as the small number of interviewees, which all had successful RCJ experiences. In addition, further studies in different regions/countries need to be conducted to address the shortcoming of a limited geographical scope.

Findings of the pre-study showed that all interviewees were enthusiastically talking about their robotics activities and experiences. Many of them competed for years in RCJ and later all of them continued in science and engineering studies. Furthermore, many former team members are still friends and work together at university or meet in leisure time. Even if none of the teams reached top placements at the competitions they were proud of their achievements. With regard to research question Qb_1 results of this pre-study show that RCJ as an educational robotics approach generates three important motivational factors (inherent values, so called 'the hooks') namely the *social experience* (friends, teamwork and international contacts), the *engaged community* (schools, motivating teachers, academics and family) and the *feelings of success* (personal development, placing and positive memories). Regarding the nine interviewees there is an obvious positive relationship between their educational robotics/RCJ experiences and their future careers. All of them pursued science and engineering related studies at different Austrian universities. Two of them also continued in the major level of RoboCup, playing a leading role in a successful RoboCup Rescue team. Furthermore, both of them already finished their bachelor and master theses in the area of robotics and entered the professional life or started a Ph.D. respectively.

The findings and results as well as the gained expertise and lessons learned from this pre-study formed the basis for the evaluation of intervention concepts and built the foundation for the development of the quantitative main study.

The qualitative/quantitative evaluation of intervention concepts (Section 4.3) addressed research question *Qb_2: "Are the novel educational intervention concepts (cross-generational educational robotics/education in AI)* (as presented in Chapter 3) *working as expected?"*

The evaluation of the first concept dealing with pre-school educational robotics in a cross- generational context comprised semi-structured qualitative interviews as well as passive and active participant observations, informal interviews, field notes and discussions. Gathered and analyzed qualitative data proved that kindergarten children were familiarized with science and technology in a playful and sustainable way, were actively involved in the hands-on activities and interacted with school students and senior citizens in the sense of an education partnership. The analysis of the semi-structured interviews with school students revealed that both students and kindergarten children gained various technical and social skills. The results of this investigation indicate that using robots as a pedagogical tool by applying a cross-generational, cross-institutional approach could be one successful way to introduce pre-school children and in parallel also school students and senior citizens to robotics and computer science. The huge amount of gathered data is still subject to further investigation. In this context, the next evaluation steps would also have to include interviews with kindergarten children and senior citizens.

The evaluation of the second concept focusing on education in artificial intelligence on different age- and educational levels comprised qualitative research methods (participant observation, field notes, discussions, informal and semi-structured interviews, drawing interpretations) but also quantitative research methods (open ended and multiple choice questions, self- and foreign-evaluation of acquired skills, feedback questionnaires). Evaluation results of the pilot implementations for each module indicate that the proposed AI education concept aiming at fostering AI literacy works (also see Figure 4.4). Kindergarten children (average age 5 years) explored fundamental AI topics in a playful way and understood the (simplified) AI concepts. Middle school students (average age 12 years) got a basic understanding (theory plus practical implementation) of basic AI/computer science topics but had problems to understand the connection between the basic AI concepts and their application in real life. The content and topics turned out to be too extensive for the short time available and the very little prior knowledge of participating students. After completing a seven week AI course, high school students got a well-founded understanding of a broad range of fundamental AI topics. By applying new AI learning tools and motivational hands-on exercises at university level almost all students successfully completed the course on basic AI techniques.

Summarizing the evaluation results after analyzing all gathered data it can be concluded that the novel intervention concepts presented in Chapter 3 are working. Within the context of first proof-of-concept implementations it turned out that both interventions concepts achieved almost all of their goals (referring to research question Qb_2). Nevertheless, due to the relatively small sample of participants in the pilot implementations of each intervention concept, evaluation results only provide preliminary insights and first hints. In order provide additional, sound underlying data documenting the success of both concepts, further implementations and evaluations in different kindergartens, schools and universities are necessary. Certain modules of the AI education concept (i.e. university) also require a more detailed evaluation (questionnaire, self-evaluation, quantitative feedback). To gather valid long-term data it would also be necessary to follow a group of students from kindergarten to university who go through the entire AI education program. Results and lessons learned from the first proof-of-concept projects form the basis to adapt, improve and extend the AI education concept (further implementations in different schools and kindergartens; proof-of-concept implementations in primary schools) in order to pursue the long-term goal of fostering AI literacy.

The quantitative main study (Section 4.4) comprised two stages. Stage I addressed the main research question Qb_3*: "Is there a difference/change in the outcome (compared between before and after participating in educational robotics activities) in terms of technical skills, social aspects and soft skills and science-related attitudes and interests between school students participating in educational robotics activities compared to school students not participating in educational robotics activities?".* Stage II dealt with the sub-research questions $Qb_{3.1}$*: "Is there a difference/change in the outcome (compared between before and after participating in educational robotics activities) in terms of technical skills, social aspects and personal interests between young students (up to the age of 12) participating in educational robotics activities compared to young students not participating in educational robotics activities?"* and $Qb_{3.2}$*: "How do students intending to participate in educational robotics activities differ from students not intending to participate in educational robotics activities in terms of technical skills, social aspects and soft skills, science related attitudes, career and personal interests as well as attitudes towards their teacher?"*

Regarding the impact of educational robotics on students' technical-, social and soft skills as well as attitudes and interests towards science and technology (stage I, main research question Qb_3) a widespread, mid-term approach was applied, aiming to gather solid and valuable empirical data on a larger geographical scale. Based on a well-proven methodology a quasi-experimental two-group design (experimental- and control-group) comprising pre- and post-tests was applied (Diekmann, 2007; Barreto and Benitti, 2012; Bortz and Döring, 2006; Trochim et al., 2015). A multiple-choice questionnaire, based on different already applied and tested tools, was used as assessment instrument (Nugent et al., 2010; Jomento-Cruz, 2010; Dagienė and Futschek, 2008; University of Waterloo, 2013; Austrian Computer Society (OCG), 2013; OECD, 2006; Clark, 2004; Fraser, 1981; Hansen and McNeal, 1997). The study covered a period of approximately eight months (autumn 2013 - mid 2014) and comprised 148 pupils from 9 different schools in Austria and Sweden. In stage II the focus was on the evaluation of the impact of educational robotics on young school students (sub-research question $Qb_{3.1}$). Therefore, a questionnaire for young school students was compiled, tested and a pilot study with 132 middle school students (average age 11.1 years) was conducted. In addition, stage II also investigated distinctive features between experimental- and control-group students (sub-research question $Qb_{3.2}$) comprising 200 participants from different types of secondary schools in different countries worldwide. Therefore, based on the findings and lessons learned from stage I of the study, the assessment instrument was adapted, extended and translated into the respective languages.

Using well-grounded statistical methods and software packages for statistical data analysis (Mayers, 2013; Meyers et al., 2013; O'Brian and Kaiser, 1985; Delisle et al., 2010; Bortz and Döring, 2006; Eckstein, 2013), the gathered data were analyzed around different sub-scales related to technical- and soft-skills, social aspects, attitudes and interests towards science, personal and career interests as well as attitudes towards the teacher.

The quasi-experimental evaluation design applied in this study has some limitations and shortcomings which are discussed in detail in Section 4.4.9 (i.a. no randomized assignment of participants; prior knowledge; learning effects; motivation, honesty of participants; inhomogeneity of groups; applying the study in different schools and countries; slightly different activities in control and experimental groups across different schools; influence of the teacher (quality of teaching, didactic and pedagogical skills)). In order to face those challenges as far as possible specific actions were taken (i.a. assessing base level of participants; assessing prior knowledge; eight-month time gap between pre- and post-test; providing incentive for participants; translation of questionnaire by native speakers; ensuring similar assessment situation in schools; ...).

The summarized results of stage I (main research question Qb_3) of the quantitative main study[**] showed that educational robotics has a significant positive impact on a group of content-related topics (e.g. a group of topics related to programming, mathematics and robotics and a group of topics related to social aspects), rather than on separate thematic topics (e.g. text-based programming or principles of computer science only). These findings suggest that educational robotics should not only focus on separate, isolated topics but rather should be applied as an integrated approach, fostering a holistic understanding and acceptance of different areas and fields. Summarized results of stage II (sub-research question $Qb_{3.1}$) did not suggest a significant change of young students technical skills but a strong impact on young school students' technical interests. Regarding stage II (sub-research question $Qb_{3.2}$) distinctive features between experimental- and control-group students were found for several scales related to career-, personal-interests and attitudes towards the teacher.

Study outcomes form the basis for further discussions about possible improvements and enhancements in the area of educational robotics. Thus, for example, covers the question of how to attract students who are not already interested in science and technology (as also discussed by Alimisis (2013)). Furthermore, it is crucial to familiarize people as early as possible with science and technology and to develop concepts to foster and support motivated young students. As study results show, there already exists great interest in those science-/technology-related topics in early school years. Young students had high expectations and sometimes maybe an idealized image of school-based robotics activities as high pre-test results at interest-/-attitude-related categories show. Those images did not always correspond to reality and, therefore, expectations were not met which led to lower post-test results in certain categories (as also discussed in the article by Nugent et al. (2012)). Results also show, that stu-

[**]For a detailed description of all stage I and stage II results please refer to Sections 4.4.5, 4.4.6 and 4.4.7. The detailed discussion of results with regard to the research questions and hypotheses can be found in Section 4.4.8

dents intending to participate in robotics activities have a diverse set of interests, not limited to certain technical aspects and categories. All these aspects have to be considered in the conceptualization of educational robotics programs. Finally, findings of this study stress the crucial role of the teacher in the context of educational robotics (as also stated by Demo et al. (2012) and Pohlen (2015)) which is documented by high positive attitude rates and correlations between attitudes towards the teacher and technical skill scores.

Future work comprises steps in order to ease the limitations and shortcomings as discussed in Section 4.4.9 such as a more detailed investigation of teachers' influence on students' skills and attitudes in the context of educational robotics. The detailed discussion of next steps and suggestions for future work can be found in Section 4.4.10.

On the one hand, outcomes of this study will further be used to improve support measures provided by university institutions (e.g. robotics introduction courses for students at the university as described by Hofmann and Steinbauer (2010)) by fostering specific skills and correlated areas (e.g. computer science/textual programming). On the other hand, findings and results will also be used to enhance educational robotics activities at school level. In this context study results will help to improve and extend the education of teachers as well as students of teaching by a train-the-trainer approach. Furthermore, results of the study also form the basis to conceptualize and develop new educational programs (in the context of using educational robotics as a learning tool) by better understanding students' interests, attitudes and motivations. Finally, the evaluation concept and instrumentation developed for this study can be applied to evaluate other initiatives and projects as well.

Chapter 5

Conclusion

The chapter provides a summary of the topics covered within the scope of this thesis. It also summarizes results, findings and conclusions (Section 5.1). Finally, limitations and shortcomings of this thesis are recapped and possible future research attempts are discussed in Section 5.2.

5.1. Summary and Conclusion

In general, the goals of this PhD thesis could be summarized as *(a)* the development of novel educational intervention concepts using robotics as a learning tool and *(b)* the systematic empirical evaluation of the impact of educational robotics on young people. Regarding the educational concept development (*a*) following main research questions have been addressed:

- Qa_1: *What are open issues and challenges in educational robotics (in the context of using robotics as a learning tool)*?
- Qa_2: *What is the current status and what are open issues in teaching fundamental concepts of artificial intelligence at different educational levels ('education in AI')?*
- Qa_3: *Which novel educational intervention concepts are needed to address those challenges (applying, amongst others, educational robotics as a learning tool)?*

In the context of the empirical evaluation (*b*) the following main questions guided this research:

- Qb_1: *What are the motivational factors and inherent values of educational robotics and, furthermore, what is the long-term effect of the involvement in educational robotics activities on the individual career development of school students?*
- Qb_2: *Are the novel educational intervention concepts (cross-generational educational robotics / education in AI) working as expected?*
- Qb_3: *Is there a difference/change in the outcome (compared between before and after participating in educational robotics activities) in terms of technical skills, social aspects and soft skills and science-related attitudes and interests between school students participating in educational robotics activities compared to school students not participating in educational robotics activities?*

– $Qb_{3.1}$: *Is there a difference/change in the outcome (compared between before and after participating in educational robotics activities) in terms of technical skills, social aspects and personal interests between young students (up to the age of 12) participating in educational robotics activities compared to young students not participating in educational robotics activities?*

– $Qb_{3.2}$: *How do students intending to participate in educational robotics activities differ from students not intending to participate in educational robotics activities in terms of technical skills, social aspects and soft skills, science related attitudes, career and personal interests as well as attitudes towards their teacher?*

5.1.1. Educational Intervention Concepts

Within the context of this thesis educational robotics was applied in terms of a motivating, hands-on learning tool to support teaching, learning and to foster technical skills (science, technology, engineering, mathematics (STEM), computer science) as well as social and cognitive skills from kindergarten to secondary school.

Regarding main research questions Qa_1 and Qa_2 (Chapters 2 and 3): As educational robotics has gained increased attention over the last decades a large number of different educational robotics approaches, projects, initiatives and publications can be found. Next to technical aspects many publications focus on there is a need to also emphasize the underlying pedagogical concepts and methods. Furthermore, educational robotics approaches with special focus on pre-school children are less widespread (compared to approaches for pre- and secondary school students). In order to be prepared for the rapidly changing field of science and technology it is important to familiarize children with science and technology from an early age on, using age-appropriate pedagogical methods. In addition, it is important as well to address people who are not yet technically interested. With artificial intelligence (AI) becoming part of our daily life it is also crucial to familiarize people with fundamental concepts and techniques behind AI (especially with regard to future jobs and careers in science and engineering). Instead of just *using* technology people need to *understand* the basics behind by developing technological/AI 'literacy'. Teaching fundamental topics of AI and computer science at school or pre-school level is quite rare at the moment. Furthermore, teaching those topics independently from specific programming languages or learning tools on different educational levels and adapted for different age groups hardly exists.

Addressing main research question Qa_3 two innovative educational intervention concepts have been designed, implemented and evaluated. Those concepts have been developed considering pedagogical and didactical aspects applying well-proven, age-appropriate learning tools and teaching techniques/methods.

The first concept entitled **'Pre-School Educational Robotics in a Cross- Generational Context'** was described in Chapter 3, Section 3.2. It applied a cross-generational, cross-institutional (kindergartens, schools, universities) approach focusing on kindergarten children and integrating school students up to the age of thirteen as well as senior citizens in order to initiate a vital social process among the different age groups (broadening the target audience). The goal was to familiarize the target audience (in particular pre-school children and school students) with science and technology in a playful way using educational robotics as learning tool. A pilot project was conducted and empirically evaluated. Overall results of the data analyses indicate that the goals which have initially been defined, were achieved (evaluation details see next section). Findings and experiences gained from this cross-generational educational robotics concept formed the basis for the second concept entitled **'Education in Artificial Intelligence'** (discussed in Chapter 3, Section 3.3). It dealt with the development and implementation of an approach to familiarize different age groups on different educational levels (from kindergarten to university) with fundamental topics of artificial intelligence (AI) using different educational tools and platforms. By using an analogy with the process of developing skills in 'classic' literacy (reading/writing) the AI education concept aimed at fostering AI literacy. The concept used educational robotics as a learning tool, along with a broad range of other tools and methods to teach fundamental concepts of artificial intelligence to kindergarten children, school students (primary, middle, secondary/high school) and undergraduate university students. Four proof-of-concept projects (kindergarten, middle school, high school, university) were conducted and empirically evaluated (evaluation details see next section).

5.1.2. Empirical Evaluation

Regarding main research questions Qb_1 - Qb_3 (Chapter 4): Various stories of success regarding the positive impact of educational robotics can be found in current literature. There is the subjective impression by students, teachers, mentors and researchers that the educational robotics approach works well. However, literature often deals with self-reported data or anecdotal reports (Barker et al., 2012a). The necessity and importance of a systematic evaluation using standardized evaluation methodology and a reliable experimental design in order to validate the impact of educational robotics through research evidence is stressed in current literature (Alimisis, 2013). Hardly any empirical studies exist which focus on the investigation of the impact in terms of the change or improvement of technical- and social-skills as well as science related attitudes and interests of involved students in an empirical way, covering a wider region, an extended period of time, different age groups and a broad population. Furthermore, there is a need for investigating the long-term effects of educational robotics on students' ways through school, college and later careers (Cole, 2012; Catlin and Blamires, 2010) but relatively few studies investigate this issue (Stubbs et al., 2012).

Addressing these challenges, a comprehensive, systematic empirical evaluation concept applying a mixed methods research approach (combining qualitative and quantitative methods (Johnson and Onwuegbuzie, 2004)) was developed and implemented (see Chapter 4). The overall evaluation concept relies on the three pillars *qualitative pre-study*, *evaluation of intervention concepts* and *quantitative main study*. Figure 4.1 schematically depicts this structure. The entire evaluation concept applies a proven, well-grounded methodology respecting general rules of designing evaluations for specific educational programs (Stubbs et al., 2012).

Qualitative Pre-Study The qualitative pre-study (Chapter 4, Section 4.2) addressing research question Qb_1 aimed at identifying the motivational factors inherent to the educational robotics approach and, furthermore, at the extraction of role models and later careers of young people who participated in educational robotics activities (investigating the long-term aspect). This was accomplished by means of investigating careers and stories of nine former participants of junior robotics competitions (in particular RoboCupJunior). The technique of conducting and analyzing semi-structured qualitative interviews (Wengraf, 2001) formed the basis of that evaluation. Results of this pre-study show that RCJ as an educational robotics approach generates three important motivational factors (inherent values, so called 'the hooks') namely the *social experience* (friends, teamwork and international contacts), the *engaged community* (schools, motivating teachers, academics and family) and the *feelings* *of success* (personal development, placing and positive memories). Regarding the nine interviewees there is an obvious positive relationship between their educational robotics/RCJ experiences and their future careers. All of them pursued science and engineering related studies, two continued in the major level of RoboCup, finished their master theses and entered the professional life (started a PhD respectively).

The lessons learned from this pre-study laid the basis for the evaluation of educational intervention concepts (see next paragraph) and, furthermore, for the development of the quantitative main study (see second next paragraph). Finally, the findings of this pre-study are also used to improve and extend the support actions for schools and students (provided by university) in order to attract more students to engineering and scientific education.

Evaluation of Intervention Concepts Addressing research question Qb_2 this evaluation investigated whether the educational intervention concepts developed (summarized in the previous Section 5.1.1) work as expected and whether the goals of each concept were achieved during the pilot implementations. In general, the applied evaluation methodology followed a qualitative approach but also comprised quantitative elements.

Regarding the evaluation of the first concept *'Pre-School Educational Robotics in a Cross- Generational Context'* semi-structured qualitative interviews as well as passive and active participant observations, informal interviews, field notes and discussions were the primary research methods (see Chapter 4, Section 4.3.1). Qualitative data showed that kindergarten children were familiarized with science and technology in a playful and sustainable way (follow-up activities in kindergarten, children talking and asking questions about the robots months afterwards). Children were actively involved in the hands-on activities (e.g. programming the Bee-Bot robots, interacting with the robots, asking and being excited about the robots) and interacted with school students and senior citizens in the sense of an education partnership. The analysis of the semi-structured interviews with school students revealed that both students and kindergarten children gained various technical and social skills during their involvement in the project (e.g. learning basics of programming and robotics; improving English and presentation skills; recognition of the difficulty of programming robots and the necessity of applying teamwork; discovering that children understand the functioning of robots quite fast).

The evaluation of the second concept *'Education in Artificial Intelligence'* comprised qualitative (participant observation, field notes, discussions, informal and semi-structured interviews, drawing interpretations) and quantitative research methods (open ended and multiple choice questions, self- and foreign-evaluation of acquired skills, feedback questionnaires) (see Chapter 4, Section 4.3.2). Evaluation results of the pilot implementations for each module indicate that the proposed AI education concept aiming at fostering AI literacy worked as expected (see the overview table in Figure 4.4). The proof-of-concept implementation in a representative kindergarten showed that children explored fundamental AI topics in a playful way and understood the (simplified) AI concepts. Results of the pilot project for the middle school module indicated that students got a basic understanding of fundamental AI/computer science topics but had problems to understand the connection between those topics and the application in real life. Results for the high school module showed that students were familiar with a broad range of fundamental AI topics and got a well-founded understanding of all AI literacy topics. At university level a course on basic AI techniques was conducted for several years. Regarding the university module it turned out that, by applying new learning tools and motivational hands-on exercises, almost all students successfully completed the course. Evaluation results of those pilot implementations indicate that the proposed AI education concept aiming at fostering AI literacy works.

Summarizing the evaluation results after analyzing all gathered data it can be concluded that the novel educational intervention concepts presented were working as expected. Within the context of first proof-of-concept implementations the evaluation results showed that both concepts achieved almost all of their goals. The results indicated that the cross-generational educational robotics intervention concept developed is one way of successfully introducing pre-school children and in parallel school students and senior citizens to robotics and computer science. Results and lessons learned from the first proof-of-concept projects are the basis to adapt, improve and extend the AI education concept, pursuing the long-term goals of establishing science and technology in early years of education and, furthermore, fostering AI literacy.

Quantitative Main Study Addressing main research question Qb_3 the goal of this study was to evaluate the impact of educational robotics on students' technical- and social-skills and the impact on students' attitudes and interests towards science and technology (Chapter 4, Section 4.4). Therefore, a widespread, mid-term approach was applied, aiming to gather solid and valuable empirical data on a larger geographical scale. Based on a well-proven methodology a quasi-experimental two-group design (experimental- and control-group) comprising pre- and post-tests was applied (Diekmann, 2007; Barreto and Benitti, 2012; Bortz and Döring, 2006; Trochim et al., 2015). The assessment instrument was a student questionnaire based on different already proven assessment tools and survey instruments which have been validated and/or applied and tested in previous studies, theses and investigations (Nugent et al., 2010; Jomento-Cruz, 2010; Dagienė and Futschek, 2008; University of Waterloo, 2013; Austrian Computer Society (OCG), 2013; OECD, 2006; Clark, 2004; Fraser, 1981; Hansen and McNeal, 1997).

The quantitative main study was divided into two stages (stage I, stage II). Stage I addressed the main research question investigating whether there is a difference between control group (CG) and experimental group (EG) students (before and after the experimental group participated in educational robotics activities). It covered a period of approximately eight months and comprised students from different types of secondary schools in Austria and Sweden.

In addition, after applying the overall evaluation design and instrumentation within the context of stage I, stage II of the quantitative main study dealt with two sub-research questions. First, it encompassed the evaluation of the impact of educational robotics on young school students (middle school; up to the age of twelve) regarding technical skills, social aspects and personal interests (sub-research question $Qb_{3.1}$). Therefore, another evaluation instrument focusing on young school students was designed, tested and a pilot study was conducted in two selected middle schools (pre-/post-test, EG/CG). Second, stage II focused on the investigation of distinctive features between experimental- and control-group students (in terms of technical skills, social aspects, soft skills, science related attitudes, career and personal interests, attitudes towards the teacher; sub-research question $Qb_{3.2}$). This study comprised participants from different types of secondary schools in eight different countries worldwide (Europe, Asia, Australia). Therefore, based on the findings and lessons learned from stage I of the study, the assessment instrument was adapted, extended and translated into the respective languages.

Using well-grounded statistical methods and software packages (Mayers, 2013; Meyers et al., 2013; O'Brian and Kaiser, 1985; Delisle et al., 2010; Bortz and Döring, 2006; Eckstein, 2013), the gathered data were analyzed around different sub-scales related to technical- and soft-skills, social aspects, attitudes and interests towards science, personal and career interests as well as attitudes towards the teacher.

The summarized results of stage I (main research question Qb_3) of the quantitative main study showed that educational robotics has a significant positive impact on a group of content-related topics (e.g. a group of topics related to programming, mathematics and robotics and a group of topics related to social aspects), rather than on separate thematic topics (e.g. text-based programming or principles of computer science only). These findings suggest that educational robotics should not only focus on separate, isolated topics but rather should be applied as an integrated approach, fostering a holistic understanding and acceptance of different areas and fields. Summarized results of stage II (sub-research question $Qb_{3.1}$) did not suggest a significant change of young students' technical skills between pre- and post-test but results indicated a strong impact on young school students' technical interests. Regarding stage II (sub-research question $Qb_{3.2}$) significant distinctive features between experimental- and control-group students were found for several scales related to career-, personal-interests and attitudes towards the teacher. The detailed discussion of all results can be found in Chapter 4, Section 4.4.8 whereas detailed results are presented in Sections 4.4.5, 4.4.6 and 4.4.7.

Outcomes of this evaluation form the basis for further discussions about possible improvements and enhancements in the area of educational robotics. Thus, for example, covers the question of how to attract students who are not already interested in science and technology (as also discussed by Alimisis (2013)). Furthermore, it is crucial to familiarize people as early as possible with science and technology and to develop concepts to support motivated young students. As shown by this study there already exists great interest in those science- and technology-related topics in early school years. Young students have high expectations and sometimes and idealized image of school-based robotics activities (documented by high pre-test results at interest- and attitude-related categories). Those images do not always correspond to reality and therefore expectations are not always met (as documented by lower post-test scores in certain categories). Results also showed that students intending to participate in robotics activities have a diverse set of interests, not limited to certain technical aspects and categories. All these aspects have to be considered during the development of educational interventions/programs. Findings of this study also stress the crucial role of the teacher in the context of educational robotics (as also stated by Demo et al. (2012)) which is documented by high positive attitude rates and correlations between attitudes towards the teacher and technical skill scores.

5.2. Limitations and Future Work

The work presented in this thesis has of course several shortcomings and limitations. This final section provides an overview of those limitations and presents suggestions for future research.

Regarding the AI education concept presented in Chapter 3 (Section 3.3) it has to be mentioned that no proof-of-concept project was implemented in a primary school. Therefore, no data is available in order to verify whether the activities developed for this age group and educational level would work. In this context an additional module focusing on primary school children aged between eight and ten years of age has to be implemented and evaluated. The content and topics for middle school students turned out to be too extensive for the short time available. Therefore, this module has to be adapted and could then be implemented as part of an elective course in a middle school.

Due to the relatively small sample of participants the evaluation results only provide preliminary insights and first hints. In order provide additional, sound underlying data documenting the success of the educational concepts, further implementations and evaluations in different kindergartens, schools and universities are necessary. In this context it is planned to modify and conduct the AI high school module in the form of a summer research week for gifted secondary school students. In general, a more detailed quantitative evaluation regarding the medium- and long-term impact of those educational concepts would be needed. Certain modules of the AI education concept (i.e. university) also require a more detailed evaluation (questionnaire, self-evaluation, quantitative feedback). To gather valid long-term data it would be necessary to follow a group of students participating in the entire program (from kindergarten to university). It has also to be stated that the applied approach of using an analogy with the development of reading/writing literacy (regarding the AI education concept) is only one possibility. Analogies with other literacies like mathematics, science, . . . might be conceivable as well. Finally, the AI education concept developed and evaluated within the scope of this thesis will serve as basis for an extensive follow-up project focusing on training and certifying teachers/mentors as well as students in basic and advanced AI topics.

Concerning the empirical evaluation of the impact of educational robotics as described in Chapter 4 following remarks, limitations and open issues can be summarized:

The qualitative pre-study (Chapter 4, Section 4.2) provides first hints and preliminary insights in order identify the inherent values of an educational robotics approach like RoboCupJunior. The group of nine interviewees (former RoboCupJunior participants) is not representative in any way, though even a small sample can provide valuable information for this kind of research question. Since all of the interviewees did have a positive opinion towards educational robotics it would be important to investigate also negative examples, for instance students who were not influenced by their involvement in educational robotics activities in their future careers, and/or have negative attitudes towards educational robotics. In this regard a series of follow-up studies, such as ethnographic studies of the teachers, content-related analysis of the teaching material and a long-term shadowing study of selected students from different age ranges need to be conducted. These follow-up studies would also ease the limitations of this pre-study (i.e. small number of interviewees which all had successful and positive experiences).

Empirical studies applying a quasi-experimental design like the quantitative main study presented in Chapter 4, Section 4.4 have to consider and eliminate or mitigate possible confounding factors. These confounding factors can have a crucial influence on study results. The current study faces some limitations and shortcomings (i.e. no randomized assignment of study participants; prior knowledge of participants; learning effects between pre- and post-test; participants' not being motivated to answer questions honestly and truthfully; inhomogeneity of experimental- and control-groups; applying the study in different schools and countries; slightly different activities in experimental- and control-groups across different schools; influence of the teacher (quality of teaching, didactic and pedagogical skills); language issues due to instrument translations, . . .). In order to face those challenges as far as possible specific actions were taken (i.e. assessing base level of participants; assessing prior knowledge; eight-month time gap between pre- and post-test; providing an incentive/reward for participating in the study; translation of questionnaire by native speakers; ensuring similar assessment situation in schools). Furthermore, the results regarding science related attitudes and social aspects/soft skills are based on self-assessment questionnaires, reflecting students' subjective view and opinion. Other assessment instruments (e.g. knowledge tests,...) might lead to different results. The evaluation design developed is one first attempt to address the extremely complex question concerning the impact of educational robotics. It is important to mention that this study provides some initial evidence on the impact of educational robotics but further investigation is needed to underpin or disprove the results.

A detailed discussion of limitations and counter measures can be found in Chapter 4, Section 4.4.9. Future work comprises steps in order to ease those limitations and shortcomings (a detailed discussion of future work can be found in Chapter 4, Section 4.4.10):

- Adapting and shortening the assessment instruments to avoid high drop-out rates at post-test due to high complexity and high expenditure of time for completing the questionnaire.
- Applying other assessment instruments like knowledge tests, problem-solving skill tests, psychological testing procedures, critical thinking assessments (important additional insights; prove or disprove results of this study).
- Conducting the entire study in different countries and different schools with a bigger sample.
- Conducting a more detailed investigation of teachers' influence on students' skills and attitudes.
- Analyzing the large body of gathered data with respect to different aspects and research questions (e.g. gender, social or regional aspects, . . .).
- Enhancing the applied evaluation design to conduct an in-depth analysis of the impact of educational robotics on certain subject areas and to address certain limitations of the current study (i.e. 3-group design, one teacher for EG/CG students; pre-/post- and follow-up-tests).

Outcomes of this empirical evaluation will further be used to improve support measures provided by university institutions (e.g. robotics introduction courses for students at the university; in this regard see Chapter 2, Section 2.1) by fostering specific skills and correlated areas (e.g. computer science/textual programming). Findings and results will also be used to enhance educational robotics activities at school level. In this context evaluation results will help to improve and extend the education of teachers as well as students of teaching by a train-the-trainer approach. Furthermore, results also form the basis to conceptualize and develop new, effective educational programs and approaches (using educational robotics as a learning tool) by better understanding students' interests, attitudes and motivations. Finally, the evaluation concept and instrumentation developed for this study can be applied to evaluate other initiatives and projects as well.

"I've still got the greatest enthusiasm and confidence in the mission."
- HAL 9000 (A Space Odyssey)

Bibliography

ACKERMANN, E. 2001. Piaget's constructivism, Papert's constructionism: What's the difference. *Future of learning group publication 5,* 3, 438. (Cited on page 19.)

ACKERMANN, E. K. 2004. Constructing knowledge and transforming the world. *A learning zone of one's own: Sharing representations and flow in collaborative learning environments 1*, 15–37. (Cited on page 19.)

ALBU, A. B. 2012. Learning Artificial Intelligence Clip by Clip. In *IEEE Frontiers in Education Conference (FIE)*. 789–794. (Cited on page 23.)

ALIMISIS, D., Ed. 2009. *Teacher Education on Robotics-Enhanced Constructivist Pedagogical Methods*. School of Pedagogical and Technological Education. (Cited on pages 1, 7, 8, 12, 13, 21, 43, 52, 53, and 54.)

ALIMISIS, D. 2012. Robotics in education & education in robotics: Shifting focus from technology to pedagogy. 7–14. (Cited on pages 1, 2, 8, 11, 12, 13, 39, 40, and 41.)

ALIMISIS, D. 2013. Educational robotics: Open questions and new challenges. *"Themes in Science and Technology Education" 6,* 1, 63–71. (Cited on pages 1, 2, 3, 7, 8, 13, 24, 25, 27, 39, 40, 41, 42, 63, 113, 119, 123, and 126.)

ALIMISIS, D., GRANOSIK, G., AND MORO, M., Eds. 2014. *Proceedings of the International Conference on Robotics in Education (RiE 2014) and the International Workshop 'Teaching robotics, teaching with robotics (TRTWR)'*. Padova, Italy. (Cited on page 12.)

ALIMISIS, D. AND KYNIGOS, C. 2009. Constructionism and robotics in education. *Teacher Education on Robotic-Enhanced Constructivist Pedagogical Methods*, 11–26. (Cited on pages 12 and 19.)

ALTIN, H. AND PEDASTE, M. 2013. Learning approaches to applying robotics in science education. *Journal of Baltic Science Education 12,* 3, 365–377. (Cited on pages 2, 12, 13, 19, 20, 21, 22, 40, 41, 52, 53, and 54.)

ANDERSON, J. R. 1990. *Cognitive psychology and its implications* . WH Freeman/Times Books/Henry Holt & Co. (Cited on page 21.)

ANNING, A. AND RING, K. 2004. *Making Sense of Children's Drawings*. Open University Press. (Cited on pages 78 and 79.)

ATMATZIDOU, S., MARKELIS, I., AND DEMETRIADIS, S. 2008. The use of LEGO Mindstorms in elementary and secondary education: game as a way of triggering learning. In *Workshop proceedings of International Conference on Simulation, Modeling, and Programming for Autonomous Robots (SIMPAR)*. Citeseer. (Cited on pages 11 and 13.)

AUSTRIAN COMPUTER SOCIETY (OCG). 2012, 2013. Biber der Informatik. http://www.ocg.at/sites/ocg.at/files/medien/pdfs/Biber-Aufgaben2012-mitLoesungen-AT-web.pdf. [Online; accessed 02-September-2016]. (Cited on pages 27, 82, 86, 88, 89, 90, 109, 118, and 125.)

BALCH, T., SUMMET, J., BLANK, D., KUMAR, D., GUZDIAL, M., OH́ARA, K., WALKER, D., SWEAT, M., GUPTA, G., TANSLEY, S., JACKSON, J., GUPTA, M., MUHAMMAD, M. N., PRASHAD, S., EILBERT, N., AND GAVIN, A. 2008. Designing Personal Robots for Education: Hardware, Software, and Curriculum. *Pervasive Computing, IEEE 7,* 2 (April), 5–9. (Cited on page 12.)

BALOGH, R., Ed. 2010. *Proceedings of the International Conference on Robotics in Education (RiE 2010)*. Bratislava, Slovakia. (Cited on pages 2 and 12.)

BANDURA, A. 1988. Organisational applications of social cognitive theory. *Australian journal of management 13,* 2, 275–302. (Cited on pages 22 and 46.)

BANDURA, A. AND WALTERS, R. H. 1977. *Social learning theory*. Prentice-Hall Englewood Cliffs, NJ. (Cited on pages 22 and 46.)

BARGH, J. A. AND SCHUL, Y. 1980. On the cognitive benefits of teaching. *Journal of Educational Psychology 72,* 5, 593. (Cited on page 22.)

BARIK, T., EVERETTY, M., CARDONA-RIVERA, R. E., ROBERTS, D. L., AND GEHRINGER, E. F. 2013. A Community College Blended Learning Classroom Experience through Artificial Intelligence in Games. In *IEEE Frontiers in Education Conference (FIE)*. 1525–1531. (Cited on page 23.)

BARKER, B., NUGENT, G., GRANDGENETT, N., AND ADAMCHUK, V., Eds. 2012a. *Robots in K-12 Education. A New Technology for Learning*. IGI Global Information Science Reference. (Cited on pages 1, 2, 3, 9, 12, 24, 27, 40, 52, 63, and 123.)

BARKER, B., NUGENT, G., GRANDGENETT, N., AND ADAMCHUK, V. 2012b. *Robots in K-12 Education. A New Technology for Learning*. IGI Global Information Science Reference. Preface. (Cited on page 8.)

BARR, D., HARRISON, J., AND CONERY, L. 2011. Computational thinking: A digital age skill for everyone. *Learning & Leading with Technology 38,* 6, 20–23. (Cited on page 11.)

BARRETO, F. AND BENITTI, V. 2012. Exploring the educational potential of robotics in schools: A systematic review. *Computers & Education 58*, 978–988. (Cited on pages 3, 13, 27, 32, 63, 82, 84, 118, and 125.)

BELL, T., WITTEN, I., AND FELLOWS, M. 1998. *Computer Science Unplugged: Off-line activities and games for all ages*. Computer Science Unplugged. (Cited on pages 52 and 53.)

BEREITER, C. 1980. Development in writing. L. W. Gregg and E. R. Steinberg, Eds. *Cognitive processes in writing*. (Cited on pages 48 and 54.)

BERS, M. U. 2007. Blocks to robots: Learning with technology in the early childhood classroom. Forword by Elking, D., Teachers College Press. (Cited on pages 12, 19, 42, and 52.)

BERS, M. U. 2008. Using robotic manipulatives to develop technological fluency in early childhood. *Contemporary Perspectives on Science and Technology in Early Childhood Education*, 105–225. (Cited on pages 11, 13, 22, 44, 52, and 53.)

BERS, M. U. 2010. The TangibleK Robotics Program: Applied Computational Thinking for Young Children. *Early Childhood Research & Practice 12,* 2. (Cited on page 23.)

BERS, M. U. AND ETTINGER, A. B. 2012. Robots in K-12 Education: A New Technology for Learning. B. S. Barker, G. Nugent, N. Grandgenett, and V. Adamchuk, Eds. IGI Global Information Science Reference, Hershey, PA. Chapter: Programming Robots in Kindergarten to Express Identity: An Ethnographic Analysis. (Cited on pages 13, 16, and 23.)

BERS, M. U., PONTE, I., JUELICH, C., VIERA, A., AND SCHENKER, J. 2002. Teachers as Designers: Integrating Robotics in Early Childhood Education. *Information Technology in Childhood Education 2002,* 1, 123–145. (Cited on page 16.)

BERS, M. U. AND URREA, C. 2000. Technological Prayers. *Robots for kids: exploring new technologies for learning*, 193. (Cited on page 22.)

BIDDIX, J. P. 2016. Research Rundowns - Instrument, Validity, Reliability. `https://researchrundowns.com/quantitative-methods/instrument-validity-reliability/`. Dewar College of Education at Valdosta State University. [Online; accessed 26-December-2016]. (Cited on pages 33 and 87.)

BLUMENFELD, P. C., SOLOWAY, E., MARX, R. W., KRAJCIK, J. S., GUZDIAL, M., AND PALINCSAR, A. 1991. Motivating project-based learning: Sustaining the doing, supporting the learning. *Educational psychologist 26,* 3-4, 369–398. (Cited on page 21.)

BOJIC, I. AND ARRATIA, J. 2015. Teaching K-12 students STEM-C related topics through playing and conducting research. In *International Conference on Frontiers in Education (FIE)*. IEEE, 548–555. (Cited on page 24.)

BORREGO, M., DOUGLAS, E. P., AND AMELINK, C. T. 2009. Quantitative, Qualitative, and Mixed Research Methods in Engineering Education. *Journal of Engineering Education*, 53–66. (Cited on pages 27, 34, and 66.)

BORTZ, J. AND DÖRING, N. 2006. *Forschungsmethoden und Evaluation für Human- und Sozialwissenschaftler*. Springer Heidelberg. (Cited on pages 33, 82, 84, 87, 91, 92, 96, 107, 113, 118, 119, and 125.)

BOTBALL. 2016. The Botball Educational Robotics Program. `http://www.botball.org/`. [Online; accessed 25-November-2016]. (Cited on pages 9 and 12.)

BRAITENBERG, V. 1984. *Vehicles: Experiments in synthetic psychology*. MIT Press, Campbridge. (Cited on page 59.)

BREDENFELD, A., HOFMANN, A., AND STEINBAUER, G. 2010. Robotics in Education Initiatives in Europe - Status, Shortcomings and Open Questions. In *International Workshop 'Teaching robotics, teaching with robotics (TRTWR)'*. Darmstadt, Germany. (Cited on pages 1, 3, 12, 26, 40, and 63.)

BÜHNER, M. 2011. *Einführung in die Test- und Fragebogenkonstruktion*. Pearson. (Cited on page 87.)

BURGSTEINER, H. 2016. Design and Evaluation of an Introductory Artificial Intelligence Class in Highschools. M.S. thesis, Faculty of Computer Science, Graz University of Technology, Graz, Austria. (Cited on pages xiii, 54, 55, 59, 60, and 80.)

BURGSTEINER, H., KANDLHOFER, M., AND STEINBAUER, G. 2016a. iRobot: Teaching an Evaluated, Competencies-based Introductory Artifcial Intelligence Class in Highschools. In *39th German Conference on Artificial Intelligence*. Klagenfurt, Austria. (Cited on pages xiii, 5, and 50.)

BURGSTEINER, H., KANDLHOFER, M., AND STEINBAUER, G. 2016b. iRobot: Teaching an Evaluated, Competencies-Based Introductory Artificial Intelligence Class in Highschools. *Lecture notes in computer science 9904,* 2016, 218–223. (Cited on pages 2, 5, 23, 40, 42, 46, 49, 55, 59, and 80.)

BURGSTEINER, H., KANDLHOFER, M., AND STEINBAUER, G. 2016c. iRobot: Teaching the Basics of Artificial Intelligence in High Schools. In *6th Symposium on Educational Advances in Artificial Intelligence (EAAI)*. Phoenix, USA, 4126–4127. (Cited on pages 5, 23, 54, 55, 59, and 78.)

BURGUILLO, J. C. 2010. Using game theory and competition-based learning to stimulate student motivation and performance. *Computers & Education 55,* 2, 566–575. (Cited on page 21.)

CACCO, L. AND MORO, M. 2015. The hedgehog: how to integrate robotics in natural science scenarios. In *Workshop position paper at International Conference on Robotics in Education (RiE 2015)*. Yverdon-les-Bains, Switzerland. (Cited on pages 9 and 13.)

CARBONARO, M., REX, M., AND CHAMBERS, J. 2004. Using LEGO robotics in a project-based learning environment. *The Interactive Multimedia Electronic Journal of Computer-Enhanced Learning 6,* 1. (Cited on page 13.)

CARLSON, S., MOSES, L., AND CLAXTON., L. 2004. Individual differences in executive functioning and theory of mind: An investigation of inhibitory control and planning ability. *Experimental Child Psychology 87*, 299–319. (Cited on page 18.)

CATLIN, D. AND BLAMIRES, M. 2010. The principles of Educational Robotic Applications (ERA): a framework for understanding and developing educational robots and their activities. The 12th EuroLogo conference. (Cited on pages 3, 9, 19, 25, 27, 40, and 123.)

CLARK, A., HOLLAND, C., KATZ, J., AND PEACE, S. 2009. Learning to see: lessons from a participatory observation research project in public spaces. *International Journal of Social Research Methodology 12,* 4, 345–360. (Cited on page 35.)

CLARK, D. 2004. Testing Programming Skills with Multiple Choice Questions. *Informatics in Education 3,* 2, 161–178. (Cited on pages 27, 82, 86, 88, 90, 109, 118, and 125.)

COHEN, L., MANION, L., AND MORRISON, K. 2013. *Research methods in education*. Routledge. (Cited on pages 28, 30, and 31.)

COLE, R. K. 2012. Robots in K-12 Education: A New Technology for Learning. B. S. Barker, G. Nugent, N. Grandgenett, and V. Adamchuk, Eds. IGI Global Information Science Reference, Hershey, PA. Chapter: STEM Outreach with the Boe-Bot. (Cited on pages 3, 23, 24, 27, 40, 42, 63, and 123.)

CORBETT, A. T., KOEDINGER, K. R., AND ANDERSON, J. R. 1997. Intelligent tutoring systems. *Handbook of human-computer interaction 5*, 849–874. (Cited on page 24.)

CORBIN, J. AND STRAUSS, A. 2014. *Basics of qualitative research: Techniques and procedures for developing grounded theory*. Sage Publications. (Cited on pages 34 and 78.)

CORRELL, N., WAILES, C., AND SLABY, S. 2014. A One-hour Curriculum to Engage Middle School Students in Robotics and Computer Science using Cubelets. In *Distributed Autonomous Robotic Systems*. University of Colorado, Boulder, USA. (Cited on page 53.)

CRAIGHEAD, J. AND MURPHY, J. B. R. 2007. Using the unity game engine to develop sarge: a case study. *Computer 4552*, 366–372. (Cited on page 60.)

DAGIENĖ, V. AND FUTSCHEK, G. 2008. Bebras international contest on informatics and computer literacy: Criteria for good tasks. In *International Conference on Informatics in Secondary Schools-Evolution and Perspectives*. Springer, 19–30. (Cited on pages 27, 82, 86, 88, 89, 90, 109, 118, and 125.)

DAVYDOV, V. AND RADZIKHOVSKII, L. 1985. Vygotsky's Theory and the Activity Orientated Approach in Psychology. in James Wertsch Editor Culture, Communication and Cognition: A Vygotskian Perspective. Cambridge University Press. (Cited on page 19.)

DE JONG, T. AND VAN JOOLINGEN, W. R. 1998. Scientific discovery learning with computer simulations of conceptual domains. *Review of educational research 68,* 2, 179–201. (Cited on pages 20 and 44.)

DELISLE, T., WERCH, C. E., WONG, A. H., BIAN, H., AND WEILER, R. 2010. Relationship Between Frequency and Intensity of Physical Activity and Health Behaviors of Adolescents. *Journal of School Health 80*, 134–140. (Cited on pages 33, 91, 94, 110, 119, and 125.)

DEMO, G. B., MORO, M., PINA, A., AND ARLEGUI, J. 2012. Robots in K-12 Education: A New Technology for Learning. B. S. Barker, G. Nugent, N. Grandgenett, and V. Adamchuk, Eds. IGI Global Information Science Reference, Hershey, PA. Chapter: In and out of the School Activities Implementing IBSE and Constructionist Learning Methodologies by Means of Robotics. (Cited on pages 1, 7, 17, 20, 113, 120, and 126.)

DENIS, B. AND HUBERT, S. 2001. Collaborative learning in an educational robotics environment. *Computers in Human Behavior 17,* 5, 465–480. (Cited on page 22.)

DENTON, K. AND WEST, J. 2002. *Children's reading and mathematics achievement in kindergarten and first grade*. National Center for Education Statistics. (Cited on page 52.)

DESMOND, D., HORTON, M., MORRISON, A., AND KHORBOTLY, S. 2016. Robotic football dance team: An engineering Fine-Arts interdisciplinary learning experience. In *International Conference on Frontiers in Education (FIE)*. IEEE. (Cited on pages 11 and 13.)

DESSIMOZ, J.-D., BALOGH, R., AND OBDRZALEK, D., Eds. 2015. *Proceedings of the International Conference on Robotics in Education (RiE 2015)*. Yverdon-les-Bains, Switzerland. (Cited on page 12.)

DIEKMANN, A. 2007. *Empirische Sozialforschung - Grundlagen, Methoden, Anwendungen*. Rowohlt Verlag Hamburg. (Cited on pages 29, 34, 35, 64, 78, 82, 84, 87, 113, 118, and 125.)

DILGER, W. 2005. *Künstliche Intelligenz in der Schule*. Technische Universität Chemnitz. (Cited on page 23.)

DUCKWORTH, E. 2005. Critical exploration in the classroom. *The New Educator 1,* 4, 257–272. (Cited on page 19.)

EBELT, K. R. 2012. The Effects of a Robotics Program on Students Skills in STEM, Problem Solving and Teamwork. M.S. thesis, Montana State University. (Cited on page 12.)

ECK, J., HIRSCHMUGL-GAISCH, S., HOFMANN, A., KANDLHOFER, M., RUBENZER, S., AND STEINBAUER, G. 2013. Innovative concepts in educational robotics: Robotics projects for kindergartens in Austria. In *Austrian Robotics Workshop 2013*. Vienna, Austria. (Cited on pages 4, 16, 17, 18, 40, 41, and 43.)

ECKSTEIN, P. P. 2013. *Datenanalyse mit SPSS*. Springer. (Cited on pages 92, 119, and 125.)

EGUCHI, A. 2007. Educational Robotics for Undergraduate Freshmen. In *EdMedia: World Conference on Educational Media and Technology*. Vol. 2007. 1792–1797. (Cited on page 11.)

EGUCHI, A. 2010. What is Educational Robotics? Theories behind it and practical implementation. In *Proceedings of Society for Information Technology & Teacher Education International Conference*, D. Gibson and B. Dodge, Eds. Chesapeake, VA, 4006–4014. (Cited on pages 1, 2, 7, 8, and 39.)

EGUCHI, A. 2012. Robots in K-12 Education: A New Technology for Learning. B. S. Barker, G. Nugent, N. Grandgenett, and V. Adamchuk, Eds. IGI Global Information Science Reference, Hershey, PA. Chapter: Theoretical and Instructional Perspectives. (Cited on pages 1, 7, 8, 10, 11, 12, 13, 19, 20, and 39.)

EGUCHI, A. 2014a. Educational robotics for promoting 21st century skills. *Journal of Automation, Mobile Robotics & Intelligent Systems 8,* 1, 5–11. (Cited on page 11.)

EGUCHI, A. 2014b. Robotics as a learning tool for educational transformation. In *International Conference on Robotics in Education (RiE 2014)*. Padova, Italy. (Cited on page 8.)

EGUCHI, A., HUGHES, N., STOCKER, M., SHEN, J., AND CHIKUMA, N. 2012. RoboCupJunior - A Decade Later. In *RoboCup 2011: Robot Soccer World Cup XV*. Springer-Verlag Berlin Heidelberg, 63–77. (Cited on pages 14 and 65.)

EGUCHI, A. AND SHEN, J. 2013. Student Learning Experience through CoSpace Educational Robotics: 3D Simulation Educational Robotics Tool. In *Cases on 3D Technology Application and Integration in Education*. IGI Global, 93–127. (Cited on page 14.)

ENGESTRÖM, Y., MIETTINEN, R., AND PUNAMÄKI, R.-L. 1999. *Perspectives on activity theory*. Cambridge University Press. (Cited on page 19.)

Engineering^3 . 2016. *Engineering*^{3} A High School Engineering Curriculum where Students Engage in 'Learning through Doing'. `http://engineering3.org/`. [Online; accessed 28-December-2016]. (Cited on pages 34 and 35.)

EPP, K. M. 2008. Outcome-Based Evaluation of a Social Skills Program Using Art Therapy and Group Therapy for Children on the Autism Spectrum. *Children & Schools 30,* 1, 27–36. (Cited on pages 27 and 66.)

ERONEN, P. J., JORMANAINEN, I., SUTINEN, E., AND VIRNES, M. 2005. Kids' Club reborn: Evolution of activities. In *Fifth IEEE International Conference on Advanced Learning Technologies (ICALT'05)*. IEEE, 545–547. (Cited on page 9.)

FEATHERSTON, E., SRIDHARAN, M., URBAN, S., AND URBAN, J. 2014. DOROTHY: Enhancing Bidirectional Communication between a 3D Programming Interface and Mobile Robots. In *5th Symposium on Educational Advances in Artificial Intelligence (EAAI)*. (Cited on page 23.)

FEIL-SEIFER, D. AND MATARIC, M. 2008. Robot-assisted therapy for children with autism spectrum disorders. In *Proceedings of the 7th international conference on Interaction design and children*. ACM, 49–52. (Cited on page 8.)

FELDER, R. M. AND SILVERMAN, L. K. 1988. Learning and teaching styles in engineering education. *Engineering education 78,* 7, 674–681. (Cited on page 20.)

FELICIA, P. 2011. *Handbook of Research on Improving Learning and Motivation through Educational Games: Multidisciplinary Approaches*. IGI Global. (Cited on page 20.)

FERREIN, A., MAIER, C., MÜHLBACHER, C., NIEMUELLER, T., STEINBAUER, G., AND VASSOS, S. 2015. Controlling Logistics Robots with the Action-based Language YAGI. In *IROS Workshop on Workshop on Task Planning for Intelligent Robots in Service and Manufacturing*. (Cited on page 60.)

FERREIN, A., MARAIS, S., POTGIETER, A., AND STEINBAUER, G. 2011. RoboCup Junior: A Vehicle for S&T Education in Africa? In *IEEE Africon 2011*. Livingstone, Zambia. (Cited on page 14.)

FERREIRA, F., DOMINGUEZ, A., AND MICHELI, E. 2012. Twitter, Robotics and Kindergarten. In *International Workshop 'Teaching robotics, teaching with robotics (TRTWR)'*, M. Moro and D. Alimisisi, Eds. Riva del Garda, Italy. (Cited on page 16.)

FH HAGENBERG. 2010. Hexapod Competition. `https://www.fh-ooe.at/campus-hagenberg/studiengaenge/bachelor/hardware-software-design/wissenswertes/hexapod-meisterschaften/`. [Online; accessed 25-August-2016]. (Cited on page 69.)

FIRST. 2016. FIRST Lego League, Tech Competition, Robotics Competition. `http://www.firstinspires.org/`. [Online; accessed 01-December-2016]. (Cited on pages 12 and 25.)

FLICK, U., VON KARDORFF, E., AND STEINKE, I. 2004. *A Companion to Qualitative Research*. SAGE Publications. (Cited on pages 27, 34, 35, 66, and 75.)

FLL. 2016. FIRST Lego League. `http://www.firstlegoleague.org/`. [Online; accessed 25-November-2016]. (Cited on page 9.)

FOK, S. AND ONG, E. 1996. A high school project on artificial intelligence in robotics. *Artificial Intelligence in Engineering 10,* 1, 61–70. (Cited on page 23.)

FRAGER, S. AND STERN, C. 1970. Learning by teaching. *The Reading Teacher 23,* 5, 403–417. (Cited on pages 22 and 43.)

FRANGOU, S., PAPANIKOLAOU, K., ARAVECCHIA, L., MONTEL, L., IONITA, S., ARLEGUI, J., PINA, A., MENEGATTI, E., MORO, M., FAVA, N., MONFALCON, S., AND PAGELLO, I. 2008. Representative examples of implementing educational robotics in school based on the constructivist approach. In *Workshop at International Conference on Simulation, Modeling and Programming for Autonomous Robots*. Venice, Italy, 54–65. (Cited on pages 43 and 52.)

FRASER, B. J. 1981. *TOSRA: Test of Science-Related Attitudes*. The Australian Council for Educational Research, Hawthorn, Victoria. (Cited on pages 27, 82, 86, 88, 89, 90, 109, 118, and 125.)

FRIEDMAN, A., Ed. 2008. *Framework for evaluating impacts of informal science education projects.* National Science Foundation. (Cited on pages 28 and 31.)

FUTSCHEK, G. AND DAGIENE, V. 2009. A contest on informatics and computer fluency attracts school students to learn basic technology concepts. *Proc. 9th WCCE 2009, Education and Technology for a Better World*. (Cited on page 52.)

FUTSCHEK, G. AND MOSCHITZ, J. 2011. Learning algorithmic thinking with tangible objects eases transition to computer programming. In *International Conference on Informatics in Schools: Situation, Evolution, and Perspectives*. Springer, 155–164. (Cited on pages 21 and 44.)

GAGO, J. 2004. Europe needs More Scientists: Report by the High Level Group on Increasing Human Resources for Science and Technology. *Brussels: European Commission*. (Cited on page 1.)

GENLOTT, A. A. AND GRONLUND, A. 2013. Improving literacy skills through learning reading by writing: The iWTR method presented and tested. *Computers and Education 67*, 98 – 104. (Cited on pages 2, 48, and 52.)

GENNARI, R., DODERO, G., AND JANES, A. 2012. Junior university workshops for children. In *International Workshop 'Teaching robotics, teaching with robotics (TRTWR)'*, M. Moro and D. Alimisisi, Eds. Riva del Garda, Italy. (Cited on page 16.)

GERMANN, P. J. 1998. Development of the attitude toward science in school assessment and its use to investigate the relationship between science achievement and attitude toward science in school. *"Journal of Research in Science Teaching" 25,* 8, 689–703. (Cited on page 18.)

GERSTAD, C., HONG, Y., AND DIAMOND., A. 1994. The relationship between cognition and action: performance of children 3 1/2-7 years old on a stroop-like day-night test. *Cognittion 53*, 129–153. (Cited on page 18.)

GOLDSCHMID, B. AND GOLDSCHMID, M. L. 1976. Peer teaching in higher education: A review. *Higher Education 5,* 1, 9–33. (Cited on page 22.)

GOODRICH, M. A. AND SCHULTZ, A. C. 2007. Human-robot interaction: a survey. *Foundations and trends in human-computer interaction 1,* 3, 203–275. (Cited on page 44.)

GRANDGENETT, N., OSTLER, E., TOPP, N., AND GOEMAN, R. 2012. Robots in K-12 Education: A New Technology for Learning. B. S. Barker, G. Nugent, N. Grandgenett, and V. Adamchuk, Eds. IGI Global Information Science Reference, Hershey, PA. Chapter: Robotics and Problem-Based Learning in STEM Formal Educational Environments. (Cited on page 21.)

GRANOSIKR, G., Ed. 2013. *Proceedings of the International Conference on Robotics in Education (RiE 2013)*. Lodz, Poland. (Cited on page 12.)

GRAUPE, D. 2013. *Principles of artificial neural networks*. Vol. 7. World Scientific. (Cited on page 55.)

GRIFFITH, D. S. 2005. First robotics as a model for experiential problem-based learning: a comparison of student attitudes and interests in science, mathematics, engineering, and technology. Ph.D. thesis, Clemson University, USA. (Cited on pages 25, 31, 84, 87, 90, and 112.)

GRISETTI, G., STACHNISS, C., AND BURGARD, W. 2005. Improving Grid-based SLAM with Rao-Blackwellized Particle Filters by Adaptive Proposals and Selective Resampling. In *IEEE International Conference on Robotics and Automation (ICRA)*. Barcelona, Spain. (Cited on page 44.)

GRUBER, H. AND VONECHE, J., Eds. 1977. *The Essential Piaget*. Basic Books. (Cited on page 51.)

GRUEHN, S. 2000. *Unterricht und schulisches Lernen*. Waxmann, Münster, Germany. (Cited on page 91.)

GRÜMER, K.-W. 1974. *Beobachtung*. Teubner, Stuttgart. (Cited on page 35.)

GRUNBERG, D., ELLENBERG, R., KIM, Y. E., AND OH, P. Y. 2009. From RoboNova to HUBO: Platforms for Robot Dance. *Progress in Robotics; Communications in Computer and Information Science 44*, 19–24. (Cited on page 45.)

HAMMER, D. 1997. Discovery learning and discovery teaching. *Cognition and instruction 15,* 4, 485–529. (Cited on page 20.)

HAMNER, E., LAUWERS, T., AND BERNSTEIN, D. 2010. The Debugging Task: Evaluating a Robotics Design Workshop. In *AAAI Spring Symposium: Educational Robotics and Beyond*. (Cited on page 30.)

HAMNER, E., LAUWERS, T., BERNSTEIN, D., NOURBAKHSH, I. R., AND DISALVO, C. F. 2008. Robot Diaries: Broadening Participation in the Computer Science Pipeline through Social Technical Exploration. In *AAAI Spring Symposium: Using AI to Motivate Greater Participation in Computer Science*. 38–43. (Cited on pages 11, 21, and 31.)

HAMNER, E., LAUWERS, T., BERNSTEIN, D., STUBBS, K., CROWLEY, K., AND NOURBAKHSH, I. 2008. Robot Diaries Interim Project Report: Development of a Technology Program for Middle School Girls. *Carnegie Mellon University, Robotics Institute, PA*. (Cited on page 11.)

HAMNER, E., ZITO, L., CROSS, J., SLEZAK, B., MELLON, S., HARAPKO, H., AND WELTER, M. 2016. Utilizing engineering to teach non-technical disciplines: Case studies of robotics within middle school English and health classes. In *International Conference on Frontiers in Education (FIE)*. IEEE. (Cited on page 11.)

HAN, J., CAMPBELL, N., JOKINEN, K., AND WILCOCK, G. 2012. Investigating the use of non-verbal cues in human-robot interaction with a Nao robot. In *IEEE 3rd International Conference on Cognitive Infocommunications (CogInfoCom)*. IEEE, 679–683. (Cited on page 45.)

HANDLER, J. 2000. Robots for the Rest of Us. *Robots for Kids: Exploring New Technologies for Learning*, 1. (Cited on page 8.)

HANSEN, W. AND MCNEAL, R. 1997. How D.A.R.E. works: An examination of program effects on mediating variables. *Health Education & Behavior 24,* 2. (Cited on pages 27, 82, 86, 88, 89, 90, 96, 109, 118, and 125.)

HEINZE, C., HAASE, J., AND HIGGINS, H. 2010. An Action Research Report from a Multi–Year Approach to Teaching Artificial Intelligence at the K–6 Level. In *1st Symposium on Educational Advances in Artificial Intelligence (EAAI)*. (Cited on page 23.)

HIDI, S. AND HARACKIEWICZ, J. M. 2000. Motivating the Academically Unmotivated: A Critical Issue for the 21st Century. *"Review of Educational Research" 70,* 2, 151–179. (Cited on page 18.)

HIRSCHMANNER, M., LAMMER, L., AND VINCZE, M. 2015. Mattie: a simple educational platform for children to realize their first robot prototype. In *Proceedings of the 14th International Conference on Interaction Design and Children*. ACM, 367–370. (Cited on page 13.)

HIRSCHMUGL-GAISCH, S., ECK, H., AND JUNGWIRTH, H. 2011. Kinder reisen durch die Wissenschaft. In *Fachtagung fuer elementare Bildung*. Graz, Austria. (Cited on pages 43 and 44.)

HO, R. 2006. *Handbook of Univariate and Multivariate Data Analysis and Interpretation with SPSS*. Chapman & Hall/CRC. (Cited on page 92.)

HOFMANN, A. AND STEINBAUER, G. 2010. The Regional Center Concept for RoboCupJunior in Austria. In *International Conference on Robotics in Education (RiE 2010)*. Bratislava, Slovakia. (Cited on pages 1, 14, 15, 26, 82, and 120.)

HOVE, S. E. AND ANDA, B. 2005. Experiences from Conducting Semi-Structured Interviews in Empirical Software Engineering Research. In *11th IEEE International Software Metrics Symposium (METRICS)*. (Cited on pages 27, 66, and 78.)

HUCK, S. W., CORMIER, W. H., AND BOUNDS, W. G. 1974. *Reading statistics and research*. Harper & Row New York. (Cited on pages 33 and 110.)

HUSSAIN, S., LINDH, J., AND SHUKUR, G. 2006. The effect of LEGO training on pupils' school performance in mathematics, problem solving ability and attitude: Swedish data. *Educational Technology & Society 9,* 3, 182–194. (Cited on page 33.)

IMST. 2011. Children visit Science (Kinder reisen durch die Wissenschaft). http://www.verwaltung.steiermark.at/cms/. Report by the IMST Initiative (Innovations make schools top); [Online; accessed 29-December-2016]. (Cited on pages 43 and 44.)

JAHODA, M., LAZARSFELD, P. F., AND ZEISEL, H. 1960. *Die Arbeitslosen von Marienthal: ein soziographischer Versuch über die Wirkungen langandauernder Arbeitslosigkeit, mit einem Anhang zur Geschichte der Soziographie*. Vol. 2. Verlag für Demoskopie. (Cited on page 29.)

JAMRIS 2014. *"Journal of Automation, Mobile Robotics & Intelligent Systems" 8,* 1. Special issue on educational robotics. (Cited on page 12.)

JEWELL, S. L. 2011. The Effects of the NXT Robotics Curriculum on High School Students' Attitudes in Science Based on Grade, Gender, and Ethnicity. Ph.D. thesis, Liberty University. (Cited on pages 2, 12, 26, and 89.)

JOHNSON, G. M. 2005. Instructionism and Constructivism: Reconciling Two Very Good Ideas. *Online Submission*. (Cited on pages 19, 45, 52, and 53.)

JOHNSON, R. B. AND ONWUEGBUZIE, A. J. 2004. Mixed methods research: A research paradigm whose time has come. *Educational researcher 33,* 7, 14–26. (Cited on pages xv, 29, 30, 63, 64, and 123.)

JOMENTO-CRUZ, I. L. 2010. Robotics as a Means of Increasing Student Achievement in Middle School Science. M.S. thesis, Louisiana State University. (Cited on pages 12, 27, 82, 86, 88, 90, 94, 108, 118, and 125.)

JONASSEN, D. H. 2000. Toward a design theory of problem solving. *Educational technology research and development 48,* 4, 63–85. (Cited on page 21.)

JORGENSEN, D. L. 1989. *Participant Observation: A Methodology for Human Studies*. Sage. (Cited on pages 76 and 78.)

JUMP, T. E. 2015. *Engineering^3 A Preparatory Course for Engineering Students Integrating Engineering Concepts with Applications*. *Engineering^3* LLC, USA. (Cited on pages 9, 21, and 34.)

JUNG, S. 2013. Experiences in developing an experimental robotics course program for undergraduate education. *IEEE Transactions on Education 56,* 1, 129–136. (Cited on page 21.)

KAFAI, Y. B., PEPPLER, K. A., BURKE, Q., MOORE, M., AND GLOSSON, D. 2010. Froebel's Forgotten Gift: Textile Construction Kits as Pathways into Play, Design and Computation. In *International Conference on Interaction Design and Children*. Barcelona, Spain. (Cited on page 16.)

KANDLHOFER, M. AND STEINBAUER, G. 2013. Evaluating the impact of RoboCupJunior on pupils' abilities. In *RoboCup 2013 Symposium Proceedings - Workshop on Educational Robotics*. Eindhoven, Netherlands. (Cited on pages 6, 63, 82, 84, 86, and 87.)

KANDLHOFER, M. AND STEINBAUER, G. 2014. Evaluating the impact of robotics in education on pupils' skills and attitudes. In *International Conference on Robotics in Education (RiE 2014)*. Padova, Italy. (Cited on pages 6, 86, and 87.)

KANDLHOFER, M. AND STEINBAUER, G. 2015. Evaluating the impact of educational robotics on pupils' technical- and social-skills and science related attitudes. Talk at European Robotics Forum 2015; Vienna, Austria. (Cited on page 6.)

KANDLHOFER, M. AND STEINBAUER, G. 2016. Evaluating the impact of educational robotics on pupils' technical- and social-skills and science related attitudes. *Journal of Robotics and Autonomous Systems 75, Part B*, 679 – 685. (Cited on pages 6, 63, and 83.)

KANDLHOFER, M., STEINBAUER, G., HIRSCHMUGL-GAISCH, S., AND ECK, J. 2013. A cross-generational robotics project day: Pre-school children, pupils and grandparents learn together. In *International Conference on Robotics in Education (RiE 2013)*. Lodz, Poland. (Cited on pages 4, 16, 40, 41, and 43.)

KANDLHOFER, M., STEINBAUER, G., HIRSCHMUGL-GAISCH, S., AND ECK, J. 2015. Children discover science: robotics, informatics and artificial intelligence in kindergarten and school. In *Workshop position paper at International Conference on Robotics in Education (RiE 2015)*. Yverdon-les-Bains, Switzerland. (Cited on pages 5, 53, and 56.)

KANDLHOFER, M., STEINBAUER, G., HIRSCHMUGL-GAISCH, S., AND HUBER, P. 2016a. Artificial Intelligence and Computer Science in Education. In *Workshop on Current AI Research at 39th German Conference on Artificial Intelligence*. Klagenfurt, Austria. (Cited on page 5.)

KANDLHOFER, M., STEINBAUER, G., HIRSCHMUGL-GAISCH, S., AND HUBER, P. 2016b. Artificial Intelligence and Computer Science in Education: From Kindergarten to University. In *International Conference on Frontiers in Education (FIE)*. IEEE, Erie, Pennsylvania. (Cited on pages 5, 48, and 78.)

KANDLHOFER, M., STEINBAUER, G., HISCHMUGL-GAISCH, S., AND ECK, J. 2014. A Cross-generational Robotics Project Day: Pre-school Children, Pupils and Grandparents Learn Together. *Journal of Automation, Mobile Robotics & Intelligent Systems 8,* 1, 12–19. (Cited on pages 1, 2, 4, 16, 43, 56, and 63.)

KANDLHOFER, M., STEINBAUER, G., AND SUNDSTROEM, P. 2012. Educational Robotics - Evaluating long-term effects. In *International Workshop 'Teaching robotics, teaching with robotics (TRTWR)'*. Riva del Garda, Italy. (Cited on pages 5 and 65.)

KANDLHOFER, M., STEINBAUER, G., SUNDSTROEM, P., AND WEISS, A. 2012. Evaluating the long-term impact of RoboCupJunior. In *International Conference on Robotics in Education (RiE 2012)*. Prague, Czech Republic. (Cited on pages 5, 12, 14, and 65.)

KARAHOCA, D., KARAHOCA, A., AND UZUNBOYLUB, H. 2011. Robotics teaching in primary school education by project based learning for supporting science and technology courses. *Procedia Computer Science 3*, 1425–1431. (Cited on page 21.)

KAWELL, G. AND SCHAFER, B. 2015. Brainstorming How to Use Lego Mindstorms EV3 in the Classroom. In *Proceedings of the 46th ACM Technical Symposium on Computer Science Education*. ACM, 692–692. (Cited on page 8.)

KHANLARI, A. 2016. Robotics integration to create an authentic learning environment in engineering education. In *International Conference on Frontiers in Education (FIE)*. IEEE, Erie, Pennsylvania. (Cited on page 13.)

KIM, S. H. AND JEON, J. W. 2007. Programming LEGO Mindstorms NXT with visual programming. In *International Conference on Control, Automation and Systems*. Seoul, Korea. (Cited on pages 8, 45, 53, and 94.)

KOLBERG, E. AND ORLEV, N. 2001. Robotics learning as a tool for integrating science technology curriculum in K-12 schools. In *International Conference on Frontiers in Education (FIE)*. Vol. 1. IEEE, T2E–12. (Cited on page 13.)

KOPPENSTEINER, G., VITTORI, L., MILLER, D., AND GOODGAME, S. 2015. Teaching programming on the Elementary Level. In *Workshop position paper at International Conference on Robotics in Education (RiE 2015)*. Yverdon-les-Bains, Switzerland. (Cited on page 9.)

KUMAR, D. AND MEEDEN, L. 1998. A Robot Laboratory for Teaching Artificial Intelligence. In *29th Technical Symposium on Computer Science Education*. Atlanta, USA. (Cited on pages 1, 8, 23, and 39.)

LAMMER, L. 2016. Introducing young people to real-life problem-solving in multi-disciplinary teams with robotic product development. Ph.D. thesis, Vienna University of Technology. (Cited on pages 7 and 13.)

LAMMER, L. AND VINCZE, M. 2015. Crazy robots - Introducing Children with Different Backgrounds and Interests to Robotics. In *Workshop position paper at International Conference on Robotics in Education (RiE 2015)*. Yverdon-les-Bains, Switzerland. (Cited on pages 9 and 21.)

LAMMER, L., VINCZE, M., KANDLHOFER, M., AND STEINBAUER, G. 2015. Which approaches actually work for introducing children to robotics? `http://rie2015.org/workshop/`. Workshop organized at International Conference on Robotics in Education (RiE 2015), Yverdon-les-Bains, Switzerland; [accessed 30-December-2016]. (Cited on page 6.)

LAMMER, L., VINCZE, M., KANDLHOFER, M., AND STEINBAUER, G. 2016a. The Educational Robotics Landscape Exploring Common Ground and Contact Points. *Advances in Intelligent Systems and Computing, Springer International Publishing 457*, 105–111. (Cited on pages xv, 2, 6, 8, 10, 12, 24, and 63.)

LAMMER, L., VINCZE, M., KANDLHOFER, M., AND STEINBAUER, G. 2016b. The Educational Robotics Landscape Exploring Common Ground and Contact Points. In *International Conference on Robotics in Education (RiE 2016)*. Vienna, Austria. (Cited on page 6.)

LANGER, W. 2000. Methoden der empirischen Sozialforschung; Die Beobachtung als Datenerhebungsverfahren. `http://langer.soziologie.uni-halle.de/pdf/meth1/beobach2.pdf`. Universität Halle-Wittenberg; [Online; accessed 29-December-2016]. (Cited on page 35.)

LAYER, R., SHERRIFF, M., AND TYCHONIEVICH, L. 2012. Inform, Experience, Implement - Teaching an Intensive High School Summer Course. In *IEEE Frontiers in Education Conference (FIE)*. 122–127. (Cited on page 23.)

LEGO. 2016. LEGO Mindstorms. `https://www.lego.com/en-us/mindstorms/`. [Online; accessed 03-December-2016]. (Cited on page 8.)

LEIMBACH, T. 2008. Roberta - Girls discover Robots; Roberta Goes EU. Tech. rep., Fraunhofer IAIS. (Cited on page 25.)

LEVESQUE, H. J. 1986. Knowledge representation and reasoning. *Annual review of computer science 1,* 1, 255–287. (Cited on page 55.)

LI, Z., O'BRIEN, L., FLINT, S., AND SANKARANARAYANA, R. 2014. Object-Oriented Sokoban Solver: A Serious Game Project for OOAD and AI Education. In *IEEE Frontiers in Education Conference (FIE)*. 788–791. (Cited on page 23.)

LINDH, J. AND HOLGERSSON, T. 2005. Does lego training stimulate pupils' ability to solve logical problems? *Computers & Education 49*, 1097–1111. (Cited on pages 26, 28, 33, and 112.)

MABE, P. AND WEST, S. 1982. Validity of self-evaluation of ability: A review and meta-analysis. *Journal of applied Psychology 67,* 3, 280–296. (Cited on page 78.)

MAIER, C. 2015. YAGI - An Easy and Light-Weighted Action-Programming Language for Education and Research in Artificial Intelligence and Robotics. M.S. thesis, Faculty of Computer Science, Graz University of Technology. (Cited on page 60.)

MARTIN, D. W. 2007. *Doing psychology experiments*. Cengage Learning. (Cited on pages 11, 33, and 110.)

MARTIN, F., MIKHAK, B., RESNICK, M., SILVERMAN, B., AND BERG, R. 2000. *To mindstorms and beyond: Evolution of a construction kit for magical machines*. Citeseer. (Cited on page 20.)

MARTIN, F. G., BUTLER, D., AND GLEASON, W. M. 2000. Design, story-telling, and robots in Irish primary education. In *IEEE International Conference on Systems, Man and Cybernetics*. Vol. 1. 730–735. (Cited on page 22.)

MASEMANN, S. AND MESSER, B. 2009. *Improvisation und Storytelling in Training und Unterricht*. Beltz. (Cited on pages 44, 52, and 53.)

MATARIC, M. J. 2004. Robotics education for all ages. In *Proceedings of the AAAI Spring Symposium on Accessible, Hands-on AI and Robotics Education*. (Cited on pages 1 and 7.)

MAURER, J., STEINBAUER, G., LEPEJ, P., AND URAN, S. 2014. TEDUSAR White Book-State of the Art in Search and Rescue Robots. Tech. rep., Graz University of Technology, University of Maribor. (Cited on page 15.)

MAYER, R. 2004. Should there be a three-strikes rule against pure discovery learning? *American psychologist 59,* 1. (Cited on page 53.)

MAYERS, A. 2013. *Introduction to Statistics and SPSS in Psychology*. Pearson. (Cited on pages 33, 91, 92, 94, 110, 119, and 125.)

MAYRING, P. 2002. *Einführung in die qualitative Sozialforschung.* Beltz Weinheim. (Cited on page 35.)

MCGOVERN, A., TIDWELL, Z., AND RUSHING, D. 2011. Teaching Introductory Artificial Intelligence through Java-Based Games. In *2nd Symposium on Educational Advances in Artificial Intelligence (EAAI)*. (Cited on page 23.)

MELCHERS, P. AND PREUSS, U. 2009. *Kaufmann Assessment Battery for Children*. Frankfurt/Main: Pearson Assessment. (Cited on page 18.)

MELCHIOR, A., COHEN, F., CUTTER, T., AND LEAVITT, T. 2005. More than Robots: An Evaluation of the FIRST Robotics Competition Participant and Institutional Impacts. Tech. rep., Brandeis University, MA. (Cited on pages 11, 25, 28, 31, 32, and 112.)

MELCHIOR, A., CUTTER, T., AND COHEN, F. 2004. Evaluation of FIRST LEGO LEAGUE. Tech. rep., Brandeis University, MA. (Cited on pages 25 and 112.)

MERDAN, M., LEPUSCHITZ, W., KOPPENSTEINER, G., AND BALOGH, R., Eds. 2016. *Proceedings of the International Conference on Robotics in Education (RiE 2016)*. Vienna, Austria. (Cited on pages 2, 12, and 41.)

MERINO, P. P., RUIZ, E. S., FERNANDEZ, G. C., AND GIL, M. C. 2016. Robotic Educational Tool to engage students on Engineering. In *International Conference on Frontiers in Education (FIE)*. IEEE. (Cited on page 12.)

MESSNER, R. 2009. *Schule forscht: Ansaetze und Methoden zum forschenden Lernen*. Edition Koerber-Stiftung. (Cited on page 44.)

MEYERS, L. S., GAMST, G., AND GUARINO, A. 2013. *Applied Multivariate Research*. Sage. (Cited on pages 33, 91, 110, 119, and 125.)

MILLER, D. P., NOURBAKHSH, I. R., AND SIEGWART, R. 2008. Robots for education. In *Springer handbook of robotics*. Springer, 1283–1301. (Cited on pages 1, 7, 8, 11, 13, and 112.)

MITNIK, R., NUSSBAUM, M., AND SOTO, A. 2008. An autonomous educational mobile robot mediator. *Autonomous Robots 25,* 4, 367–382. (Cited on page 32.)

MOLL, L. C. 2013. *L.S. Vygotsky and education*. Routledge. (Cited on page 19.)

MORO, M. AND ALIMISISI, D., Eds. 2012. *Proceedings of the International Workshop 'Teaching robotics, teaching with robotics (TRTWR)'*. Riva del Garda, Italy. (Cited on page 12.)

MYBERG, E. 2007. The effect of formal teacher education on reading achievement of 3rd-grade students in public and independent schools in Sweden. *Educational Studies 33,* 2, 145–162. (Cited on pages 2, 48, and 52.)

NAEYC. 2013. Learning to Read and Write: Developmentally Appropriate Practices for Young Children. A joint position statement of the International Reading Association and the National Association for the Education of Young Children. *Young Children 53,* 4, 30–46. NAEYC - National Association for the Education of Young Children. (Cited on pages 48, 51, and 53.)

NEPPEL, M. 2014. Use of Robots in the Classroom. M.S. thesis, Faculty of Computer Science, Graz University of Technology. (Cited on page 12.)

NEUENDORF, K. A. 2002. *The Content Analysis Guidebook*. Sage. (Cited on pages 35, 66, 76, and 78.)

NEUMAN, S. AND K.ROSKOS, Eds. 1998. *How can we enable all children to achieve? In Children achieving: Best practices in early literacy*. International Reading Association. (Cited on page 48.)

NEUMAN, S. B., COPPLE, C., AND BREDEKAMP, S. 2000. *Learning to Read and Write: Developmentally Appropriate Practices for Young Children*. Mcgraw-Hill. (Cited on pages 48, 51, and 53.)

NEWMAN, I. AND BENZ, C. R. 1998. *Qualitative-quantitative research methodology: Exploring the interactive continuum.* SIU Press. (Cited on pages 29 and 64.)

NOURBAKHSH, I., HAMNER, E., DUNLAVEY, B., BERNSTEIN, D., AND CROWLEY, K. 2005. Educational results of the personal exploration rover museum exhibit. In *International Conference on Robotics and Automation*. IEEE, 4278–4283. (Cited on pages 28 and 31.)

NOURBAKHSH, I. R., CROWLEY, K., BHAVE, A., HAMNER, E., HSIU, T., PEREZ-BERGQUIST, A., RICHARDS, S., AND WILKINSON, K. 2005. The Robotic Autonomy Mobile Robotics Course: Robot Design, Curriculum Design and Educational Assessment. *Autonomous Robots 18,* 1 (January), 103–127. (Cited on pages 12 and 25.)

NOURBAKHSH, I. R., CROWLEY, K., WILKINSON, K., AND HAMNER, E. 2003. The educational impact of the Robotic Autonomy mobile robotics course. *Carnegie Mellon University*. (Cited on pages 28 and 31.)

NUGENT, G., BARKER, B., AND GRANDGENETT, N. 2012. Robots in K-12 Education: A New Technology for Learning. B. S. Barker, G. Nugent, N. Grandgenett, and V. Adamchuk, Eds. IGI Global Information Science Reference, Hershey, PA. Chapter: The Impact of Educational Robotics on Student STEM Learning, Attidudes, and Workplace Skills. (Cited on pages 113 and 119.)

NUGENT, G., BARKER, B., GRANDGENETT, N., AND ADAMCHUK, V. 2009. The use of digital manipulatives in k-12: robotics, GPS/GIS and programming. In *International Conference on Frontiers in Education (FIE)*. IEEE. (Cited on pages 28, 31, and 32.)

NUGENT, G., BARKER, B., GRANDGENETT, N., AND WELCH, G. 2014. Robotics Camps, Clubs, and Competitions: Results from a U.S. Robotics Project. In *International Conference on Robotics in Education (RiE 2014)*. Padova, Italy. (Cited on pages 27 and 113.)

NUGENT, G., BARKER, B. S., GRANDGENETT, N., AND ADAMCHUK, V. I. 2010. Impact of Robotics and Geospatial Technology Interventions on Youth STEM Learning and Attitudes. *JRTE; Teacher Education Faculty Publications, University of Nebraska 42,* 3, 391–408. (Cited on pages 27, 31, 82, 86, 87, 88, 90, 94, 95, 102, 103, 108, 118, and 125.)

NXC. 2016. Next Byte Codes, Not eXactly C, and SuperPro C. `http://bricxcc.sourceforge.net/nbc/`. [Online; accessed 28-December-2016]. (Cited on page 58.)

OBDRZALEK, D., Ed. 2012. *Proceedings of the International Conference on Robotics in Education (RiE 2012)*. Prague, Czech Republic. (Cited on page 12.)

O'BRIAN, R. G. AND KAISER, M. K. 1985. MANOVA Method for Analyzing Repeated Measures Designs: An Extensive Primer. *Psychological Bulletin 97*, 316–333. (Cited on pages 33, 91, 110, 119, and 125.)

OCG. 2016. Austrian Computer Society. `https://www.ocg.at/en/node/4499`. [Online; accessed 25-November-2016]. (Cited on page 17.)

OECD. 2006. PISA Released Items - Mathematics. *PISA 2006*. (Cited on pages 27, 82, 86, 88, 90, 94, 109, 118, and 125.)

OECD. 2009. PISA National Pupil Questionnaire. *PISA 2009*. (Cited on pages 89 and 91.)

OPPLIGER, D. 2002. Using first Lego league to enhance engineering education and to increase the pool of future engineering students. In *International Conference on Frontiers in Education (FIE)*. Vol. 3. IEEE, S4D–11. (Cited on page 13.)

ORMROD, J. E. 1995. *Educational psychology: Principles and applications*. Merrill. (Cited on pages 20, 45, and 46.)

ORMROD, J. E. 2007. *Educational Psychology: Developing Learners*. Prentice Hall. (Cited on pages 22 and 46.)

ORPINAS, P., KELDER, S., FRANKOWSKI, R., MURRAY, N., ZHANG, Q., AND MCALISTER, A. 2000. Outcome evaluation of a multi-component violence-prevention program for middle schools: the Students for Peace project. *Health education research 15,* 1, 45–58. (Cited on pages 27 and 66.)

OSBORNE, J. AND DILLON, J. 2008. *Science education in Europe: Critical reflections*. Vol. 13. London: The Nuffield Foundation. (Cited on page 1.)

P21. 2016. Partnership for 21st Century Learning. `http://www.p21.org/`. [Online; accessed 05-December-2016]. (Cited on page 11.)

PAPERT, S. 1993a. *Mindstorms: Children, Computers, and Powerful Ideas*, 2nd ed. Basic Books. (Cited on pages 1, 8, 19, 20, 45, 51, and 53.)

PAPERT, S. 1993b. *The children's machine: Rethinking school in the age of the computer*. Basic books. (Cited on page 21.)

PAPERT, S. AND HAREL, I. 1991. Situating constructionism. *Constructionism 36*, 1–11. (Cited on pages 19, 51, and 54.)

PARETO, L. 2014. A teachable agent game engaging primary school children to learn arithmetic concepts and reasoning. *International Journal of Artificial Intelligence in Education 24,* 3, 251–283. (Cited on page 24.)

PEDASTE, M., MÄEOTS, M., LEIJEN, Ä., AND SARAPUU, T. 2012. Improving Students' Inquiry Skills through Reflection and Self-Regulation Scaffolds. *Technology, Instruction, Cognition & Learning 9*. (Cited on page 21.)

PEKAROVA, J. 2008. Using a Programmable Toy at Preschool Age: Why and How? In *Teaching with robotics: didactic approaches and experiences. Workshop at the International Conference on Simulation, Modeling and Programming Autonomous Robots (SIMPAR 2008)*. (Cited on pages 16, 45, and 53.)

PETERSEN, U., THEIDIG, G., BOERDING, J., LEIMBACH, T., AND FLINTROP, B. 2007. Roberta Final Report. Tech. rep., Fraunhofer IAIS. (Cited on pages 25 and 112.)

PETRE, M. AND PRICE, B. 2004. Using robotics to motivate 'back door' learning. *Education and information technologies 9,* 2, 147–158. (Cited on pages 16, 21, 22, and 24.)

PETROVIC, P. 2011. Ten Years of Creative Robotics Contests. In *Fifth International Conference on Informatics in Schools: Situation, Evolution and Perspectives (ISSEP)*. Bratislava, Slovakia. (Cited on pages 12 and 25.)

PHELPS, E., ZIMMERMAN, S., WARREN, A., JELIČIĆ, H., VON EYE, A., AND LERNER, R. M. 2009. The structure and developmental course of positive youth development (PYD) in early adolescence: Implications for theory and practice. *Journal of Applied Developmental Psychology 30,* 5, 571–584. (Cited on page 23.)

PIAGET, J. 1973. *To understand is to invent: The future of education*. Penguin Books. (Cited on page 18.)

PIAGET, J., GARCIA, R., AND DAVIDSON, P. 2013. *Toward a logic of meanings*. Psychology Press. (Cited on page 19.)

POHLEN, S. M. 2015. Phenomenological Study of Engaging Mindset Development in Authentic, Applied Learning Enviornments in a Secondary School. Ph.D. thesis, University of St. Thomas, Minnesota. (Cited on pages 34, 38, and 120.)

QUINLAN, J. R. 1986. Induction of decision trees. *Machine learning 1,* 1, 81–106. (Cited on page 55.)

RAS 2016. *"Journal of Robotics and Autonomous Systems " 77*. Special issue on educational robotics. (Cited on pages 2 and 12.)

RCJ. 2016. RoboCupJunior. `http://rcj.robocup.org/`. [Online; accessed 01-December-2016]. (Cited on pages 9, 12, and 13.)

RCJ WIKI. 2016. RoboCupJunior Wiki. `http://wiki.robocup.org/`. [Online; accessed 14-December-2016]. (Cited on page 14.)

REITER, R. 2001. *Knowledge in Action. Logical Foundations for Specifying and Implementing Dynamical Systems*. MIT Press. (Cited on page 59.)

RENNER, M. AND TAYLOR-POWELL, E. 2003. Analyzing qualitative data. *Programme Development & Evaluation, University of Wisconsin-Extension Cooperative Extension*. (Cited on page 34.)

RESNICK, M., OCKO, S., AND PAPERT, S. 1988. LEGO, Logo, and design. *Children's Environments Quarterly*, 14–18. (Cited on page 20.)

REYES, M., PEREZ, C., UPCHURCH, R., YUEN, T., AND ZHANG, Y. 2016. Using Declarative Programming in an Introductory Computer Science Course for High School Students. In *6th Symposium on Educational Advances in Artificial Intelligence (EAAI)*. Phoenix, USA, 4132–4133. (Cited on page 23.)

ROBERTA. 2016. Roberta - Learning with Robots. `http://roberta-home.de/en`. [Online; accessed 01-December-2016]. (Cited on pages 12 and 25.)

ROBOCUP. 2016. RoboCup International Scientific Initiative. `http://www.robocup.org/about-robocup/`. [Online; accessed 07-September-2016]. (Cited on pages 13, 34, and 84.)

ROCKLAND, R., KIMMEL, H., CARPINELLI, J., HIRSCH, L., AND BURR-ALEXANDER, L. 2012. Robots in K-12 Education: A New Technology for Learning. B. S. Barker, G. Nugent, N. Grandgenett, and V. Adamchuk, Eds. IGI Global Information Science Reference, Hershey, PA. Chapter: Medical Robotics in K-12 Education. (Cited on pages 1 and 9.)

ROLL, I. AND WYLIE, R. 2016. Evolution and Revolution in Artificial Intelligence in Education. *International Journal of Artificial Intelligence in Education 26,* 2, 582–599. (Cited on page 24.)

ROMERO, E., LOPEZ, A., AND HERNANDEZ, O. 2012. A Pilot Study of Robotics in Elementary Education. In *10th Latin American and Caribbean Conference for Engineering and Technology*. Panama City, Panama. (Cited on pages 43, 52, and 53.)

ROSEN, J., STILLWELL, F., AND USSELMAN, M. 2012. Robots in K-12 Education: A New Technology for Learning. B. S. Barker, G. Nugent, N. Grandgenett, and V. Adamchuk, Eds. IGI Global Information Science Reference, Hershey, PA. Chapter: Promoting Diversity and Public School Success in Robotics Competitions. (Cited on page 9.)

RUSK, N., RESNICK, M., BERG, R., AND PEZALLA-GRANLUND, M. 2008. New pathways into robotics: Strategies for broadening participation. *Journal of Science Education and Technology 17,* 1, 59–69. (Cited on pages 12 and 13.)

RUSSELL, S. AND NORVIG, P. 2009. *Artificial Intelligence: A Modern Approach*. Pearson. (Cited on pages 44, 46, 49, 54, 56, and 59.)

RUZZENENTE, M., KOO, M., NIELSEN, K., GRESPAN, L., AND FIORINI, P. 2012. A review of robotics kits for tertiary education. In *International Workshop 'Teaching robotics, teaching with robotics (TRTWR)'*. Citeseer, 153–162. (Cited on page 8.)

SAMUELS, P. AND HAAPASALO, L. 2012. Real and virtual robotics in mathematics education at the school–university transition. *International Journal of Mathematical Education in Science and Technology 43,* 3, 285–301. (Cited on page 13.)

SAPOUNIDIS, T. AND DEMETRIADIS, S. 2016. Educational robotics driven by tangible programming languages: A review on the field. In *International Conference Educational Robotics 2016 (EduRobotics 2016)*. Athens, Greece. in press. (Cited on page 16.)

SARDINA, S. AND VASSOS, S. 2005. The wumpus world in IndiGolog: A preliminary report. In *Proceedings of the Workshop on Non-monotonic Reasoning, Action and Change at IJCAI (NRAC-05)*. 90–95. (Cited on page 60.)

SARTATZEMI, M., DAGDILELIS, V., AND KAGANI, K. 2005. Teaching programming with robots: a case study on greek secondary education. In *Panhellenic Conference on Informatics*. Springer, 502–512. (Cited on page 21.)

SCHREINER, C. AND SJOBERG, S. 2004. *Sowing the seeds of ROSE Background, rationale, questionnaire development and data collection for ROSE (The Relevance of Science Education)*. University of Oslo. (Cited on pages 87 and 113.)

SCHWENK, T. L. AND WHITMAN, N. A. 1984. Residents as Teachers: A Guide to Educational Practice. (Cited on page 22.)

SCRIBNER-MACLEAN, M., MARTIN, F., PRIME, D., PENTA, M., CHRISTY, S., AND RUDNICKI, I. 2008. Implementing iCODE (Internet Community of Design Engineers): A Collaborative Engineering and Technology Project for Middle and High School Students in Urban Settings. *Technology and Teacher Education Annual 19,* 7, 4321. (Cited on pages 28 and 31.)

SEVERSON, H. H., ANDREWS, J. A., LICHTENSTEIN, E., WALL, M., AND AKERS, L. 1997. Reducing Maternal Smoking and Relapse: Long-Term Evaluation of a Pediatric Intervention. *Preventive Medicine 26,* 1, 120–130. (Cited on pages 27 and 66.)

SHIEBER, S. M., Ed. 2004. *The Turing Test: Verbal Behavior as the Hallmark of Intelligence*. MIT Press. (Cited on pages 23 and 54.)

SINGH, R., MAIRE, F., SITTE, J., AND TICKLE, A. 2005. A Low Cost Controller Board for Teaching Robotics. In *Third International Symposium on Autonomous Minirobots for Research and Education*. Fukui, Japan. (Cited on page 12.)

SIPSER, M. 2012. *Introduction to the Theory of Computation*, 3rd ed. Cengage Learning. (Cited on page 56.)

SJØBERG, S. AND SCHREINER, C. 2006. How do students perceive science and technology? *Science in School*, 66–69. (Cited on page 1.)

SKLAR, E. 2004. A long-term approach to improving human-robot interaction: RoboCupJunior Rescue. In *IEEE International Conference on Robotics and Automation (ICRA)*. 2321–2326. (Cited on pages 14 and 31.)

SKLAR, E. AND EGUCHI, A. 2004. Learning while teaching robotics. In *AAAI spring symposium*. (Cited on page 31.)

SKLAR, E. AND EGUCHI, A. 2005. RoboCupJunior - Four Years Later. In *RoboCup 2004: Robot Soccer World Cup VIII*. Springer Berlin, 172–183. (Cited on pages 1, 9, 13, and 26.)

SKLAR, E., EGUCHI, A., AND JOHNSON, J. 2002. RoboCupJunior: Learning with Educational Robotics. In *Proceedings fo RoboCup-2002: Robot Soccer World Cup VI*. (Cited on pages 11, 13, 21, 26, and 31.)

SKLAR, E. AND PARSONS, S. 2002. RoboCupJunior: A Vehicle for Enhancing Technical Literacy. In *AAAI Mobile Robot Competition 2002, Papers from the AAAI Workshop*. Edmonton, Canada. (Cited on pages 24, 49, 50, and 51.)

SKLAR, E. I., JOHNSON, J. H., AND LUND, H. H. 2000. Children learning from team robotics: Robocup junior 2000. *Educational Research Report, Department of Design and Innovation, Faculty of Technology, The Open University, Milton Keynes, UK*. (Cited on page 26.)

SNOW, C., BURNS, M., AND GRIFFIN, P., Eds. 1998. *Preventing reading difficulties in young children*. National Academy Press. (Cited on page 52.)

STAGER, G. 2010. A Constructionist Approach to Teaching with Robotics. In *Proceedings of Constructionism and Creativity Conference, Paris*. (Cited on page 9.)

STEIN, B., HAYNES, A., REDDING, M., ENNIS, T., AND CECIL, M. 2007. Assessing critical thinking in STEM and beyond. *Innovations in e-learning, instruction, technology, assessment and engineering education, Springer Netherlands, Dordrecht, Netherlands*, 79–82. (Cited on page 115.)

STEINBAUER, G. AND FERREIN, A. 2016. 20 Years of RoboCup. *KI - Künstliche Intelligenz 30,* 3, 221–224. (Cited on page 13.)

STELZER, R. AND JAFARMADAR, K., Eds. 2011. *Proceedings of the International Conference on Robotics in Education (RiE 2011)*. Vienna, Austria. (Cited on page 12.)

STICKLAND, D. 1998. *Teaching phonics today: A primer for educators*. International Reading Association. (Cited on page 52.)

STOECKELMAYER, K., TESAR, M., AND HOFMANN, A. 2011. Kindergarten Children Programming Robots: A First Attempt. In *International Conference on Robotics in Education (RiE 2011)*. Vienna, Austria. (Cited on pages 16 and 17.)

STONER, G. 1996. Implementing learning technology. *Learning Technology Dissemination Initiative, Institute for Computer Based Learning, Heriot Watt University: Edinburgh*. (Cited on pages 28 and 31.)

STUBBS, K., CASPER, J., AND YANCO, H. A. 2012. Robots in K-12 Education: A New Technology for Learning. B. S. Barker, G. Nugent, N. Grandgenett, and V. Adamchuk, Eds. IGI Global Information Science Reference, Hershey, PA. Chapter: Designing Evaluations for K-12 Robotics Education Programs. (Cited on pages 3, 24, 25, 27, 28, 30, 31, 32, 33, 34, 40, 63, 64, 65, 66, 73, 113, and 123.)

SULLIVAN, F. R. 2008. Robotics and science literacy: Thinking skills, science process skills and systems understanding. *Journal of Research in Science Teaching 45,* 3, 373–394. (Cited on page 32.)

SULLIVAN, F. R. AND MORIARTY, M. A. 2009. Robotics and discovery learning: pedagogical beliefs, teacher practice, and technology integration. *Journal of Technology and Teacher Education 17,* 1, 109–142. (Cited on pages 12, 13, 20, 40, and 41.)

SUTTON, R. S. AND BARTO, A. G. 1998. *Reinforcement learning: An introduction*. Vol. 1. MIT press Cambridge. (Cited on page 55.)

SYMONDS, E. 2011. A practical application of SurveyMonkey as a remote usability-testing tool. *Library Hi Tech 29,* 3, 436–445. (Cited on page 87.)

TEITELBAUM, M. 2007. Do we need more scientists and engineers. In *Conference on the National Value of Science Education, University of York*. (Cited on page 1.)

TERECOP. 2009. Teacher Education on Robotics-Enhanced Constructivist Pedagogical Methods. `http://www.terecop.eu/`. [Online; accessed 01-December-2016]. (Cited on page 12.)

TEXTOR, M. 2011. *Bildungs- und Erziehungspartnerschaft in Kindertageseinrichtungen*. Books on Demand. (Cited on page 43.)

TGET. 2016. euRobotics Topic Group on Education and Training. https://robeduerf16.sciencesconf.org/. [Online; accessed 01-December-2016]. (Cited on page 12.)

THOMPSON, T., HEER, D., BROWN, S., TRAYLOR, R., AND FIEZ, T. S. 2004. Educational design, evaluation, & development of platforms for learning. In *International Conference on Frontiers in Education (FIE)*. IEEE, T3E–1. (Cited on page 21.)

TOE 2013. *"IEEE Transactions on Education" 56,* 1. Special Issue on Robotics in Education. (Cited on pages 1, 12, 24, and 63.)

TORREY, L. 2012. Teaching Problem-Solving in Algorithms and AI. In *3rd Symposium on Educational Advances in Artificial Intelligence (EAAI)*. (Cited on page 23.)

TORREY, L., JOHNSON, K., SONDERGARD, S., PONCE, P., AND DESMOND, L. 2016. The Turing Test in the Classroom. In *6th Symposium on Educational Advances in Artificial Intelligence (EAAI)*. Phoenix, USA, 4113–4118. (Cited on page 23.)

TROCHIM, W. M., DONNELLY, J. P., AND ARORA, K. 2015. *Research Methods: The Essential Knowledge Base*. Wadsworth Inc Fulfillment. [online version: http://www.socialresearchmethods.net/kb/; accessed 26-December-2016]. (Cited on pages 32, 33, 82, 84, 118, and 125.)

TSUKAMOTO, H., TAKEMURA, Y., NAGUMO, H., IKEDA, I., MONDEN, A., AND MATSUMOTO, K. 2015. Programming education for primary school children using a textual programming language. In *IEEE Frontiers in Education Conference (FIE)*. 1008–1014. (Cited on page 24.)

TU VIENNA. 2016. Technology and natural sciences in playschool - Playschool at the University of Technology. http://www.complang.tuwien.ac.at/ewa/playschool. [Online; accessed 25-November-2016]. (Cited on page 17.)

TURBAK, F. AND BERG, R. 2002. Robotic design studio: Exploring the big ideas of engineering in a liberal arts environment. *Journal of Science Education and Technology 11,* 3, 237–253. (Cited on page 12.)

UNICEF. 2008. *Long-term evaluation of the Tostan programme in Senegal*. United Nations Children's Fund. (Cited on pages 27 and 66.)

UNIVERSITY OF WATERLOO. 2012, 2013. Beaver Computing Challenge. http://www.cemc.uwaterloo.ca/contests/bcc.html. [Online; accessed 02-September-2016]. (Cited on pages 27, 82, 86, 88, 89, 90, 109, 118, and 125.)

VARNADO, T. E. 2005. The Effects of a Technological Problem Solving Activity on FIRST LEGO League Participants' Problem Solving Style and Performance. Ph.D. thesis, Virginia Polytechnic Institute and State University, Virginia. (Cited on page 27.)

VIRNES, M. AND SUTINEN, E. 2009. Topobo in kindergarten: educational robotics promoting dedicated learning. In *International Conference on Computers in Education*. Hong Kong. (Cited on pages 16, 43, 52, and 78.)

VMT. 2016. Vienna Museum of Technology. https://www.technischesmuseum.at/event/summ-summ-die-roboterbiene-faehrt-herum-1. [Online; accessed 25-November-2016]. (Cited on page 17.)

VYGOTSKY, L. 1978. Interaction between learning and development. *Readings on the development of children 23,* 3, 34–41. (Cited on page 19.)

WEINBERG, J. B., PETTIBONE, J. C., THOMAS, S. L., STEPHEN, M. L., AND STEIN, C. 2007. The impact of robot projects on girls' attitudes toward science and engineering. In *Workshop on Research in Robots for Education*. Vol. 3. Citeseer. (Cited on page 31.)

WELCH, A. G. 2007. The effect of the FIRST Robotics Competition on high school students' attitudes toward science. Ph.D. thesis, University of Kansas. (Cited on pages 12, 26, and 27.)

WELCH, A. G. 2010. Using the TOSRA to Assess High School Students' Attitudes toward Science after Competing In the FIRST Robotics Competition: An Exploratory Study. *Eurasia Journal of Mathematics, Science & Technology Education 6,* 3, 187–197. (Cited on pages 1, 18, 26, 89, 92, 99, and 113.)

WENGRAF, T. 2001. *Qualitative Research Interviewing*. Sage Publications. (Cited on pages 34, 66, and 123.)

WERTSCH, J. V. 1986. *Culture, communication, and cognition: Vygotskian perspectives*. CUP Archive. (Cited on page 19.)

WESTLUND, J. K. AND BREAZEAL, C. 2015. The interplay of robot language level with children's language learning during storytelling. In *Proceedings of the Tenth Annual ACM/IEEE International Conference on Human-Robot Interaction Extended Abstracts*. ACM, 65–66. (Cited on pages 13, 22, 44, 52, and 53.)

WHITEHEAD, S. H. 2010. Relationship of Robotic Implementation on Changes in Middle School Students' Beliefs and Interest toward Science, Technology, Engineering and Mathematics. Ph.D. thesis, Indiana University of Pennsylvania. (Cited on pages 12, 26, and 27.)

WHITMAN, N. AND JONATHAN, F. 1988. *Peer Teaching: To Teach Is To Learn Twice. ASHE-ERIC Higher Education Report No. 4*. ASHE-ERIC Higher Education Reports, The George Washington University. (Cited on pages 22, 43, and 56.)

WING, J. M. 2006. Computational thinking. *Communications of the ACM 49,* 3, 33–35. (Cited on page 11.)

WULF, L. 2012. Effects of Robotics. M.S. thesis, University of Vienna. (Cited on pages 12, 17, 18, 27, and 115.)

YOU, Z.-J., SHEN, C.-Y., CHANG, C.-W., LIU, B.-J., AND CHEN, G.-D. 2006. A robot as a teaching assistant in an English class. In *Sixth IEEE International Conference on Advanced Learning Technologies (ICALT'06)*. IEEE, 87–91. (Cited on page 8.)

ZAMAN, S., SLANY, W., AND STEINBAUER, G. 2011. ROS-based mapping, localization and autonomous navigation using a Pioneer 3-DX robot and their relevant issues. In *Electronics, Communications and Photonics Conference (SIECPC), 2011 Saudi International*. IEEE, 1–5. (Cited on page 45.)

ZELAZO, P., FRYE, D., AND RAPUS, T. 1996. An age-related dissociation between knowing rules and using them. *Cognitive Development 1*, 37–63. (Cited on page 18.)

Appendix A

Appendix

A.1. Qualitative Pre-Study: Informed Consent University Students

Informed Consent

I, ……..
do agree that this interview will be recorded.
It is my right to tell you to turn the recorder off at any time or to stop the interview at any time if I want to. Also afterwards it is my right to tell you to destroy this recording and not use it or other personal data in your research. I do agree that this recording will be transcribed and made anonymous and used together with other similar stories to extend on the research community's knowledge of the long-term learning effects of RoboCupJunior and RoboCupJunior training.

………………………………… ……………………………………………

Date Signature

A.2. Intervention Concept Evaluation: Informed Consent Parents of Kindergarten Children

TU Graz
Graz University of Technology

Informed Consent Parents

I, ……..
hereby do agree that my daughter/my son …………………………………………………………
participates in an interview concerning the robotics project day which took place at the Kindergarten Rosental a.d. Kainach on 6th of November 2012. I do agree that this interview will be recorded (only audio). All collected data will be treated strictly confidentially. During the interview the audio recorder can be turned off at any time and the interview can be stopped at any time if my daughter/my son wants so. Also afterwards it is my right to tell the researcher to destroy this recording and not use it or other personal data in his research.
I do agree that this recording will be transcribed, made anonymous and used together with other similar stories to extend the research community's knowledge and to evaluate the long-term learning effects of the robotics project in particular and of educational robotics in general. Furthermore, I do agree that anonymized data can also be used in scientific publications.
Responsible for conducting and analyzing the interview: Martin Kandlhofer, MSc; Graz University of Technology, Institute for Software Technology – Educational Robotics

………………………………… ……………………………………………
Date Signature

A.3. Intervention Concept Evaluation: Informed Consent High School Students

TU Graz
Graz University of Technology

Informed Consent

I, ……………………………………………………………………………………………………….. do agree to participate in an interview regarding the 'iRobot' project in which I participated this semester. I also do agree that this interview will be recorded (audio only). All collected data will be treated strictly confidentially. It is my right to tell the researcher to turn the recorder off at any time or to stop the interview at any time if I want to. Also afterwards it is my right to tell the researcher to destroy this recording and not use it or other personal data for further research. I do agree that this recording will be transcribed and made anonymous and used together with other similar stories to evaluate the project. Furthermore, I do agree that anonymized data can also be used in scientific publications.

…………………………………
Date

…………………………………………..…
Signature

A.4. Quantitative Main Study: School Information and Recruiting Sheet

Graz University of Technology
Institute for Software Technology, Inffeldgasse 13/V, 8010 Graz, Austria
Dipl.-Ing. Martin Kandlhofer
Mail: mkandlho@ist.tugraz.at
Tel.: +4366473676795

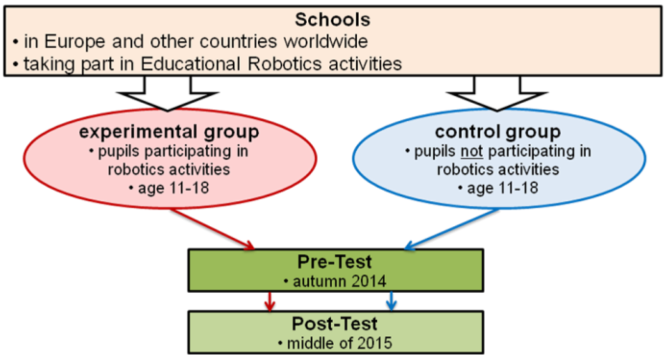
Evaluating the impact of Educational Robotics

An international empirical study conducted by Graz University of Technology (Austria) seeks to investigate the impact of *Educational Robotics* (e.g. *RoboCupJunior (RCJ))* on pupils' technical and social skills. The basic aim is to gather solid and valuable empirical data regarding following key issues:

- Impact of Educational Robotics on pupils' **technical skills**
- Impact of Educational Robotics on pupils' **attitudes and interests** regarding science, technology and social aspects

A successful implementation of this study strongly depends on the support and cooperation of schools, mentors and teachers engaged in Educational Robotics/RCJ. The main study will be conducted in 2014/2015 in Europe and further countries worldwide. Data collection will be done using an online multiple-choice questionnaire. There are no risks involved for pupils or schools participating in this study. Each questionnaire is completely anonymous. Basically the study uses a two-group design:

- The **experimental group** will consist of pupils and young students who participate in robotics activities
- The **control group** comprises students who do not participate in robotics activities but share comparable demographic attributes (age, educational background,…)



The online questionnaire will be done at two distinct points in time:

1. **Pre-Test**: autumn 2014/begin of winter term 2014 (before pupils start with their robotics activities)
2. **Post-test**: middle of 2015

Required support by schools, mentors and teachers:

- Assigning pupils to control- and experimental group
- Supervising the conducting of pre- and post-tests

Benefits for schools, mentors and teachers participating in this study:

- Exclusive access to data and results
- Access to one of the first studies scientifically measuring the impact of RCJ/Educational Robotics
- Results of this study form strong arguments while negotiating with funding agencies, sponsors, administration
- Revealing possible areas of improvements

If you are interested please contact:

Dipl.-Ing. Martin Kandlhofer, Graz University of Technology; Mail: mkandlho@ist.tugraz.at; Phone: +4366473676795

Investing in your future
Operation part financed by the European Union
European Regional Development Fund
REPUBLIC OF SLOVENIA
MINISTRY OF ECONOMIC DEVELOPMENT AND TECHNOLOGY
Das Land Steiermark
University of Maribor

A.5. Quantitative Main Study: Step-By-Step Manual

Evaluating the impact of Educational Robotics

Step-by-step manual for teachers and mentors

Thanks for your support in this study! In order to keep the implementation of the survey at your school as easy as possible please follow the step-by-step instructions below. If you have any questions you can contact the researcher at any time (Martin Kandlhofer; Email: mkandlho@ist.tugraz.at; Phone: +4366473676795)

1. Preparations:

- Tell the researcher (via email) the postal address of your school in order that documents for written permissions and a pre-paid return-envelope can be send to this address
- Obtain approval from your school administration / headmaster or responsible teacher:
  - digital version of this permission document was sent to you via email: 'school_permission.pdf'
  - printed version (2 copies) will also be send to you by postal mail

- **Acquire pupils for experimental group and control group:**
  - **experimental group**: pupils who
    - prepare for junior robotics competition
    - and/or attend e.g. a robotics course,
    - a robotics elective,
    - a robotics project,
    - a robotics club or a similar robotics activity <u>for the first time</u>.
  - **control group**: pupils who are
    - from the same school,
    - around the same age and
    - maybe also the same class as pupils of the experimental group, but
    - **<u>not</u>** preparing for junior robotics competition and
    - **<u>not</u>** attending robotics elective, project, club or similar robotics activity and
    - **<u>not</u>** have been attending one of these robotics activities before
  - the more pupils participate the better, but pupils should be more or less equally distributed to experimental and control group

- Please tell the researcher (via email) the
  - approximate number of pupils in control group and experimental group and
  - the planned date of the pre-test (should be at beginning of autumn/winter term 2013)
- Obtain written permission from pupils of control and experimental group and their parents:
  - digital versions of this documents were sent to you via email ('parent_permission.pdf', 'pupil_permission.pdf');
  - printed versions will also be send to you by postal mail
- Once you obtained all written permissions (school, parents, pupils) please send them back to the researcher using the pre-paid envelope provided to you.

2. Information on survey questionnaire:

- **The same questionnaire should be done by pupils of experimental group and the control group <u>twice</u>**:
  - **pre-test**: at the <u>begin of autumn / winter term 2013</u> (before robotics preparation/course starts)
  - **post-test**: <u>mid 2014</u> (e.g. around one week after national junior competition/play offs took place)

- It is important, that the <u>same pupils doing the pre-test will also do the post-test</u> (in order to make result comparison of pre- and post-test possible)

- The pre- and post tests will be done online (using the tool *SurveyMonkey*).
- Therefore each pupil would need a separate computer with internet access for filling in the questionnaire

- The pre- and post-tests should be done at the same time by pupils of the control group and the experimental group (at least on the same day)
- No calculator, no Google or other tools will be required nor should be allowed

- The questionnaire is completely anonymous, no names will be collected nor will any information be linked to the study participants.
- Depending on age and previous knowledge time required for completing the questionnaire would be between 70 and 120 minutes.
- Basically pupils should get enough time to complete the whole questionnaire. Nevertheless the maximum time should be limited (suggestion: 150 minutes).
- A teacher/mentor should supervise the tests in order to prevent cheating, answer questions and take care of time
- The basic structure of the questionnaire:
    - The first part comprises demographic questions
    - The second part comprises knowledge questions (multiple-choice, one correct answer each)
    - The third part comprises questions regarding attitudes and interests (scale questions ranging from 'strongly agree' to 'strongly disagree')
    - For a complete overview of covered topics and questions take a look at the document 'Overview_Topics_Questions.pdf'. All questions and answers can be found in the document 'EN_Questionnaire_RCJ.doc'

3. Conducting the Pre-Test:

- Set a date for the pre-test at begin of autumn/winter term 2013
- The link for the questionnaire (English version):

http://www.surveymonkey.com/s/9QJG7DG

- Please provide this link only immediately before the pre-test starts to each pupil participating in the study
- The link for the online questionnaire in other languages will be provided to you by the researcher via email separately.
- Before starting the questionnaire please inform pupils about the time-limit for the test
- Further instructions and information for participants are included directly in the questionnaire.

4. Next steps:

- If you find some time please fill in the school background information questionnaire provided to you be the researcher (the link for this background questionnaire will be provided to you soon).
- Basically steps for conducting the post-test will be the same as for conducting the pre-test.
- The date of the post-test will depend on the date of the national RoboCupJunior competition / play offs in your country
- You will be informed on time about further details regarding the post-test
- Preliminary results / findings of the survey will be provided to you as soon as possible

Thank you very much for your help!

Dipl.-Ing. Martin Kandlhofer
Graz University of Technology, Institute for Software Technology; Educational Robotics
Inffeldgasse 13/5, 8010 Graz, Austria
Email: mkandlho@ist.tugraz.at;
Phone: +43 664 73 67 67 95

A.6. Quantitative Main Study: Informed Consents of Students, Parents, School Administrations, Mentors

Evaluating the impact of Educational Robotics

Pupil information sheet and informed consent

My name is Martin Kandlhofer, I'm doctorand at Graz University of Technology in Austria. As part of my research I'm conducting an evaluation investigating the impact of educational robotics on pupils' attitudes towards science and technology and the impact on the development of technical skills. This research is part of the TEDUSAR project (Technology and Education for Search and Rescue Robots) which is a cross-border EU program between Graz University of Technology and the University of Maribor.

In order to collect valuable data for this research you will be asked to complete an online questionnaire this autumn/winter semester, and again in about eight months time a second online questionnaire. Basically the questionnaire consists of three parts:

1. Anonymous background information questions (age, class, country,…)
2. Multiple-choice questions on technical aspects (easily to answer just by ticking one out of four possible answers)
3. Scale questions focusing on attitudes and interests regarding science, technology and social aspects (answering range from ‘strongly agree’ to ‘strongly disagree’)

The time required for completing the questionnaire will be between 70 and 120 minutes.

There are no risks involved in participating in this study. Each questionnaire is completely anonymous. Names will not be collected nor linked to submitted data. No one will know who responded to any of the questions. All collected data will be treated confidentially.
Your participation is completely voluntary. You can refuse to answer any question at any time without penalty. You can withdraw from the study any time without penalty.

As a thank you for your participation in this study you get the opportunity to win a Raspberry Pi computer.

Your participation is essential for this scientific investigation - each questionnaire is important!
If you have any questions, suggestions or comments you can contact me anytime:

Dipl.-Ing. Martin Kandlhofer
Graz University of Technology, Institute for Software Technology; Educational Robotics
Inffeldgasse 13/5, 8010 Graz, Austria
Email: mkandlho@ist.tugraz.at;
Phone: +43 664 73 67 67 95

Thanks for your participation!
Sincerely,

Martin Kandlhofer

If you agree to participate in the study described please put in your name (in block letters), the date and your signature below:

Name:____

Date:____________________________

Signature: ____

Evaluating the impact of Educational Robotics

Parent information sheet and informed consent

My name is Martin Kandlhofer, I'm doctorand at Graz University of Technology in Austria. As part of my research I'm conducting an evaluation investigating the impact of educational robotics on pupils' attitudes towards science and technology and the impact on the development of technical skills. This research is part of the TEDUSAR project (Technology and Education for Search and Rescue Robots) which is a cross-border EU program between Graz University of Technology and the University of Maribor.

In order to collect valuable data for this research your child will be asked to complete an online questionnaire this autumn/winter semester, and again in about eight months time a second online questionnaire. Basically the questionnaire consists of three parts:

1. Anonymous background information questions (age, class, country,…)
2. Multiple-choice questions on technical aspects (easily to answer just by ticking one out of four possible answers)
3. Scale questions focusing on attitudes and interests regarding science, technology and social aspects (answering range from ‘strongly agree’ to ‘strongly disagree’)

The time required for completing the questionnaire will be between 70 and 120 minutes.

There are no risks involved in participating in this study. Each questionnaire is completely anonymous. Names will not be collected nor linked to submitted data. No one will know who responded to any of the questions. All collected data will be treated confidentially.
The participation is completely voluntary. It is possible to refuse to answer any question at any time without penalty. Withdrawing from the study can be done any time without any penalty.

As a thank you for participation in this study your child will get the opportunity to win a Raspberry Pi computer.

Participation of your child is essential for this scientific investigation.
If you have any questions, suggestions or comments you can contact me anytime:

Dipl.-Ing. Martin Kandlhofer
Graz University of Technology, Institute for Software Technology; Educational Robotics
Inffeldgasse 13/5, 8010 Graz, Austria
Email: mkandlho@ist.tugraz.at;
Phone: +43 664 73 67 67 95

Thanks a lot for your help and understanding!
Sincerely,

Martin Kandlhofer

If you allow your child to participate in the study described please put in your and your child’s name (in block letters), the date and your signature below:

Your Name:____

Name of your child: ____

Date:_________________________

Signature: ____

Evaluating the impact of Educational Robotics
School administration/Mentor information sheet and informed consent

My name is Martin Kandlhofer, I'm doctorand at Graz University of Technology in Austria. As part of my research I'm conducting an evaluation investigating the impact of educational robotics on pupils' skills and attitudes. This research is part of the TEDUSAR project (Technology and Education for Search and Rescue Robots) which is a cross-border EU program between Graz University of Technology and the University of Maribor.
The basic aim of the study is to gather solid and valuable empirical data regarding following key issues:

- Impact of educational robotics on pupils' technical skills
- Impact of educational robotics on pupils' attitudes and interests regarding science, technology and social aspects

The study will be piloted 2013/2014 in cooperation with selected schools in different European countries. Data collection will be done online using a multiple-choice questionnaire as survey instrument. The study relies on a two-group design (treatment- and control-group) and comprises both pre- and post-test (autumn/winter semester 2013, mid 2014 respectively).

Basically the survey instrument consists of three parts:

1. Anonymous background information questions (age, class, country,…)
2. Multiple-choice questions on technical aspects (easily to answer just by ticking one out of four possible answers)
3. Scale questions focusing on attitudes and interests regarding science, technology and social aspects (answering range from 'strongly agree' to 'strongly disagree')

The time required for completing the questionnaire will be between 70 and 120 minutes.

There are no risks involved for pupils and schools participating in this study. Each questionnaire is completely anonymous. Names of pupils will not be collected nor linked to submitted data. All collected data will be treated confidentially. The participation is completely voluntary. It is possible for pupils to refuse to answer any question at any time without penalty. Withdrawing from the study can be done by pupils and/or schools at any time without any penalty. Names of participating schools will be made anonymous and remain confidential an undisclosed. Written permissions of parents and pupils will be obtained prior to completion of the survey.

Attached to this letter there are documents for further detailed information (step-by-step checklist for study implementation at schools, overview of used questionnaire, parent / pupil informed consent, overview of study design)

If there are any questions, suggestions for refinement/revision or comments please contact me anytime.

Thanks a lot for consideration and support!
Sincerely,

Martin Kandlhofer

Dipl.-Ing. Martin Kandlhofer
Graz University of Technology
Institute for Software Technology
Inffeldgasse 13/5, 8010 Graz, Austria
Email: mkandlho@ist.tugraz.at;
Phone: +43 664 73 67 67 95

Please fill in: Approval by school administration / responsible teacher/mentor for participating in the study described above:

Name:

School:

Date:

Signature:

Investing in your future
Operation part financed by the European Union
European Regional Development Fund
REPUBLIC OF SLOVENIA
MINISTRY OF ECONOMIC DEVELOPMENT AND TECHNOLOGY
Das Land Steiermark
University of Maribor
TU Graz

A.7. Quantitative Main Study: Approval by the Commission for Scientific Integrity and Ethics

TU Graz

Graz University of Technology

Commission for Scientific Integrity and Ethics

Univ.-Prof. Dr.phil.
Johann GÖTSCHL
Head

e-mail:
johann.goetschl@uni-graz.at

Büro der Commission:
Eva-Maria Schmidt-Hasewend
Rechbauestraße 12
8010 Graz

Tel.: ++43 316 873 – 6080, 6081
Fax: ++43 316 873 – 106081
e.schmidt-hasewend@tugraz.at

DVR: 008 1833 UID: ATU 574 77 929

Mr. Martin KANDLHOFER, DI, Bakk.rer.soc.oec.
Institute for Software Technology (7160)
Inffeldgasse 16b/II
8010 Graz

Graz, 8. Oktober 2013

Re: Educational Robotics: Impact Evaluation of RoboCupJunior

Dear Mr. Kandlhofer,

no application to the Commission for Scientific Integrity and Ethics is necessary in respect of the project 'Educational Robotics: Impact Evaluation of RoboCupJunior'.
This project is being carried out in conformity with current social-scientific methodology. Consent statements have been obtained from the participants and their anonymity is assured.

With kind regards

Prof. Johann Götschl
Chair

Prof. Horst Bischof
Vice Rector for Research

A.8. Quantitative Main Study: Instrument (Questionnaire Stage I Study)

Evaluating the Impact of Educational Robotics

Student Questionnaire

Main Study Stage I

2013/2014

English version

Investing in your future
Operation part financed by the European Union
European Regional Development Fund
REPUBLIC OF SLOVENIA
MINISTRY OF ECONOMIC DEVELOPMENT AND TECHNOLOGY
Das Land Steiermark
University of Maribor
TU Graz

I. Demographic / background information

My name is Martin Kandlhofer, I'm PhD student at Graz University of Technology in Austria. As part of my research I'm conducting an evaluation investigating the impact of educational robotics on pupils' attitudes and skills. This research is part of the TEDUSAR project (Technology and Education for Search and Rescue Robots) which is a cross-border EU program between Graz University of Technology and the University of Maribor.

In order to collect valuable data for this research you will be asked to complete the following questionnaire, and again in about eight months another questionnaire. As a thank you for your participation in this study you will get the opportunity to win a Raspberry Pi computer. Please read the questions carefully and answer each of them honestly. There are no risks involved, each questionnaire is completely anonymous. All collected data will be treated confidentially. The participation is voluntary; you can refuse to answer any question at any time and can withdraw without any penalty.

The questionnaire is completely anonymous; no one will know who responded to any of the questions; none of your teachers will see your answers.

Your participation is essential for this scientific investigation. Each questionnaire is important!

Thank you very much for your help!
Martin Kandlhofer

This question will be used to match the survey now with the survey in eight months time. Therefore please construct a new word by applying the following rules in the given order:

1. write down the first two letters of your mother's first name
2. write down the first two letters of your first name
3. write down the first two letters of your father's first name
4. write down the last two numbers of the year of your birth

Example:
your mother's name: **Ma**ria
your name: **Ro**bert
your father's name: **Jo**hn
your year of birth: 19**96**
Result: **MaRoJo96**

____

Do you take part in a robotics course, an optional robotics subject, a robotics workshop, a robotics project, a robotics club or another robotics related activity this year?

- Yes
- No

If you answered the previous question with 'Yes' please specify where you take part in a robotics activity (multiple answers are possible):

- in school
- at home
- at a club
- other (please specify):_______________________

Do you plan to participate in the robotics competition in 2014?

- Yes
- No

Investing in your future
Operation part financed by the European Union
European Regional Development Fund
REPUBLIC OF SLOVENIA
MINISTRY OF ECONOMIC DEVELOPMENT AND TECHNOLOGY
Das Land Steiermark
University of Maribor
TU Graz

If you answered the previous question with ‘yes’ please specify in which discipline/competion you are planning to participate:

- RoboCupJunior Dance
- RoboCupJunior Rescue A
- RoboCupJunior Rescue B
- RoboCupJunior Soccer
- FLL
- FRC
- Other (please specify):___________________________

Have you ever been involved in one or more of the following robotics activities before? (Note: multiple answers are possible)

- Yes, robotics competition
- Yes, robotics club
- Yes, robotics camp
- Yes, robotics workshop
- Yes, other robotics activities
- No, I’ve never been in touch with robotics before
- No, I’ve never been involved in any robotics activities before

If yes, please specify:

____

Are you familiar with the following programming types?

- graphical programming (e.g. LEGO NXT, LabView,…)
- textual programming (e.g. Basic, C, C++, Java, C#, NXC, Python,…)
- both graphical AND textual programming
- none

What is your age?
(9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19)

Gender:

- female
- male

Type of your school (e.g. gymnasium, technical school,…):

____

Name of your school:

____

Country of your school:
____

Please select your year in your current school (e.g. if you are for your first year in your current school tick 1; if you are for you second year, tick 2; …):
(1, 2, 3, 4, 5, 6, 7, 8, 9)

What is your native language?

____

II. Technical Skills

The following section deals with the technical aspects and skills. The questions you will be asked can be answered just by ticking one out of four possible answers. For each of this multiple-choice questions there is exact one correct answer.
You can switch between the questions using the 'next' and 'prev' buttons in order to check or revise your previous answers.

General programming knowledge/robotics

Reference: G. Nugent, B. S. Barker, N. Grandgenett, V. I. Adamchuk, Impact of Robotics and Geospatial Technology Interventions on Youth STEM Learning and Attitudes, JRTE; Teacher Education Faculty Publications, University of Nebraska 42 (3) (2010) 391-408.

In order to follow a list of commands, without someone steering a robot on each step, a robot must be…

A) …controlled by a remote.
B) …computerized.
C) …programmed.
D) …trained.

A programming "loop"…

A) …starts the program code
B) …stops the program code
C) …turns the robot off
D) …repeats some program steps or code

A computer program is/are ______ that tell(s) the computer to do something.

A) sensors
B) code
C) lights
D) robots

What helps a robot to explore its environment?

A) Tires
B) Sensors
C) LCD panels
D) Mechanical arms

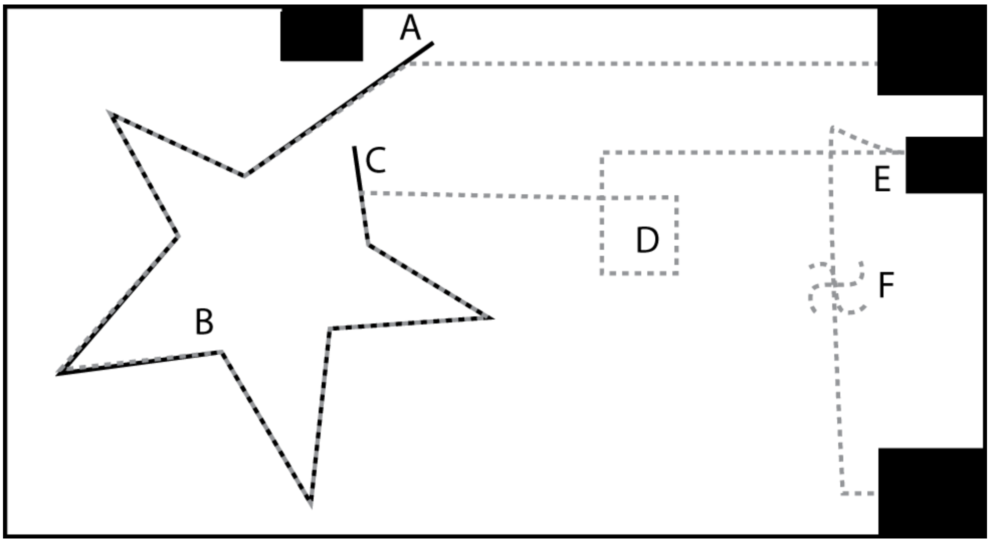
What is a computer program?

A) Computer-created text
B) The hardware that controls a computer
C) Instructions or steps written so a computer understands
D) Language that is built into a robot

When writing a computer program, a switch block or if/then/else statement is used to…

A) …ask a question.
B) …stop the program.
C) …speed up the program.
D) …repeat the code

Use the picture of the obstacle course to answer following questions. The dashed line(s) shows the path of the robot. The solid line is black electrical tape, the black rectangles indicate obstacles.



Which sensor is the best to get the robot between points A and C?

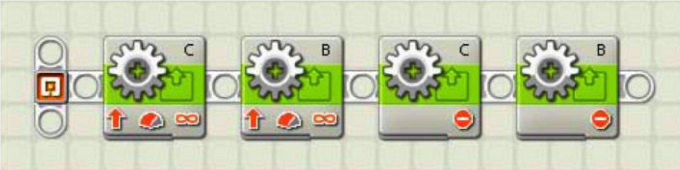
- **A) Light**
- B) Sound
- C) Touch
- D) Ultrasonic

On which point on the image above the robot does the following:
Repeat 4 times: [Forward one tire rotation; robot turn ninety degrees right]

- A) Point B
- **B) Point D**
- C) Point E
- D) Point F

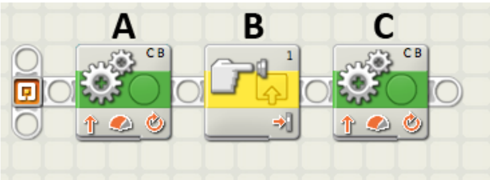
Which sensor would be *LEAST* likely to complete the challenge shown in the picture?

- A) Light
- **B) Sound**
- C) Touch
- D) Rotation



What will the robot do when the program shown in the picture above is downloaded and run?

A) Move forward
B) Nothing
C) Move backwards
D) Turn for 360 degrees

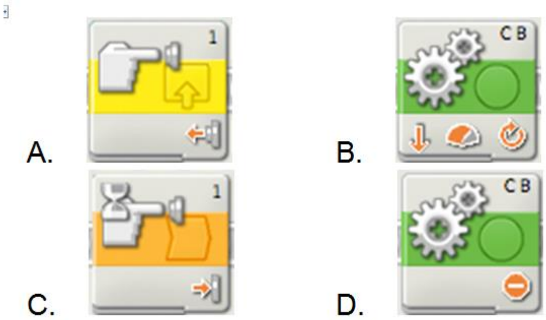


The LEGO program in the picture above has some mistakes. The robot should do:

1. Move forward
2. Detect the touch sensor being pressed
3. Move backward

Which programming block in the picture above is wrong?

A) A
B) B
C) C
D) Both A and C



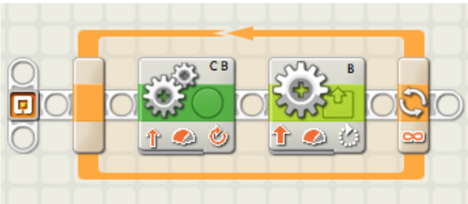
Take a look at the four pictures above. Which block should be used instead in order to fix the program from the previous question?

A) A
B) B
C) C
D) D

Take a look at the picture above. What is the programming mistake?
The robot should:

1. Move forward until the light sensor detects a dark line.
2. Stop.

A) The light sensor's threshold value is too high.
B) The light sensor's threshold value is too low.
C) The move blocks do not control the same motors.
D) The second move block should be set to move backward two rotations.

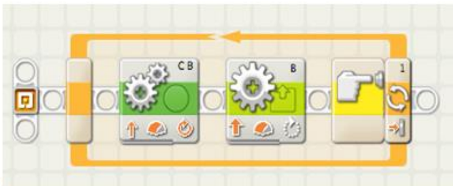


What is the mistake in the picture above?
The robot should:

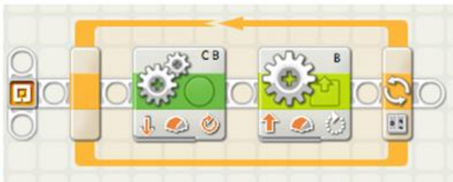
1. Repeat four times
2. Move forward one rotation
3. Make a right 90˚ turn

A) The motor block is set for the wrong motor.
B) The move block is set to go backwards.
C) This program does not need a loop block.
D) The loop block is set to repeat over and over again.

A) 

B) 

C) 

D) 

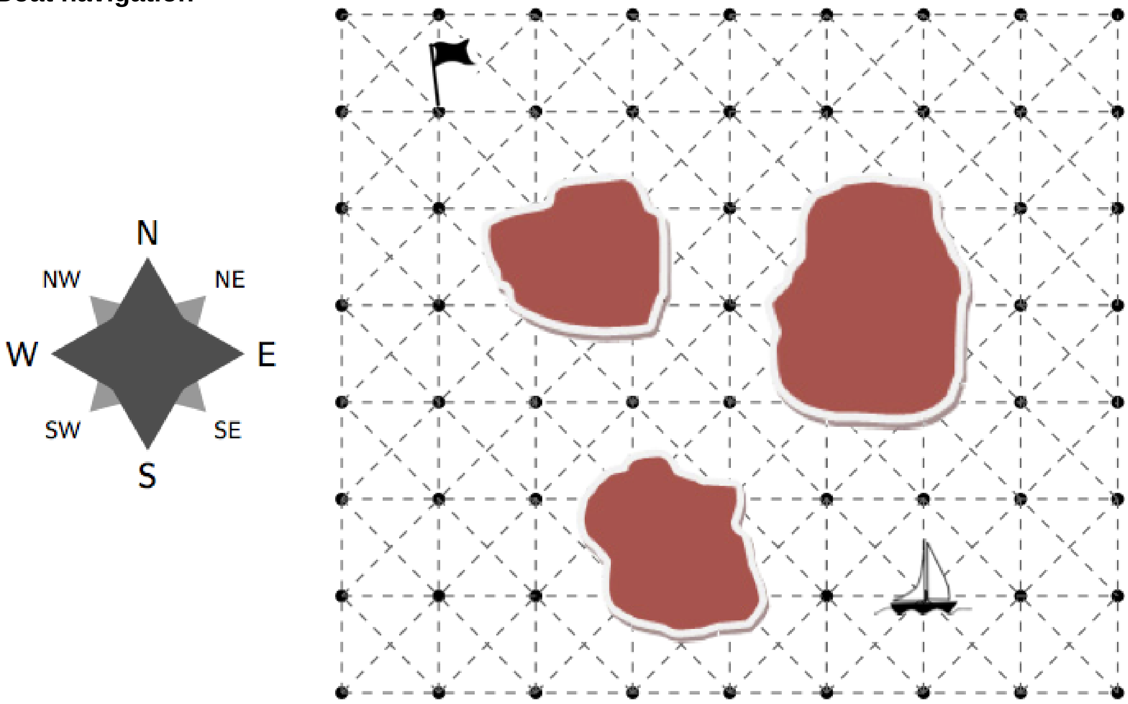
Take a look at the 4 pictures above. Which program will correct the mistake from the previous question?

A) A
B) B
C) C
D) D

Computer science

References: Beaver Computing Challenge;
University of Waterloo, Beaver Computing Challenge (2012, 2013).
Austrian Computer Society (OCG), Biber der Informatik (2012, 2013).

Boat navigation

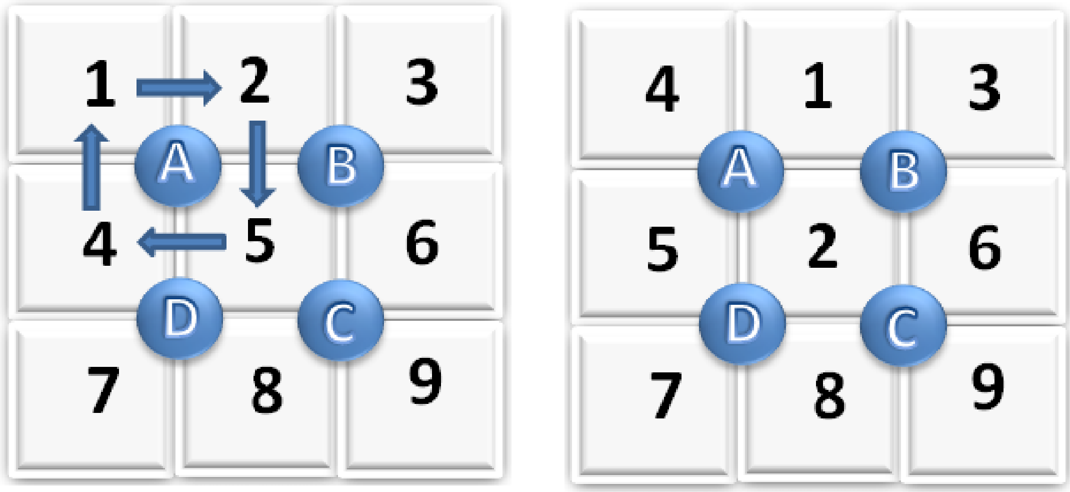


Take a look at the picture above. A sailor takes her boat on the lake with islands. Her aim is to sail to the flag by programming the boat’s autopilot. The autopilot commands the boat to sail along the dashed lines. In one step, the boat moves from a point to the nearest point along a dashed line in one of eight different directions. For example, the command 1 N means take 1 step in the northern direction, and the command 2 NE means take 2 steps diagonally in the northeastern direction. Each point is a small black circle on the map. The 8 different directions (N, NE, E, SE, S, SW, W, NW) are also shown in the picture above.
(Explanation of the letters in the picture: N…North, NE…North-East, E…East, SE…Sout-East, S…South, SW…South-West, W…West, NW…North-West)

Which of the following routes to the flag avoids the islands using the smallest number of steps?
Possible answers:

A) 5 NW
B) 2 NW, 2 W, 1 N, 1W, 2N
C) 2 NW, 3 N, 3 W
D) 2 NW, 2 W, 1 NW, 2 N

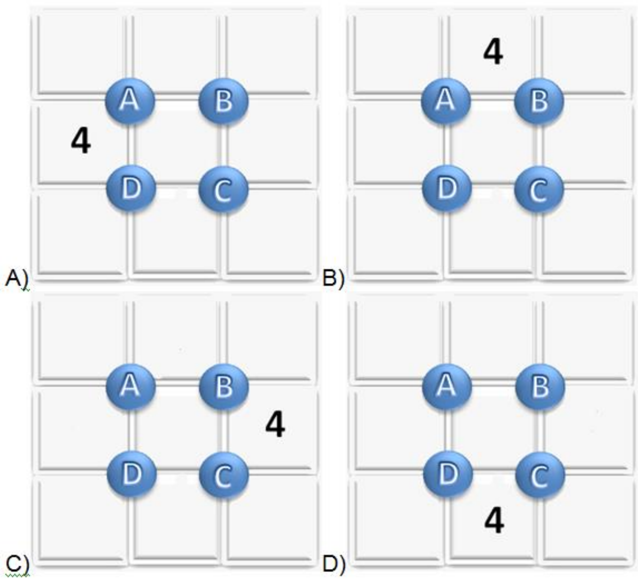
Rotating puzzle



Robot Alan plays a new game. If he presses one of the buttons A, B, C or D, the four numbers adjacent to the button will be rotated clockwise as shown in the picture above on the left. The result of pressing the button A is shown in the picture above on the right.

Starting from the picture above on the left, robot Alan pressed four buttons in the order of D, C, B, B.
Where is the number 4 after Alan pressed the buttons?
Please take a look at the 4 pictures below for possible answers:

A) A
B) B
C) C
D) D



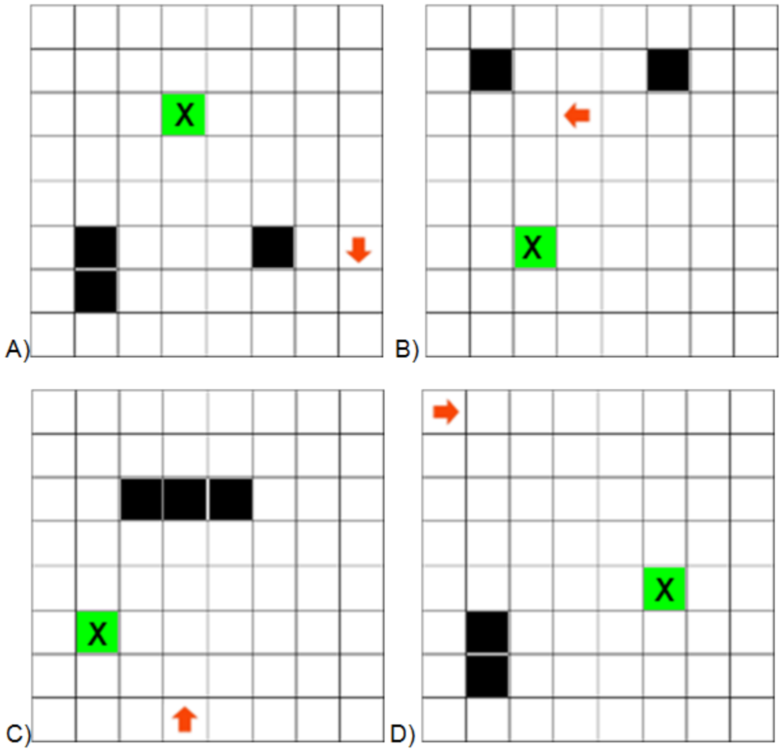
Autonomous robot
A robot is programmed to find a target (the green field marked with X) on a map of square fields (take a look at the image below). The robot has its movements programmed as follows:

- The robot moves straight forward until it reaches an obstacle (black field) or the edge of the map.
- When reaching an obstacle or the edge of the map, the robot turns right by 90 degrees.
- When the robot moves out of a field, the field becomes a black obstacle.

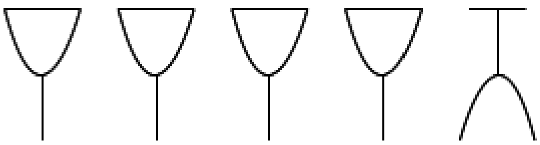
The arrows on the maps below show the starting position as well as the starting direction of the robot.

On which of the 4 maps shown in the image below does the robot NOT eventually reach the target (green field marked with X)?

A) A
B) B
C) C
D) D



Glasses

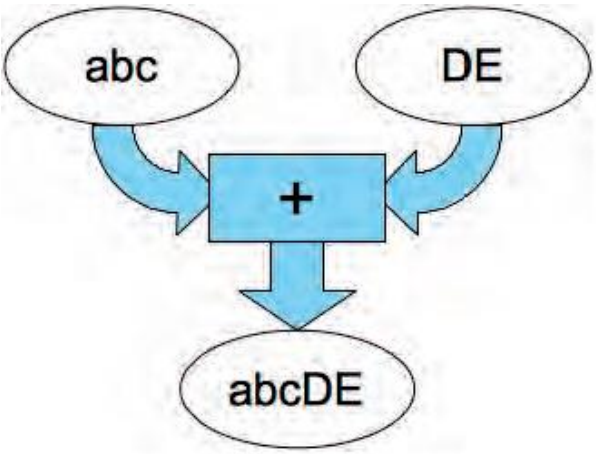


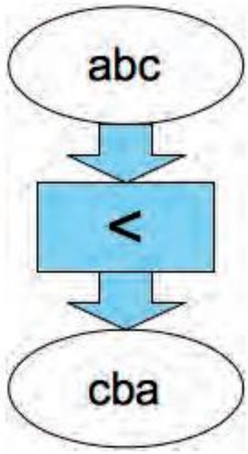
There are 5 empty glasses on a table as shown in the picture above. One is facing down and four are facing up.
Flipping a glass changes it from facing up to facing down, or from facing down to facing up.
In one turn, you must flip exactly three different glasses. The glasses which are flipped do not need to be adjacent.
What is the minimum number of turns to make all glasses facing up?

Possible Answers:

- A) 2 turns
- **B) 3 turns**
- C) 5 turns
- D) it is not possible to make all glasses facing up

Text machine



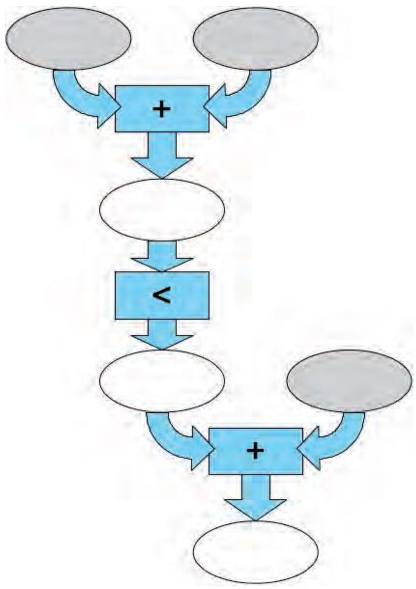


A Glue machine (+) takes two pieces of text and puts one after the other. An example is shown in the left picture above.
A Reverse machine (<) takes one piece of text and puts the characters in reverse order. An example is shown in the right picture above.

Two Glue machines and one Reverse machine are combined to create the Combined machine shown in the picture below. The Combined machine takes three pieces of text (in the grey ovals) and after processing them, gives one piece of final text (in the bottom-most oval).

Which three pieces of text will produce the final text INFORMATION when given to the Combined machine, in the order specified?

A) FNI AMRO NOIT
B) AMR OFNI NOIT
C) AMR OFNI TION
D) INF ORMA TION



Bebrocarina

A bebrocarina is a musical instrument with the following features:

- It can play only 6 different tones.
- The tones can be arranged from lowest to highest
- After having played one tone, it is possible to play only the same tone, the next higher tone (if it exists) or the next lower tone (if it exists).

This means that melodies can be represented using only three different symbols:

= means "the current tone must be the same as the previous tone", and
- means "the current tone must be one lower than the previous tone", and
+ means "the current tone must be one higher than the previous tone."

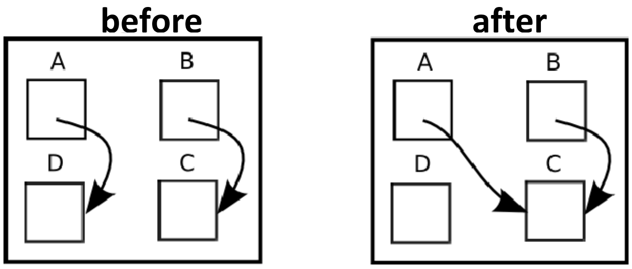
For example, melody - + means "play 3 tones, the second tone is lower than the first one and the third tone is higher than the second tone (i.e. the same as the first tone)."

For which of these melodies there is no starting tone that makes playing the melody possible?

Possible Answers:

A) + = = = + = = = + = = = + = = = = +
B) - - - = + - = - - = = = +
C) - - - - - = + + + + + = - - - - -
D) - - + - - + - - = - + - -

Arrows



The instruction A<-B changes a picture of boxes and arrows in the following way:

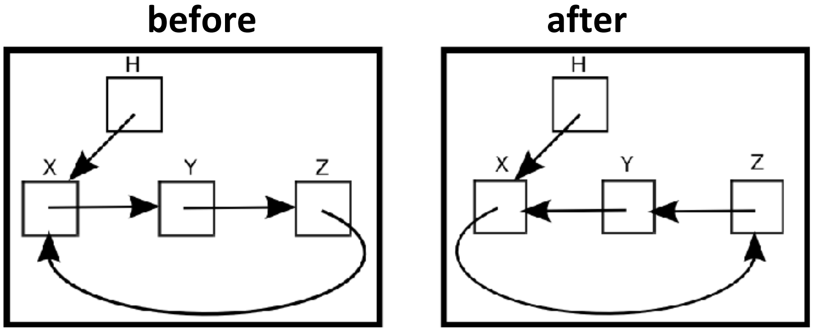
- The arrow which points out of the box labeled A is removed.
- Then, a new arrow out of the box labeled A is added. This new arrow points to the same box as the arrow out of the box labeled B points to.

Take a look at the two pictures above for an example (before and after applying the instruction A<-B).

What sequence of instructions (performed in order) changes the 'before' picture to the 'after' picture in the image below?

Possible answers:

A) X <- Y, Y <- Z, Z <- X
B) X <- Z, Z <- X, Y <- H
C) Z <- Y, X <- Z, Y <- H
D) Z <- X, X <- Y, Y <- H



Textual programming

Reference: D. Clark, Testing Programming Skills with Multiple Choice Questions., Informatics in Education 3 (2) (2004) 161-178.

```
a = 2
b = 2
c = 4
If (a > b) Then
       If (a > c) Then
              m = 1
       Else
              m = 2
       End If
Else
       If (c != 0) Then
              m = 3
       Else
              m = 4
       End If
End If
```

What is the value of m after the code fragment above is executed? (note: '!=' means 'unequal')

A) 1
B) 3
C) 2
D) 4

```
y = 1
Do While (y <= x)
   y = y * 2
Loop
```

If x is 8, what is the value of y after the code above is executed?

A) 8
B) 10
C) 12
D) 16

```
y = 0
Do While (y < x)
       y = y + 7
Loop
```

Which is true after the code above is executed? Assume that x is >= 0. (note: only one statement is correct)

A) *y* must be greater than *x.*
B) *y* may be equal *x* + 7.
C) *y* must be greater than 0.
D) *y* may be equal to *x*.

```
"statement 1"
For i = 0 to numItems - 2
      data(i) = data(i+1)
Next i
"statement 2"
```

The array 'data' contains 'numItems' number of elements. The code above is intended to shift the elements in the array 'data' to the left with wrap around.

That is to convert
7 3 8 1 0 5
into
3 8 1 0 5 7

In order for the code to execute correctly "statement 1" and "statement 2" should be (take a look at image below for possible answers):

A)
```
temp = data(0)
data(0) = temp
```

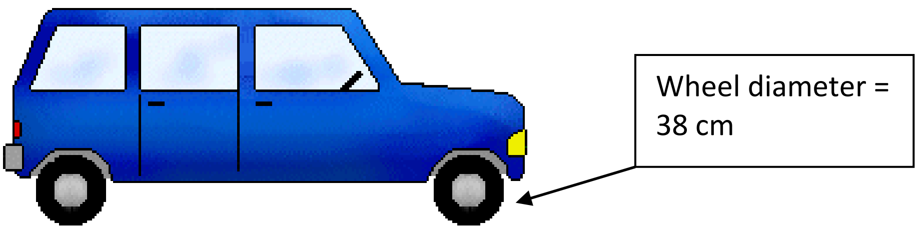
B)
```
temp = data(0)
data(numItems-1) = temp
```

C)
```
temp = data(numItems-1)
data(0) = temp
```

D)
```
temp = data(numItems-1)
data(numItems-1) = temp
```

Mathematics and scientific investigation

References:
G. Nugent, B. S. Barker, N. Grandgenett, V. I. Adamchuk, Impact of Robotics and Geospatial Technology Interventions on Youth STEM Learning and Attitudes, JRTE; Teacher Education Faculty Publications, University of Nebraska 42 (3) (2010) 391-408.
OECD Programme for International Student Assessment 2006 (PISA) – Released items
I. L. Jomento-Cruz, Robotics as a Means of Increasing Student Achievement in Middle School Science, Master's thesis, Louisiana State University (2010).



Use the picture of the car to answer following questions (remember that Pi is about 3.14)

Which math formula would help you know how far the car would go if the wheel turned one time?

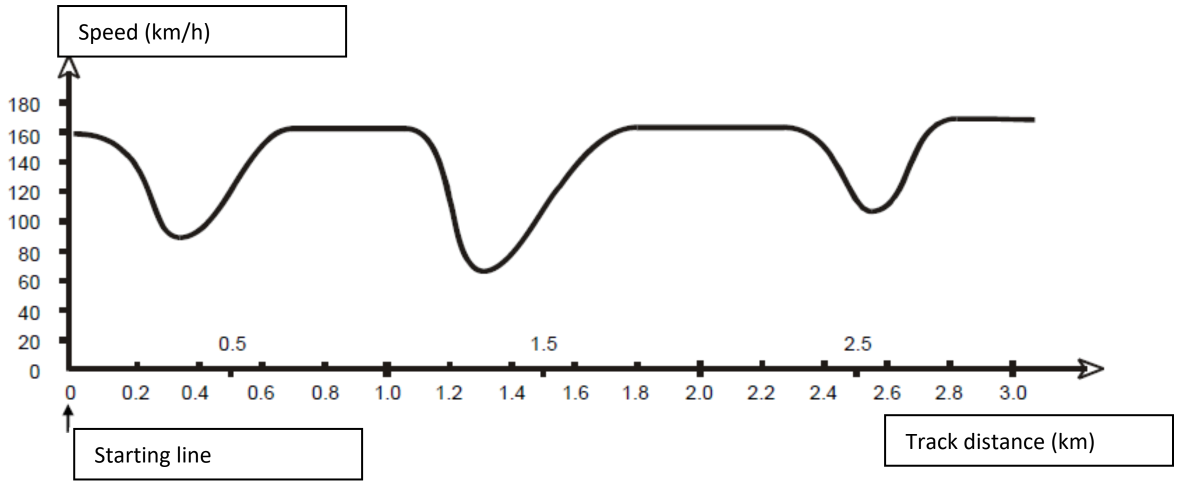
A. H = r - d
B. C = π*d
C. A = (π*d)*(π*d) / 4
D. K = d*s / 4

Calculate the approximate distance traveled in four turns of the wheels.
A. 3,7 meter
B. 4,3 meter
C. 4,8 meter
D. 5,5 meter

How many rotations of the wheels are needed to go 76 meter?
A. 48 rotations
B. 56 rotations
C. 64 rotations
D. 72 rotations

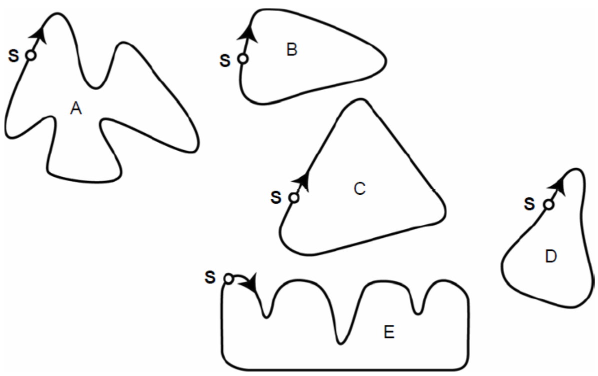
Your car can also be programmed to move by degrees of a circle. How many degrees would you need to program your car to move 3 rotations?
A. 360
B. 720
C. 1080
D. 1440

Speed of a racing car



The graph above (called a 'speedgraph') shows how the speed of a racing car varies along a flat 3 kilometer track during its second lap.
On which of the tracks shown in the picture below the racing car drove according to the speedgraph figure above (the point in S indicates the starting line)?

A) A
B) B
C) C
D) D
E) E



Earthquake
A documentary was broadcast about earthquakes and how often earthquakes occur. It included a discussion about the predictability of earthquakes.
A geologist stated: “In the next twenty years, the chance that an earthquake will occur in Zed City is two out of three”.

Which of the following best reflects the meaning of the geologist’s statement?

A) 2/3 x 20 = 13.3, so between 13 and 14 years from now there will be an earthquake in Zed City
B) 2/3 is more than 1/2, so you can be sure there will be an earthquake in Zed City at some time during the next 20 years.
C) The likelihood that there will be an earthquake in Zed City at some time during the next 20 years is higher than the likelihood of no earthquake.
D) You cannot tell what will happen, because nobody can be sure when an earthquake will occur.

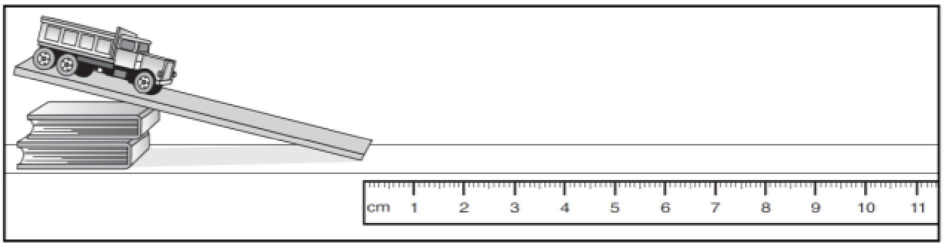
The ball experiment
Anna performed an experiment to study the effect of slope of a ramp on the speed of moving objects.

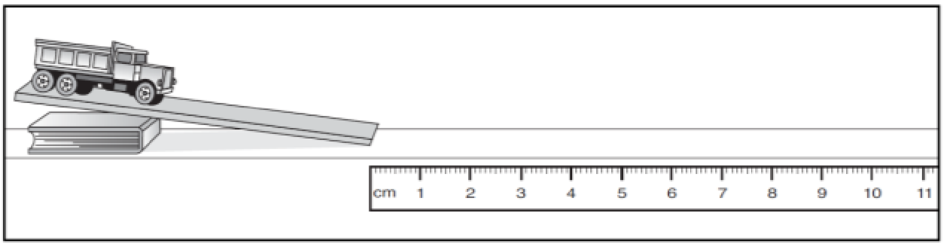
- She built three ramps from the same material, but with different slopes.
- She rolled a ball down each ramp.
- She measured the speed of the ball on each ramp.

What is the independent variable in this experiment?
(Note: In an experiment the dependent variable represents the effect, the independent variable represents the cause)

A) the speed of the ball
B) the same material on all three ramps
C) the different slopes on the ramps
D) the type of balls used

The truck experiment



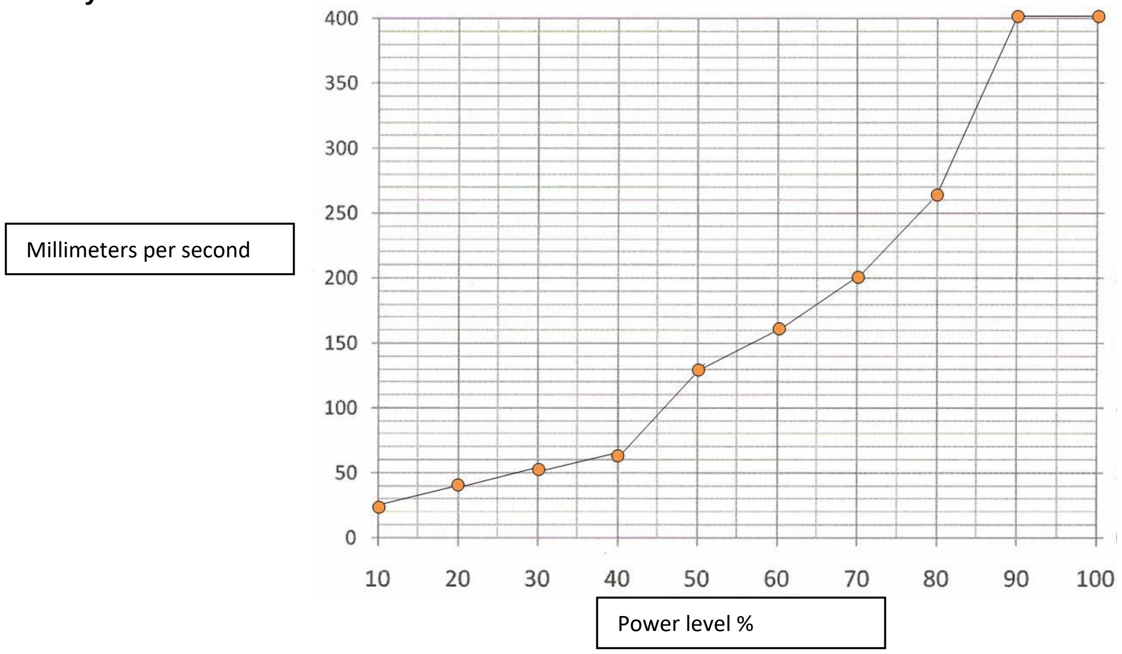


Take a look at the pictures above: Maria let the truck go at the top of each ramp and measured the distance it traveled. Which of the following is most likely what she was trying to prove?

A) A toy truck will roll down a ramp held up with books.
B) A toy truck will move straight down a ramp whether the ramp is held up with one book or two books.

C) A toy truck will roll about twice as far coming off a two-book ramp than a one-book ramp.
D) A toy truck on a one-book ramp has half the force of gravity as a truck on a two-book ramp.

Robot in sandy area



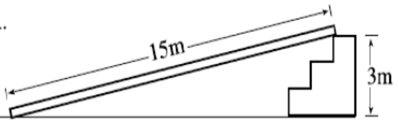
A robot needs to run in a sandy area and the only advisable speed to use is 180 mm/sec to prevent the robot from turning over. Based on the graph above, what power level will you recommend to set the robot.

A) 65%
B) 50%
C) 70%
D) 85%

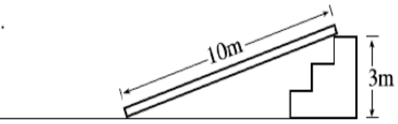
Climbing robot
A robot must climb a ramp that is 3 meters off the ground. Which of the ramps shown in the picture below would require the LEAST amount of work (in terms of physical effort) by the robot?

A) A
B) B
C) C
D) D

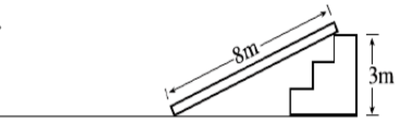
A.



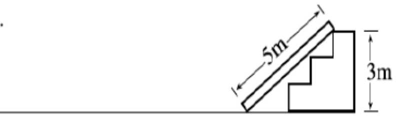
B.



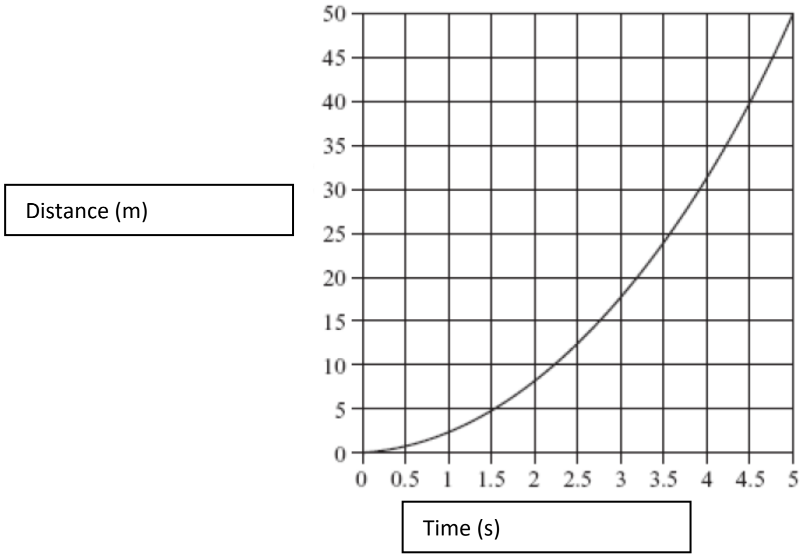
C.



D.



Moving robot



The distance vs. time graph above shows data collected as a robot moved across a level parking lot. According to the graph, which of the following conclusions about the robot‘s motion is supported?

A) The robot is accelerating.
B) The robot is stopping and starting.
C) The robot is traveling at a constant velocity.
D) The robot is moving through an obstacle course.

III. Attitudes and interests

The following section asks for your attitudes and interests regarding science, technology and social aspects. There are no 'wrong' or 'right' answers, in this section we are exclusively interested in your personal opinion. For each question please tick one answer.

Science related attitudes and interests

Reference: B. J. Fraser, TOSRA: Test of Science-Related Attitudes, The Australian Council for Educational Research, Hawthorn, Victoria, 1981.

.

I would prefer to find out why something happens by doing an experiment than by being told.
Strongly Agree Agree Uncertain Disagree Strongly Disagree

I enjoy reading about things which disagree with my previous ideas.
Strongly Agree Agree Uncertain Disagree Strongly Disagree

Science lessons are fun.
Strongly Agree Agree Uncertain Disagree Strongly Disagree

I would like to belong to a science club.
Strongly Agree Agree Uncertain Disagree Strongly Disagree

I would dislike being a scientist after I leave school.
Strongly Agree Agree Uncertain Disagree Strongly Disagree

Doing experiments is not as good as finding out information from teachers.
Strongly Agree Agree Uncertain Disagree Strongly Disagree

I dislike repeating experiments to check that I get the same results.
Strongly Agree Agree Uncertain Disagree Strongly Disagree

I dislike science lessons.
Strongly Agree Agree Uncertain Disagree Strongly Disagree

I get bored when watching science programs on TV at home.
Strongly Agree Agree Uncertain Disagree Strongly Disagree

When I leave school, I would like to work with people who make discoveries in science.
Strongly Agree Agree Uncertain Disagree Strongly Disagree

I would prefer to do experiments than to read about them.
Strongly Agree Agree Uncertain Disagree Strongly Disagree

I am curious about the world in which we live.
Strongly Agree Agree Uncertain Disagree Strongly Disagree

School should have more science lessons each week
Strongly Agree Agree Uncertain Disagree Strongly Disagree

I would like to be given a science book or a piece of scientific equipment as a present.
Strongly Agree Agree Uncertain Disagree Strongly Disagree

I would dislike a job in a science laboratory after I leave school.
Strongly Agree Agree Uncertain Disagree Strongly Disagree

Investing in your future
Operation part financed by the European Union European Regional Development Fund
REPUBLIC OF SLOVENIA
MINISTRY OF ECONOMIC DEVELOPMENT AND TECHNOLOGY
Das Land Steiermark
University of Maribor
TU Graz

I would rather agree with other people than do an experiment to find out for myself.
Strongly Agree Agree Uncertain Disagree Strongly Disagree

Finding out about new things is unimportant.
Strongly Agree Agree Uncertain Disagree Strongly Disagree

Science lessons bore me.
Strongly Agree Agree Uncertain Disagree Strongly Disagree

I dislike reading books about science during my holidays.
Strongly Agree Agree Uncertain Disagree Strongly Disagree

Working in a science laboratory would be an interesting way to earn a living.
Strongly Agree Agree Uncertain Disagree Strongly Disagree

I would prefer to do my own experiments than to find out information from a teacher.
Strongly Agree Agree Uncertain Disagree Strongly Disagree

I like to listen to people whose opinions are different from mine.
Strongly Agree Agree Uncertain Disagree Strongly Disagree

Science is one of the most interesting schools subjects.
Strongly Agree Agree Uncertain Disagree Strongly Disagree

I would I like to do science experiments at home.
Strongly Agree Agree Uncertain Disagree Strongly Disagree

A career in science would be dull and boring.
Strongly Agree Agree Uncertain Disagree Strongly Disagree

I would rather find out about things by asking an expert than by doing an experiment.
Strongly Agree Agree Uncertain Disagree Strongly Disagree

I find it boring to hear about new ideas.
Strongly Agree Agree Uncertain Disagree Strongly Disagree

Science lessons are a waste of time.
Strongly Agree Agree Uncertain Disagree Strongly Disagree

Talking to friends about science after school would be boring.
Strongly Agree Agree Uncertain Disagree Strongly Disagree

I would like to teach science when I leave school .
Strongly Agree Agree Uncertain Disagree Strongly Disagree

I would rather solve a problem by doing an experiment than be told the answer.
Strongly Agree Agree Uncertain Disagree Strongly Disagree

In science experiments, I like to use new methods which I have not used before.
Strongly Agree Agree Uncertain Disagree Strongly Disagree

I really enjoy going to science lessons.
Strongly Agree Agree Uncertain Disagree Strongly Disagree

I would enjoy having a job in a science laboratory during my school holidays.
Strongly Agree Agree Uncertain Disagree Strongly Disagree

A job as a scientist would be boring.
Strongly Agree Agree Uncertain Disagree Strongly Disagree

It is better to ask the teacher the answer than to find it out by doing experiments.
Strongly Agree Agree Uncertain Disagree Strongly Disagree

I am unwilling to change my ideas when evidence shows that the ideas are poor.
Strongly Agree Agree Uncertain Disagree Strongly Disagree

The material covered in science lessons is uninteresting.
Strongly Agree Agree Uncertain Disagree Strongly Disagree

Listening to talk about science on the radio would be boring.
Strongly Agree Agree Uncertain Disagree Strongly Disagree

A job as a scientist would be interesting.
Strongly Agree Agree Uncertain Disagree Strongly Disagree

I would prefer to do an experiment on a topic than to read about it in science magazines.
Strongly Agree Agree Uncertain Disagree Strongly Disagree

In science experiments, I report unexpected results as well as expected ones.
Strongly Agree Agree Uncertain Disagree Strongly Disagree

I look forward to science lessons.
Strongly Agree Agree Uncertain Disagree Strongly Disagree

I would enjoy visiting a science museum at the weekend.
Strongly Agree Agree Uncertain Disagree Strongly Disagree

I would dislike becoming a scientist because it needs too much education.
Strongly Agree Agree Uncertain Disagree Strongly Disagree

It is better to be told scientific facts than to find them out from experiments.
Strongly Agree Agree Uncertain Disagree Strongly Disagree

I dislike listening to other people's opinions.
Strongly Agree Agree Uncertain Disagree Strongly Disagree

I would enjoy school more if there were no science lessons.
Strongly Agree Agree Uncertain Disagree Strongly Disagree

I dislike reading newspaper articles about science.
Strongly Agree Agree Uncertain Disagree Strongly Disagree

I would like to be a scientist when I leave school .
Strongly Agree Agree Uncertain Disagree Strongly Disagree

IV. Social-/soft-skills

Self-efficacy in robotics

Reference: G. Nugent, B. S. Barker, N. Grandgenett, V. I. Adamchuk, Impact of Robotics and Geospatial Technology Interventions on Youth STEM Learning and Attitudes, JRTE; Teacher Education Faculty Publications, University of Nebraska 42 (3) (2010) 391-408.

I am confident that I can program a robot to move forward two wheel rotations (i.e. 720 degrees) and then stop.
Strongly Agree Agree Uncertain Disagree Strongly Disagree

I am certain that I can build a LEGO or similar robot by following design instructions.

Strongly Agree Agree Uncertain Disagree Strongly Disagree

I am certain that I can fix the software program for a robot that does not behave as expected.
Strongly Agree Agree Uncertain Disagree Strongly Disagree

I am confident that I can program a LEGO or similar robot to follow a black line using a light sensor.
Strongly Agree Agree Uncertain Disagree Strongly Disagree

Problem solving skills

Reference: G. Nugent, B. S. Barker, N. Grandgenett, V. I. Adamchuk, Impact of Robotics and Geospatial Technology Interventions on Youth STEM Learning and Attitudes, JRTE; Teacher Education Faculty Publications, University of Nebraska 42 (3) (2010) 391-408.

I use a step by step process to solve problems.
Strongly Agree Agree Uncertain Disagree Strongly Disagree

I make a plan before I start to solve a problem
Strongly Agree Agree Uncertain Disagree Strongly Disagree

I try new methods to solve a problem when a known method does not work.
Strongly Agree Agree Uncertain Disagree Strongly Disagree

I carefully analyze a problem before I begin to develop a solution.
Strongly Agree Agree Uncertain Disagree Strongly Disagree

In order to solve a complex problem, I break it down into smaller steps.
Strongly Agree Agree Uncertain Disagree Strongly Disagree

Teamwork

Reference: G. Nugent, B. S. Barker, N. Grandgenett, V. I. Adamchuk, Impact of Robotics and Geospatial Technology Interventions on Youth STEM Learning and Attitudes, JRTE; Teacher Education Faculty Publications, University of Nebraska 42 (3) (2010) 391-408.

I like listening to others when trying to decide how to approach a task or problem.
Strongly Agree Agree Uncertain Disagree Strongly Disagree

I like being part of a team that is trying to solve a problem.
Strongly Agree Agree Uncertain Disagree Strongly Disagree

When working in teams, I ask my teammates for help when I run into a problem or don't understand something.
Strongly Agree Agree Uncertain Disagree Strongly Disagree

I like to work with others to complete projects.
Strongly Agree Agree Uncertain Disagree Strongly Disagree

Social skills

Reference: Social Skills: W. Hansen, R. McNeal, How D.A.R.E. works: An examination of program effects on mediating variables., Health Education & Behavior 24 (2).

I know how to make friends with people of the opposite sex
Strongly Agree Agree Disagree Strongly Disagree

If I want my friends to go along with me, I know what to say to them.
Strongly Agree Agree Disagree Strongly Disagree

It is easy for me to make new friends.
Strongly Agree Agree Disagree Strongly Disagree

It is easy for me to ask my friends for favors and help when I need to.
Strongly Agree Agree Disagree Strongly Disagree

How hard or easy is it for you to get along with other people?
Very easy Pretty easy Pretty hard Very hard

Goal setting skills

Reference: Social Skills: W. Hansen, R. McNeal, How D.A.R.E. works: An examination of program effects on mediating variables., Health Education & Behavior 24 (2).

How often do you work on goals that you have set for yourself?
Never Sometimes but not often Often All the time

Once I set a goal, I don't give up until I achieve it.
Strongly Agree Agree Disagree Strongly Disagree

Whenever I do something, I always give it my best.
Strongly Agree Agree Disagree Strongly Disagree

I think about what I would like to be when I become an adult.
Never Sometimes but not often Often All the time

When I set a goal, I think about what I need to do to achieve that goal.
Never Sometimes but not often Often All the time

V. Feedback

Finally we would like to ask you to provide some feedback regarding this questionnaire.

Please rate the overall difficulty of the questions.
Too Easy Pretty Easy Exactly appropriate Pretty Difficult Too Difficult

Please rate the overall clarity of the questions.
Very clear Pretty Clear Exactly appropriate Pretty Unclear Very Unclear

Please rate whether or not the time for filling in the questionnaire was enough.
Absolutely enough Pretty Enough Exactly appropriate Not Really Enough Absolutely not Enough

What do you think about the length (amount of questions + time required for filling in) of this questionnaire?
Way Too Short Too Short Appropriate Too Long Way Too Long

Do you have any further comments, feedback or suggestions?

____

Thank you very much for your help!

A.9. Quantitative Main Study: Instrument (Questionnaire Stage II Study; Young School Students)

Evaluating the Impact of Educational Robotics

Student Questionnaire

Main Study Stage II Middle School Students
2014/2015

English Version

Investing in your future
Operation part financed by the European Union
European Regional Development Fund
REPUBLIC OF SLOVENIA
MINISTRY OF ECONOMIC DEVELOPMENT
AND TECHNOLOGY

I. Demographic / background information

My name is Martin Kandlhofer, I'm PhD student at Graz University of Technology in Austria. As part of my research I'm conducting an evaluation investigating the impact of educational robotics on pupils' attitudes and skills.

In order to collect valuable data for this research you will be asked to complete the following questionnaire, and again in about seven months time another questionnaire.

Please read the questions carefully and answer each of them honestly. There are no risks involved, each questionnaire is completely anonymous. All collected data will be treated confidentially. The participation is voluntarily; you can refuse to answer any question at any time and can withdraw without any penalty. Of course you can skip questions if you consider them too difficult.
The questionnaire is completely anonymous; no one will know who responded to any of the questions;

Your participation is essential for this scientific investigation. Each questionnaire is important!

Thank you very much for your help!
Martin Kandlhofer

1)This question will be used to match the survey now with the survey in seven months time. Therefore please construct a new word by applying the following rules in the given order:

1. write down the first two letters of your mother's first name
2. write down the first two letters of your first name
3. write down the first two letters of your father's first name
4. write down the last two numbers of the year of your birth

Example:
your mother's name: **Ma**ria
your name: **Ro**bert
your father's name: **Jo**hn
your year of birth: 19**96**
Result: **MaRoJo96**

____

____

2) Do you take part in a robotics course, an optional robotics subject, a robotics workshop, a robotics project, a robotics club or another robotics related activity this year?

- Yes
- No

3) Have you ever been involved in robotics activities before?

- Yes
- No

4) How old are you?

(9, 10, 11, 12)

5) Gender:

- female
- male

6) Name of your school:

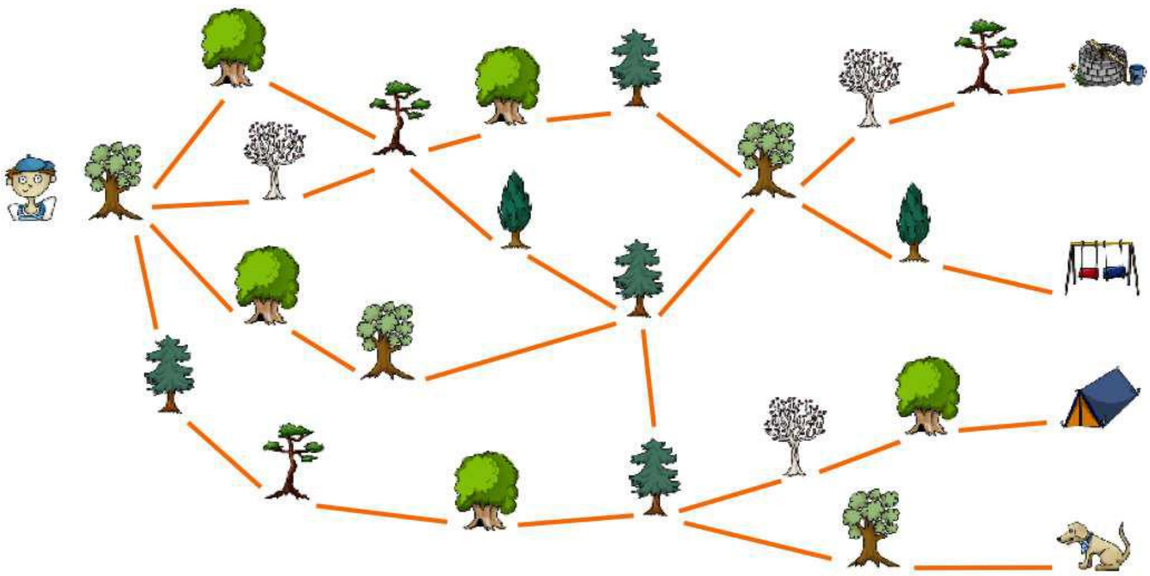
II. Technical Skills

The following section deals with the technical aspects and skills. The questions you will be asked can be answered just by ticking one out of four possible answers. For each of this multiple-choice questions there is exact <u>one</u> correct answer. Of course you can skip questions if you consider them too difficult.
You can switch between the questions using buttons below in order to check or revise your previous answers.

References: Beaver Computing Challenge;
University of Waterloo, Beaver Computing Challenge (2012, 2013).
Austrian Computer Society (OCG), Biber der Informatik (2012, 2013).

Concept of Graphs/Data Structures in Computer Science

7) In the forest
(Beaver Computing Challenge 2013; easy)



Look at the picture above:
Rupert walks through the forest. At the end of his journey he meets the dog.

At which of the tree rows below Rupert passed by?
A)
B)
C)
D

A)

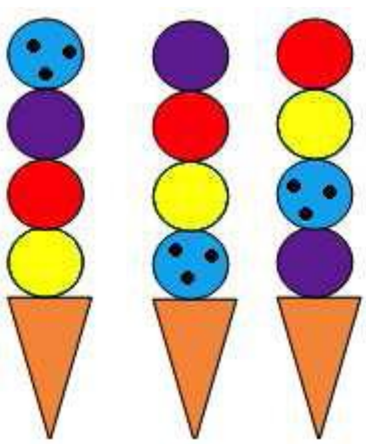
B)

C)

D)

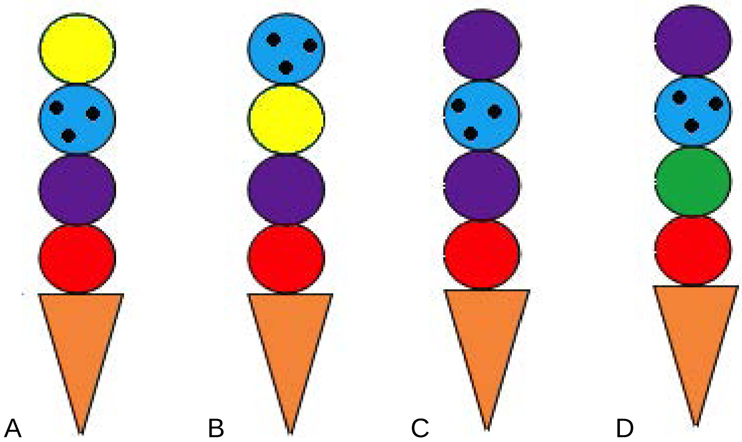
Principles of automata / computer programs

8) Ice Cream Machine
(Beaver Computing Challenge 2013; easy)



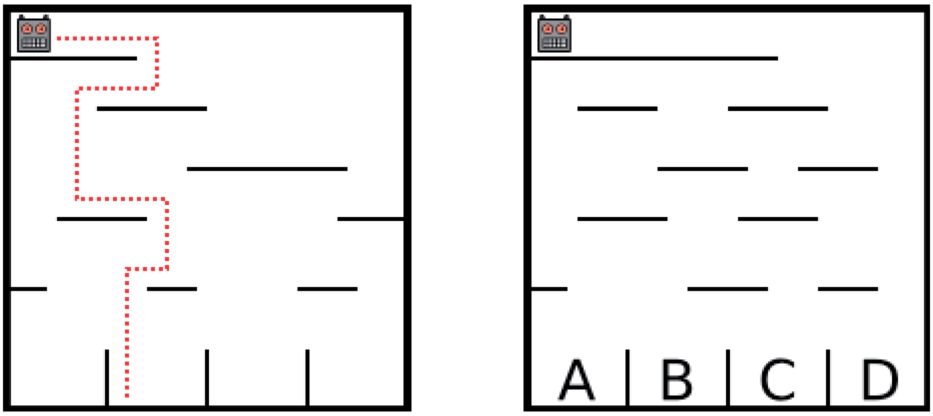
This special ice cream machine produces cornets with 4 scoops of ice cream.
The machine does this in a systematical (sorted) way.
The picture above (from left to right) shows the 3 of the cornets produced by this machine.

Which of the cornets in the picture below will be produced next?
A)
B)
C)
D)



Principles of algorithms

9) Falling Robot
(Beaver Computing Challenge 2012; medium)

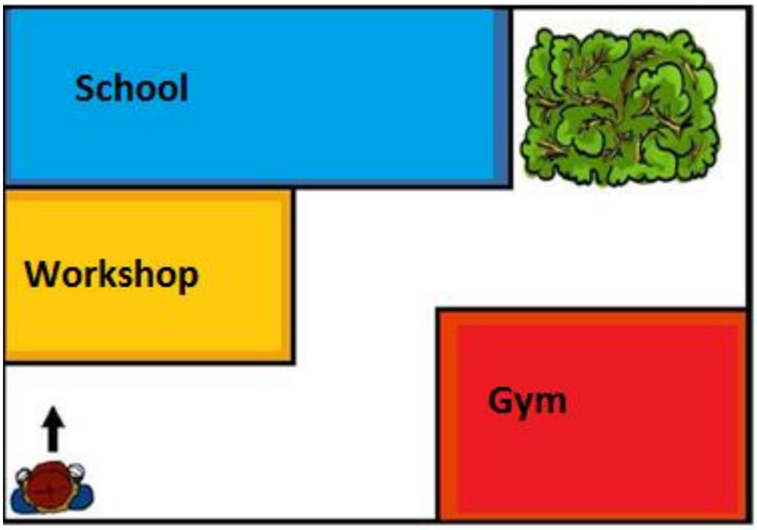


Look at the picture above:
The robot walks through a maze standing at right angles. In doing so, he falls from one platform to the next platform on level below. After landing on that platform the robot changes its walking direction. Finally, the robot will land on one of the bottom boxes.

If you consider the right picture above, in which box the robot will finally land?
A) Box A
B) Box B
C) Box C
D) Box D

Concepts of programming languages and programs

10) At the schoolyard
(Beaver Computing Challenge 2013, medium)



Look at the picture above:
The children are playing robot at the schoolyard. Jeremy acts as robot and only understands the following three commands:
Ahead!
Left!
Right!

If the children say Ahead! Jeremy walks ahead until he hits a building.
If the children say Left! Jeremy turns left.
If the children say Right! Jeremy turns right.

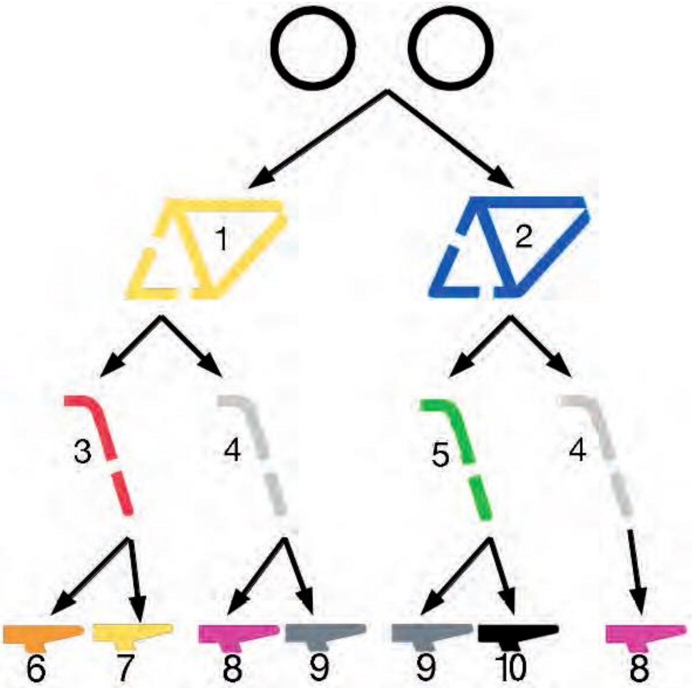
Jeremy is standing at one corner of the schoolyard as shown in the picture above. He is looking towards the workshop. The children now want him to move behind the bush.

Which sequence of commands the children have to call in order to move Jimmy behind the bush?

A) Ahead! Right! Ahead! Left! Ahead! Right! Ahead! Left! Ahead!
B) Right! Ahead! Left! Ahead! Left! Ahead!
C) Right! Ahead! Left! Ahead! Right! Ahead! Right! Ahead!
C) Ahead! Right! Ahead! Left! Ahead! Left! Ahead! Left! Ahead!

Data structures in computer science (trees)

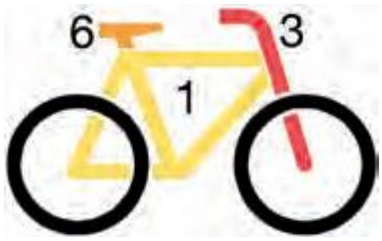
11) New bikes:
(Beaver Computing Challenge 2012; hard)

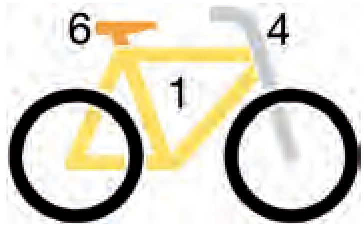


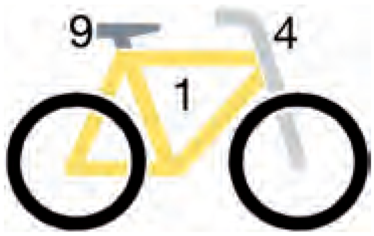
In Bebras-City people like to paint their bikes very colorful. But the government decided regulations how to assemble the bikes using numbered parts.

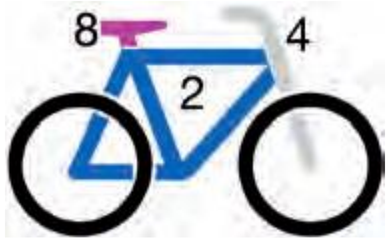
The picture above shows from which colored parts a bike may be assembled.
You start from the top with the two wheels, then you decide for the next part following the pointed lines, and so on.

Which of the bikes in the picture below does NOT follow the regulations of the government?
A)
B)
C)
D)

A) 

B) 

C) 

D) 

III. Attitudes and Interests

The following section asks for your attitudes and interests. There are no 'wrong' or 'right' answers, in this section we are exclusively interested in your personal opinion. For each question please tick one answer.

Social Skills

Social Skills: (Hansen, W.B., & McNeal, R.B. How D.A.R.E. works: An examination of program effects on mediating variables. Health Education & Behavior. 1997; 24(2): 165-176.)

12) I know how to make friends with other children.
Strongly Agree *Agree* *Disagree* *Strongly Disagree*

13) If I want my friends to go along with me, I know what to say to them.
Strongly Agree *Agree* *Disagree* *Strongly Disagree*

14) It is easy for me to make new friends.
Strongly Agree *Agree* *Disagree* *Strongly Disagree*

15) It is easy for me to ask my friends for favors and help when I need to.
Strongly Agree *Agree* *Disagree* *Strongly Disagree*

16) How hard or easy is it for you to get along with other people?
Very easy *Pretty easy* *Pretty hard* *Very hard*

Investing in your future
Operation part financed by the European Union
European Regional Development Fund
REPUBLIC OF SLOVENIA
MINISTRY OF ECONOMIC DEVELOPMENT AND TECHNOLOGY

Personal interests

based on PISA 2009 Questionnaire for pupils

17) How interested are you in each of the following activities (interested means you like doing those things)?

	very interested	somewhat interested	neither interested nor uninterested	somewhat uninterested	very uninterested
Working with machines or technical equipment					
Investigating how things work					
Doing things where creativity and imagination are important					
Adding new parts to a computer					
Joining an acting or music group					
Learning a foreign language					
Establishing contacts, starting a conversation with other people					
Developing a computer program					
Drawing, painting pictures					

IV. Feedback

Finally we would like to ask you to provide some feedback regarding this questionnaire.

18) Please rate the overall difficulty of the questions.

Too Easy *Pretty Easy* *Exactly appropriate* *Pretty Difficult* *Too Difficult*

19) Do you have any further comments, feedback or suggestions?

____

To finalize this questionnaire please click on the 'Done' button below.

Thank you very much for your help!

A.10. Quantitative Main Study: Instrument (Questionnaire Stage II Study; Distinctive Features)

Evaluating the Impact of Educational Robotics

Student Questionnaire

Main Study Stage II

2014/2015

English Version

Investing in your future
Operation part financed by the European Union
European Regional Development Fund

REPUBLIC OF SLOVENIA
MINISTRY OF ECONOMIC DEVELOPMENT AND TECHNOLOGY

University of Maribor

Das Land Steiermark

I. Demographic / background information

My name is Martin Kandlhofer, I'm PhD student at Graz University of Technology in Austria. As part of my research I'm conducting an evaluation investigating the impact of educational robotics on pupils' attitudes and skills.

In order to collect valuable data for this research you will be asked to complete the following questionnaire, and again in about seven months time another questionnaire.

Please read the questions carefully and answer each of them honestly. There are no risks involved, each questionnaire is completely anonymous. All collected data will be treated confidentially. The participation is voluntarily; you can refuse to answer any question at any time and can withdraw without any penalty. Of course you can skip questions if you consider them too difficult.
The questionnaire is completely anonymous; no one will know who responded to any of the questions;

Your participation is essential for this scientific investigation. Each questionnaire is important!

Thank you very much for your help!
Martin Kandlhofer

1)This question will be used to match the survey now with the survey in seven months time. Therefore please construct a new word by applying the following rules in the given order:

1. write down the first two letters of your mother's first name
2. write down the first two letters of your first name
3. write down the first two letters of your father's first name
4. write down the last two numbers of the year of your birth

Example:
your mother's name: **Ma**ria
your name: **Ro**bert
your father's name: **Jo**hn
your year of birth: 19**96**
Result: **MaRoJo96**

____

2) Do you take part in a robotics course, an optional robotics subject, a robotics workshop, a robotics project, a robotics club or another robotics related activity this year?

- Yes
- No

3) If you answered the previous question with 'Yes' please specify where you take part in a robotics activity (multiple answers are possible):

- in school
- at home
- at a club
- other (please specify):________________________

4) Do you plan to participate in a robotics competition in 2015?

- Yes
- No

5) If you answered the previous question with 'yes' please specify in which robotics competition/discipline you are planning to participate:

- RoboCupJunior Dance
- RoboCupJunior Rescue A
- RoboCupJunior Rescue B
- RoboCupJunior Soccer
- CoSpace
- FIRST Lego League (FLL)
- FIRST Robotics Competition (FRC)
- Other (please specify):___________________________

6) Have you ever been involved in one or more of the following robotics activities before? (Note: multiple answers are possible)

- Yes, robotics competition
- Yes, robotics club
- Yes, robotics camp
- Yes, robotics workshop
- Yes, other robotics activities
- No, I've never been in touch with robotics before
- No, I've never been involved in any robotics activities before

If yes, please specify:

____

7) Are you familiar with the following programming types?

- graphical programming (e.g. LEGO NXT, EV3, LabView,…)
- textual programming (e.g. Basic, C, C++, Java, C#, NXC, Python,…)
- both graphical AND textual programming
- none

8) Your age:
(9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19)

9) Your gender:

- female
- male

10) Type of your school (e.g. gymnasium, technical school,…):

____

11) Name of your school:

____

12) Your country:

____

13) Please select your year in your current school (e.g. if you are for your first year in your current school tick 1; if you are for you second year, tick 2; …):
(1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11)

14) What is your native language?

____

II. Technical Skills

The following section deals with the technical aspects and skills. The questions you will be asked can be answered just by ticking one out of four possible answers. For each of this multiple-choice questions there is exact one correct answer. Of course you can skip questions if you consider them too difficult.
You can switch between the questions using buttons below in order to check or revise your previous answers.

General robotics/programming knowledge

Reference: G. Nugent, B. S. Barker, N. Grandgenett, V. I. Adamchuk, Impact of Robotics and Geospatial Technology Interventions on Youth STEM Learning and Attitudes, JRTE; Teacher Education Faculty Publications, University of Nebraska 42 (3) (2010) 391-408.

15) In order to follow a list of commands, without someone steering a robot on each step, a robot must be…

A) …controlled by a remote.
B) …computerized.
C) …programmed.
D) …trained.

16) A programming "loop"…

A) …starts the program code
B) …stops the program code
C) …turns the robot off
D) …repeats some program steps or code

17) A computer program is/are ______ that tell(s) the computer to do something.

A) sensors
B) code
C) lights
D) robots

18) What helps a robot to explore its environment?

A) Tires
B) Sensors
C) LCD panels
D) Mechanical arms

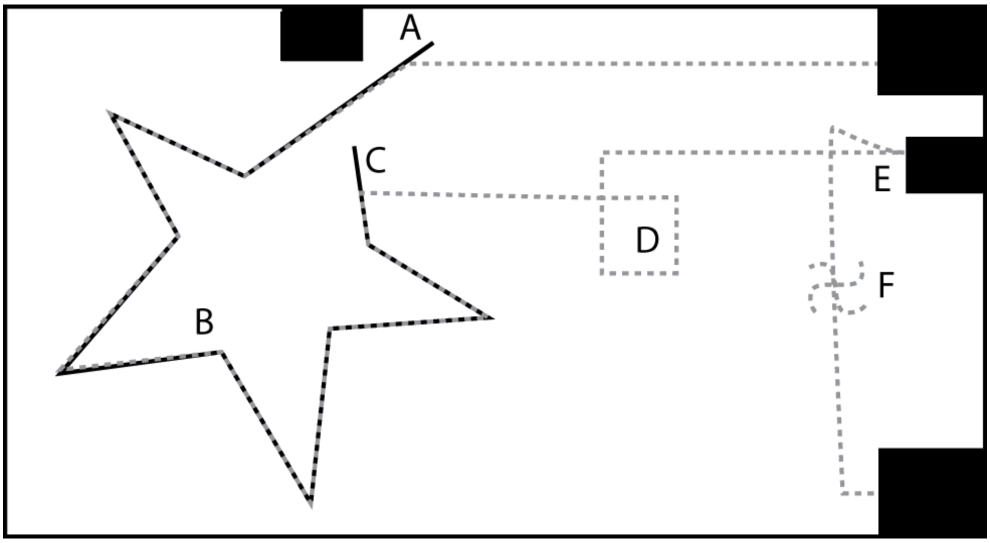
19) What is a computer program?

A) Computer-created text
B) The hardware that controls a computer
C) Instructions or steps written so a computer understands
D) Language that is built into a robot

20) When writing a computer program, a switch block or if/then/else statement is used to…

A) …ask a question.
B) …stop the program.
C) …speed up the program.
D) …repeat the code

Use the picture of the obstacle course to answer following questions. The dashed line(s) shows the path of the robot. The solid line is black electrical tape, the black rectangles indicate obstacles.



21) Which sensor is the best to get the robot between points A and C?

- **A) Light**
- B) Sound
- C) Touch
- D) Ultrasonic

22) On which point on the image above the robot does the following:
Repeat 4 times: [Forward one tire rotation; robot turn ninety degrees right]

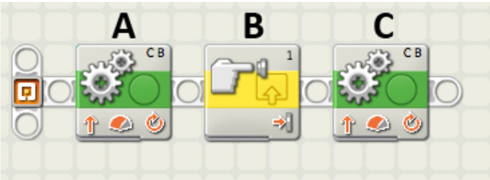
- A) Point B
- **B) Point D**
- C) Point E
- D) Point F

23) Which sensor would be *LEAST* likely to complete the challenge shown in the picture?

- A) Light
- **B) Sound**
- C) Touch
- D) Rotation

Graphical programming

Reference: G. Nugent, B. S. Barker, N. Grandgenett, V. I. Adamchuk, Impact of Robotics and Geospatial Technology Interventions on Youth STEM Learning and Attitudes, JRTE; Teacher Education Faculty Publications, University of Nebraska 42 (3) (2010) 391-408.

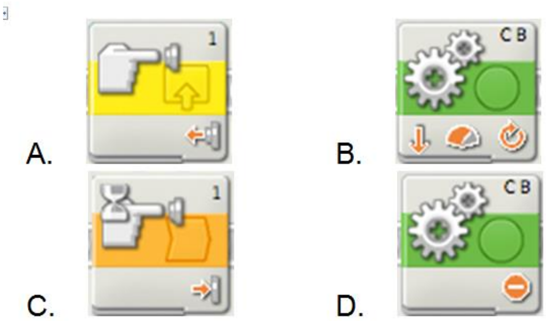


24) The LEGO program in the picture above has some mistakes. The robot should do:

1. Move forward
2. Detect the touch sensor being pressed
3. Move backward

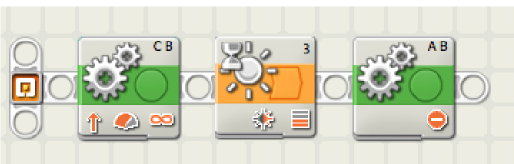
Which programming block in the picture above is wrong?

A) A
B) B
C) C
D) Both A and C



25) Take a look at the four pictures above. Which block should be used instead in order to fix the program from the previous question?

A) A
B) B
C) C
D) D

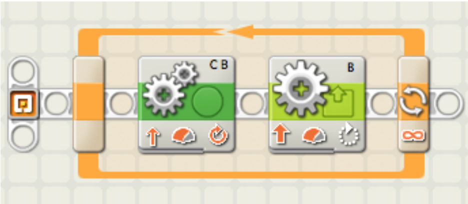


26) Take a look at the picture above. What is the programming mistake?

The robot should:

1. Move forward until the light sensor detects a dark line.
2. Stop.

A) The light sensor’s threshold value is too high.
B) The light sensor’s threshold value is too low.
C) The move blocks do not control the same motors.
D) The second move block should be set to move backward two rotations.

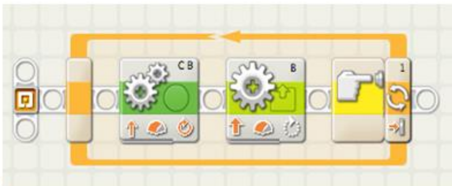


27) What is the mistake in the picture above?
The robot should:

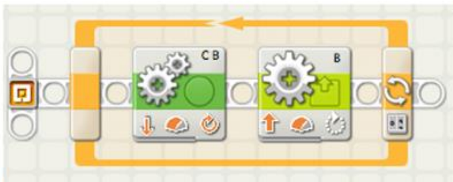
1. Repeat four times
2. Move forward one rotation
3. Make a right 90˚ turn

A) The motor block is set for the wrong motor.
B) The move block is set to go backwards.
C) This program does not need a loop block.
D) The loop block is set to repeat over and over again.

A) 

B) 

C) 

D) 

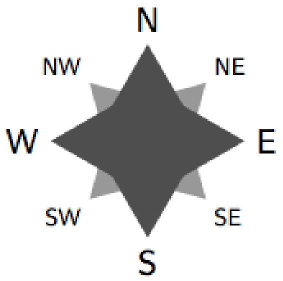
28) Take a look at the 4 pictures above. Which program will correct the mistake from the previous question?

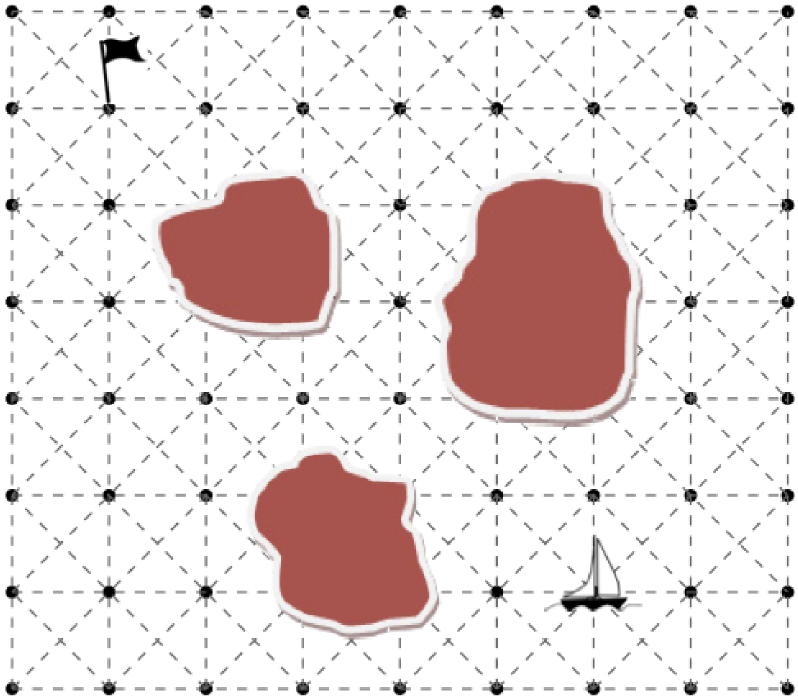
A) A
B) B
C) C
D) D

Computer science

References: Beaver Computing Challenge;
University of Waterloo, Beaver Computing Challenge (2012, 2013).
Austrian Computer Society (OCG), Biber der Informatik (2012, 2013).

29) Boat navigation



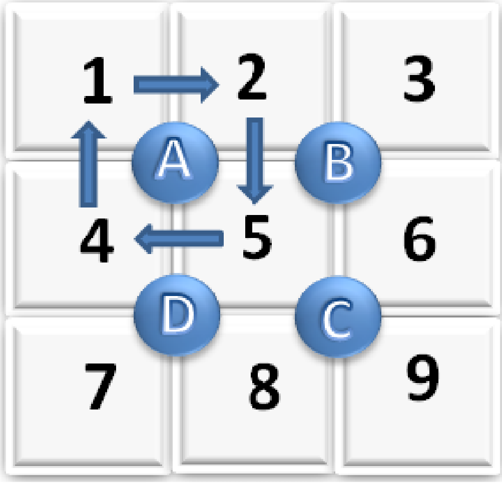


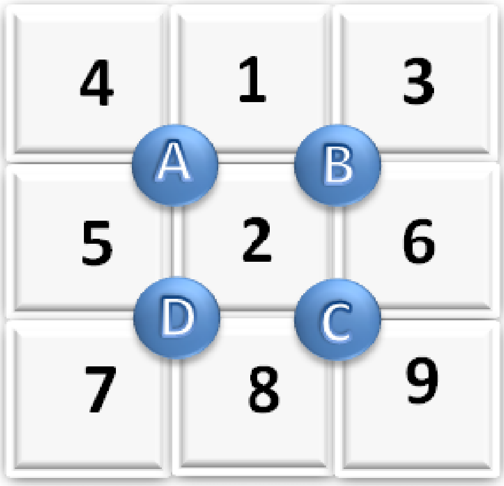
Take a look at the picture above. A sailor takes her boat on the lake with islands. Her aim is to sail to the flag by programming the boat's autopilot. The autopilot commands the boat to sail along the dashed lines. In one step, the boat moves from a point to the nearest point along a dashed line in one of eight different directions. For example, the command 1 N means take 1 step in the northern direction, and the command 2 NE means take 2 steps diagonally in the northeastern direction. Each point is a small black circle on the map. The 8 different directions (N, NE, E, SE, S, SW, W, NW) are also shown in the picture above.
(Explanation of the letters in the picture: N…North, NE…North-East, E…East, SE…Sout-East, S…South, SW…South-West, W…West, NW…North-West)

Which of the following routes to the flag avoids the islands using the smallest number of steps?
Possible answers:
- A) 5 NW
- B) 2 NW, 2 W, 1 N, 1W, 2N
- C) 2 NW, 3 N, 3 W
- **D) 2 NW, 2 W, 1 NW, 2 N**

SI-AT European Territorial Cooperation
Investing in your future
Operation part financed by the European Union
European Regional Development Fund
REPUBLIC OF SLOVENIA
MINISTRY OF ECONOMIC DEVELOPMENT AND TECHNOLOGY
University of Maribor
Das Land Steiermark

30) Rotating puzzle

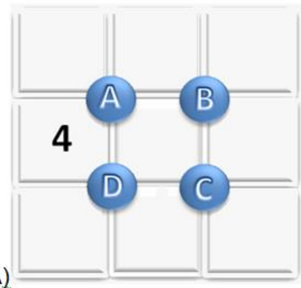


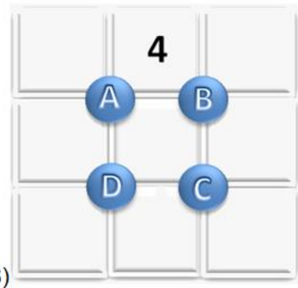


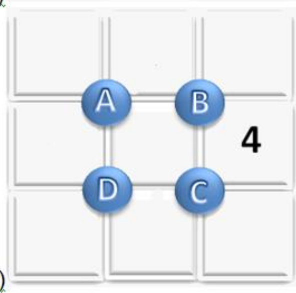
Robot Alan plays a new game. If he presses one of the buttons A, B, C or D, the four numbers adjacent to the button will be rotated clockwise as shown in the picture above on the left. The result of pressing the button A is shown in the picture above on the right.

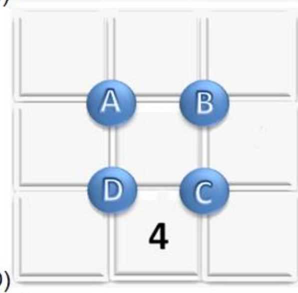
Starting from the picture above on the left, robot Alan pressed four buttons in the order of D, C, B, B.
Where is the number 4 after Alan pressed the buttons?
Please take a look at the 4 pictures below for possible answers:

A) A
B) B
C) C
D) D

A)


B)


C)


D)


31) Autonomous robot

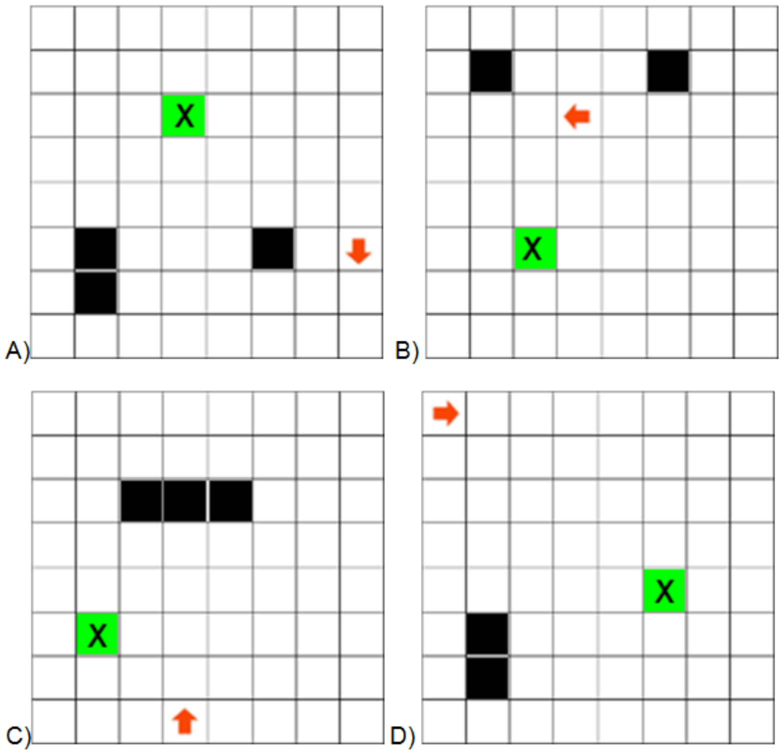
A robot is programmed to find a target (the green field marked with X) on a map of square fields (take a look at the image below). The robot has its movements programmed as follows:

- The robot moves straight forward until it reaches an obstacle (black field) or the edge of the map.
- When reaching an obstacle or the edge of the map, the robot turns right by 90 degrees.
- When the robot moves out of a field, the field becomes an obstacle. Also the starting position (red arrow) becomes an obstacle.

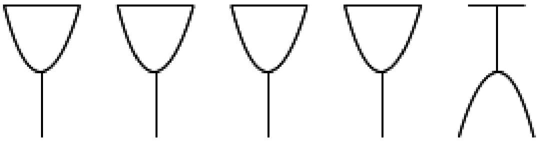
The arrows on the maps below show the starting position as well as the starting direction of the robot.

On which of the 4 maps shown in the image below does the robot NOT eventually reach the target (green field marked with X)?

A) A
B) B
C) C
D) D



32) Glasses



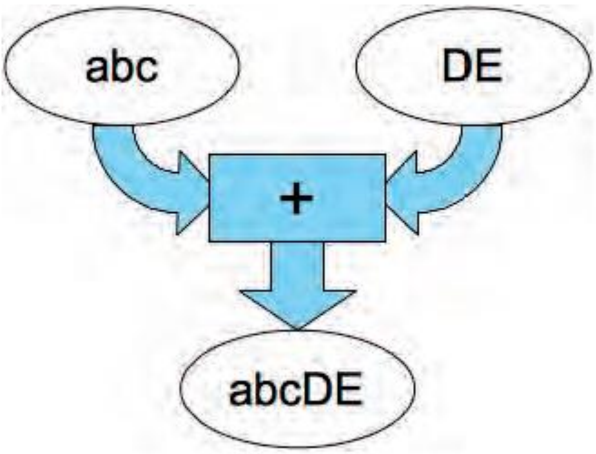
There are 5 empty glasses on a table as shown in the picture above. One is facing down and four are facing up.
Flipping a glass changes it from facing up to facing down, or from facing down to facing up.
In one turn, you must flip exactly three different glasses. The glasses which are flipped do not need to be adjacent.
What is the minimum number of turns to make all glasses facing up?

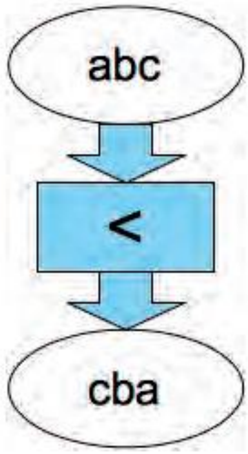
Possible Answers:

- A) 2 turns
- **B) 3 turns**
- C) 5 turns
- D) it is not possible to make all glasses facing up

Investing in your future
Operation part financed by the European Union
European Regional Development Fund
REPUBLIC OF SLOVENIA
MINISTRY OF ECONOMIC DEVELOPMENT
AND TECHNOLOGY
University of Maribor
Das Land
Steiermark

33) Text machine



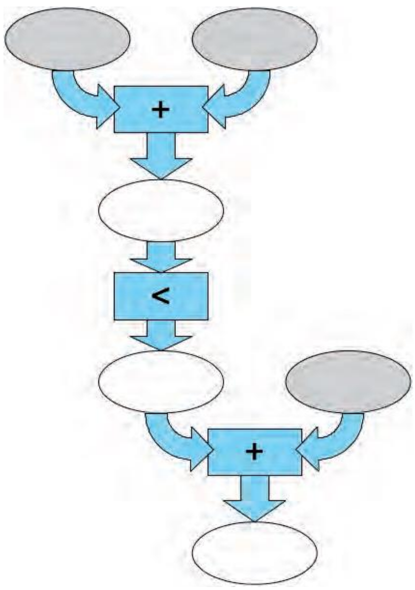


A Glue machine (+) takes two pieces of text and puts one after the other. An example is shown in the left picture above.
A Reverse machine (<) takes one piece of text and puts the characters in reverse order. An example is shown in the right picture above.

Two Glue machines and one Reverse machine are combined to create the Combined machine shown in the picture below. The Combined machine takes three pieces of text (in the grey ovals) and after processing them, gives one piece of final text (in the bottom-most oval).

Which three pieces of text will produce the final text INFORMATION when given to the Combined machine, in the order specified?

A) FNI AMRO NOIT
B) AMR OFNI NOIT
C) AMR OFNI TION
D) INF ORMA TION



34) Bebrocarina

A bebrocarina is a musical instrument with the following features:

- It can play only 6 different tones.
- The tones can be arranged from lowest to highest
- After having played one tone, it is possible to play only the same tone, the next higher tone (if it exists) or the next lower tone (if it exists).

This means that melodies can be represented using only three different symbols:

= means "the current tone must be the same as the previous tone", and
- means "the current tone must be one lower than the previous tone", and
+ means "the current tone must be one higher than the previous tone."

For example, melody - + means "play 3 tones, the second tone is lower than the first one and the third tone is higher than the second tone (i.e. the same as the first tone)."

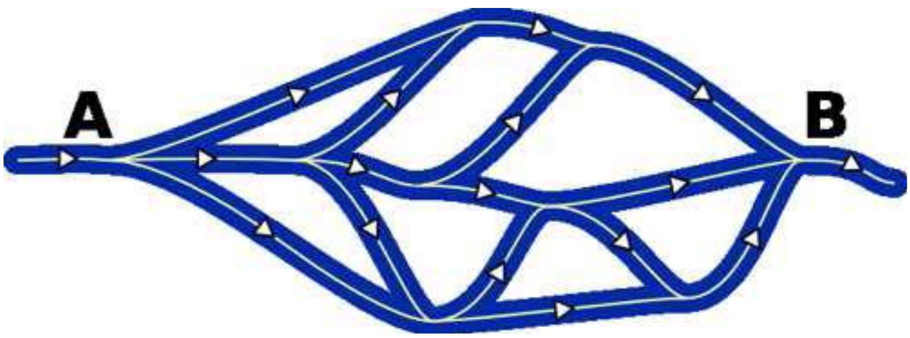
For which of these melodies there is no starting tone that makes playing the melody possible?

Possible Answers:

A) + = = = + = = = + = = = + = = = +
B) - - - = + - = - - = = = +
C) - - - - - = + + + + + = - - - - -
D) - - + - - + - - = - + - -

---

35) River inspection

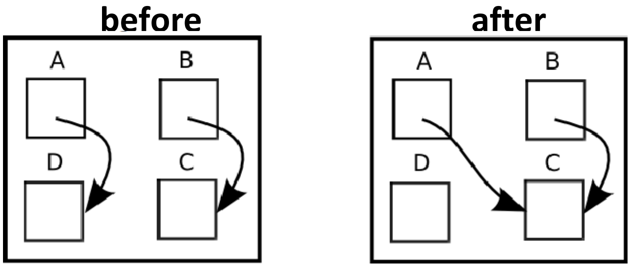


Beavers want to explore the system of rivers in the image above. At least one beaver has to swim along each river.
Due to the heavy current, beavers can only swim downstream and they can only do one trip from A to B. So the beavers start at A, and meet at B.

What is the minimum number of beavers needed to explore the system of rivers?

Possible Answers:
A) 3
B) 4
C) 5
D) 6

36) Arrows



The instruction A<-B changes a picture of boxes and arrows in the following way:

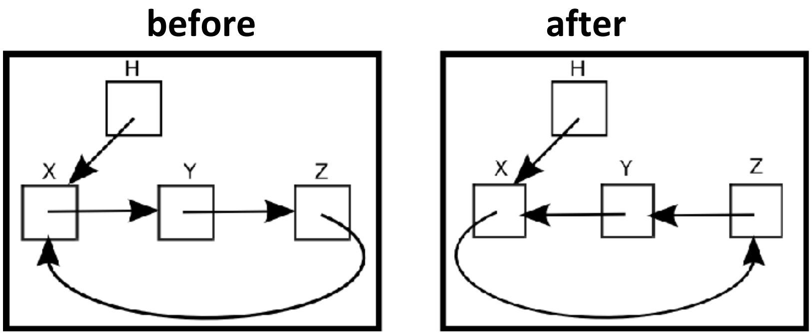
- The arrow which points out of the box labeled A is removed.
- Then, a new arrow out of the box labeled A is added. This new arrow points to the same box as the arrow out of the box labeled B points to.

Take a look at the two pictures above for an example (before and after applying the instruction A<-B).

What sequence of instructions (performed in order) changes the ‘before’ picture to the ‘after’ picture in the image below?

Possible answers:

A) X <- Y, Y <- Z, Z <- X
B) X <- Z, Z <- X, Y <- H
C) Z <- Y, X <- Z, Y <- H
D) Z <- X, X <- Y, Y <- H



Textual programming

Reference: D. Clark, Testing Programming Skills with Multiple Choice Questions., Informatics in Education 3 (2) (2004) 161-178.

```
a = 2
b = 2
c = 4
If (a > b) Then
       If (a > c) Then
              m = 1
       Else
              m = 2
       End If
Else
       If (c != 0) Then
              m = 3
       Else
              m = 4
       End If
End If
```

37) What is the value of m after the code fragment above is executed? (note: '!=' means 'unequal')

A) 1
B) 3
C) 2
D) 4

```
y = 1
Do While (y <= x)
   y = y * 2
Loop
```

38) If x is 8, what is the value of y after the code above is executed?

A) 8
B) 10
C) 12
D) 16

EUROPEAN TERRITORIAL COOPERATION SI AT
Investing in your future
Operation part financed by the European Union
European Regional Development Fund
REPUBLIC OF SLOVENIA
MINISTRY OF ECONOMIC DEVELOPMENT AND TECHNOLOGY
University of Maribor
Das Land Steiermark

```
"statement 1"
For i = 0 to numItems - 2
       data(i) = data(i+1)
Next i
"statement 2"
```

39) The array 'data' contains 'numItems' number of elements. The code above is intended to shift the elements in the array 'data' to the left with wrap around.

That is to convert
7 3 8 1 0 5
into
3 8 1 0 5 7

In order for the code to execute correctly "statement 1" and "statement 2" should be (take a look at image below for possible answers):

A)

```
temp = data(0)
data(0) = temp
```

B)

```
temp = data(0)
data(numItems-1) = temp
```

C)

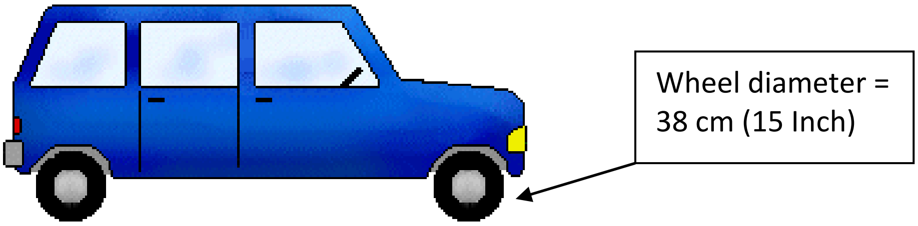
```
temp = data(numItems-1)
data(0) = temp
```

D)

```
temp = data(numItems-1)
data(numItems-1) = temp
```

Mathematics

References:
G. Nugent, B. S. Barker, N. Grandgenett, V. I. Adamchuk, Impact of Robotics and Geospatial Technology Interventions on Youth STEM Learning and Attitudes, JRTE; Teacher Education Faculty Publications, University of Nebraska 42 (3) (2010) 391-408.
Items 'Speed of a racing car' and 'Earthquake': OECD Programme for International Student Assessment 2006 (PISA) – Released items



Use the picture of the car to answer following questions (remember that Pi is about 3.14)

40) Which math formula would help you know how far the car would go if the wheel turned one time?

A. H = r - d
B. C = π*d
C. A = (π*d)*(π*d) / 4
D. K = d*s / 4

41) Calculate the approximate distance traveled in four turns of the wheels.

A. 3,7 meter (12 feet)
B. 4,3 meter (14 feet)
C. 4,8 meter (16 feet)
D. 5,5 meter (18 feet)

42) How many rotations of the wheels are needed to go 76 meter (250 feet)?

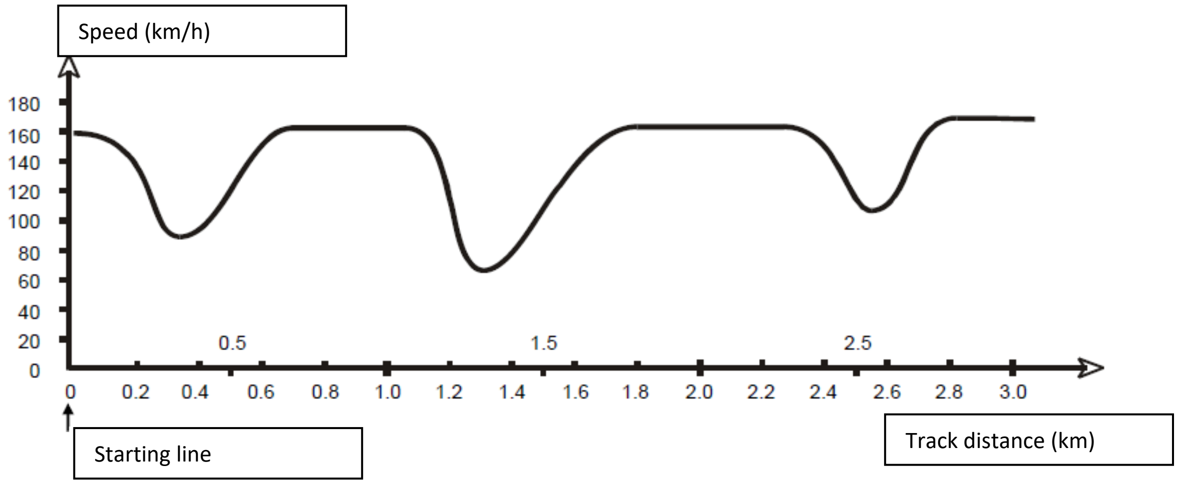
A. 48 rotations
B. 56 rotations
C. 64 rotations
D. 72 rotations

43) Your car can also be programmed to move by degrees of a circle. How many degrees would you need to program your car to move 3 rotations?

A. 360
B. 720
C. 1080
D. 1440

---

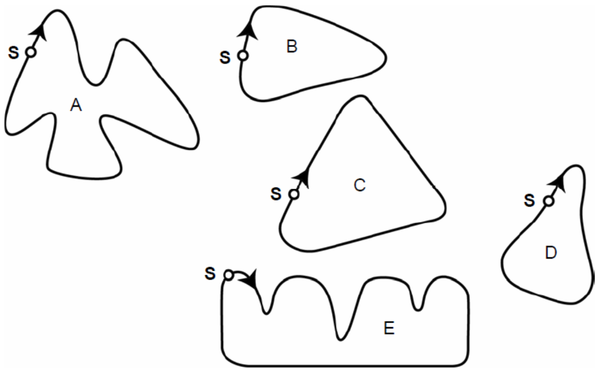
44) Speed of a racing car



The graph above (called a 'speedgraph') shows how the speed of a racing car varies along a flat 3 kilometer track during its second lap.

On which of the tracks shown in the picture below the racing car drove according to the speedgraph figure above (the point in S indicates the starting line)?

A) A
B) B
C) C
D) D
E) E



45) Earthquake

A documentary was broadcast about earthquakes and how often earthquakes occur. It included a discussion about the predictability of earthquakes.

A geologist stated: “In the next twenty years, the chance that an earthquake will occur in Zed City is two out of three”.

Which of the following best reflects the meaning of the geologist’s statement?

A) 2/3 x 20 = 13.3, so between 13 and 14 years from now there will be an earthquake in Zed City

B) 2/3 is more than 1/2, so you can be sure there will be an earthquake in Zed City at some time during the next 20 years.

C) The likelihood that there will be an earthquake in Zed City at some time during the next 20 years is higher than the likelihood of no earthquake.

D) You cannot tell what will happen, because nobody can be sure when an earthquake will occur.

Investing in your future
Operation part financed by the European Union
European Regional Development Fund
REPUBLIC OF SLOVENIA
MINISTRY OF ECONOMIC DEVELOPMENT
AND TECHNOLOGY

Science as an inquiry / Physical science

Reference: I. L. Jomento-Cruz, Robotics as a Means of Increasing Student Achievement in Middle School Science, Master's thesis, Louisiana State University (2010).

46) The ball experiment

Anna performed an experiment to study the effect of slope of a ramp on the speed of moving objects.

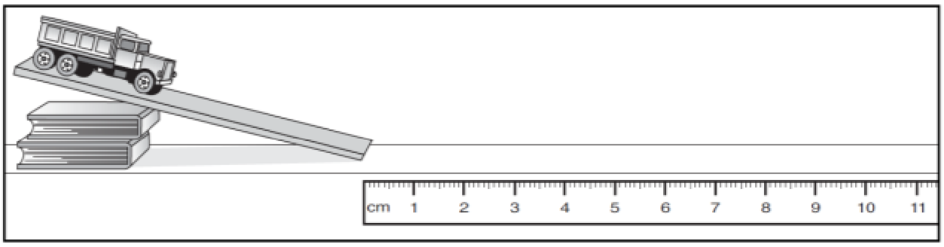
- She built three ramps from the same material, but with different slopes.
- She rolled a ball down each ramp.
- She measured the speed of the ball on each ramp.

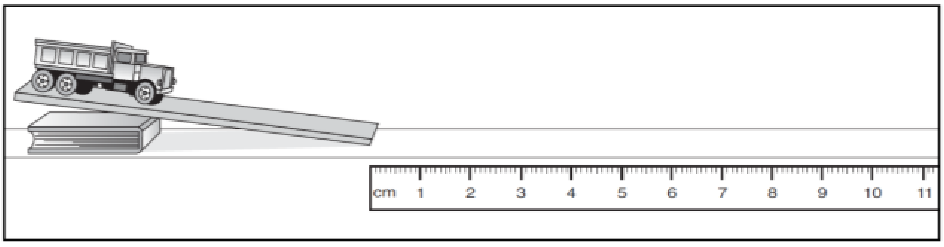
What is the independent variable in this experiment?
(Note: In an experiment the dependent variable represents the effect, the independent variable represents the cause)

A) the speed of the ball
B) the same material on all three ramps
C) the different slopes on the ramps
D) the type of balls used

---

47) The truck experiment



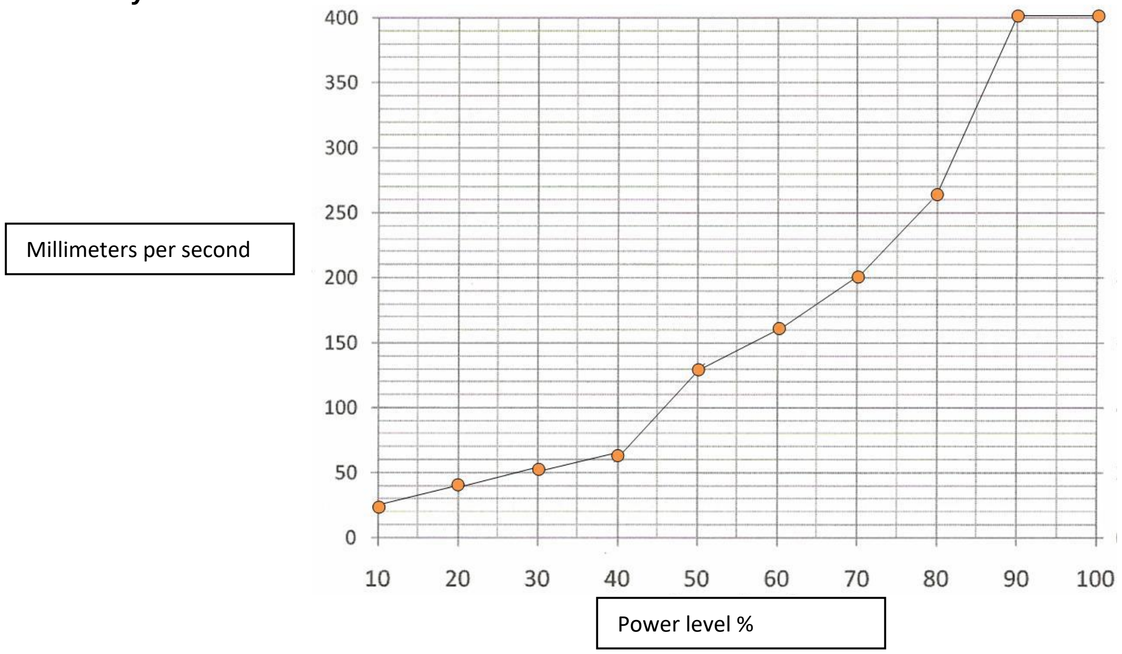


Take a look at the pictures above: Maria let the truck go at the top of each ramp and measured the distance it traveled. Which of the following is most likely what she was trying to prove?

A) A toy truck will roll down a ramp held up with books.
B) A toy truck will move straight down a ramp whether the ramp is held up with one book or two books.
C) A toy truck will roll about twice as far coming off a two-book ramp than a one-book ramp.
D) A toy truck on a one-book ramp has half the force of gravity as a truck on a two-book ramp.

---

48) Robot in sandy area

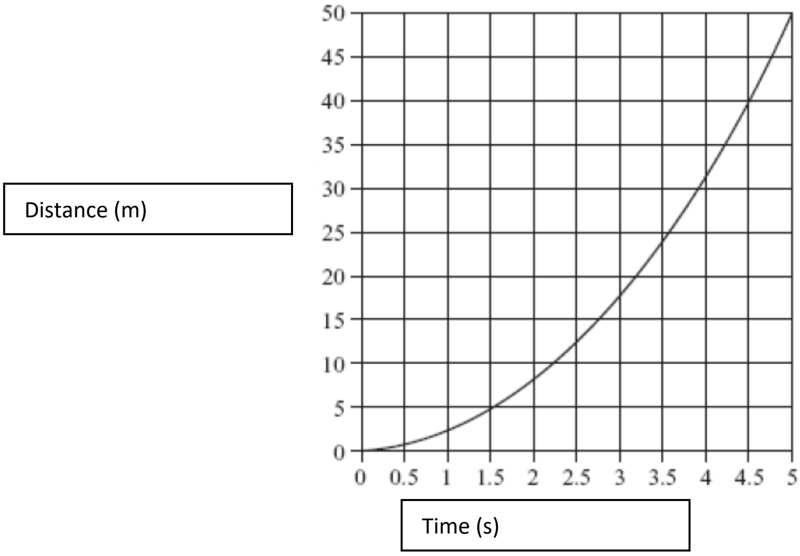


A robot needs to run in a sandy area and the only advisable speed to use is 180 mm/sec to prevent the robot from turning over. Based on the graph above, what power level will you recommend to set the robot.

A) 65%
B) 50%
C) 70%
D) 85%

---

49) Moving robot



The distance vs. time graph above shows data collected as a robot moved across a level parking lot. According to the graph, which of the following conclusions about the robot‘s motion is supported?

A) The robot is accelerating.
B) The robot is stopping and starting.
C) The robot is traveling at a constant velocity.
D) The robot is moving through an obstacle course.

TU Graz

III. Attitudes and interests

The following section asks for your attitudes and interests regarding science, technology and social aspects. There are no 'wrong' or 'right' answers, in this section we are exclusively interested in your personal opinion. For each question please tick one answer.

Science related attitudes and interests

Reference: B. J. Fraser, TOSRA: Test of Science-Related Attitudes, The Australian Council for Educational Research, Hawthorn, Victoria, 1981.

50) I would prefer to find out why something happens by doing an experiment than by being told.
Strongly Agree Agree Uncertain Disagree Strongly Disagree

51) Doing experiments is not as good as finding out information from teachers.
Strongly Agree Agree Uncertain Disagree Strongly Disagree

52) I would prefer to do experiments than to read about them.
Strongly Agree Agree Uncertain Disagree Strongly Disagree

53) I would rather agree with other people than do an experiment to find out for myself.
Strongly Agree Agree Uncertain Disagree Strongly Disagree

54) I would prefer to do my own experiments than to find out information from a teacher.
Strongly Agree Agree Uncertain Disagree Strongly Disagree

55) I would rather find out about things by asking an expert than by doing an experiment.
Strongly Agree Agree Uncertain Disagree Strongly Disagree

56) I would rather solve a problem by doing an experiment than be told the answer.
Strongly Agree Agree Uncertain Disagree Strongly Disagree

57) It is better to ask the teacher the answer than to find it out by doing experiments.
Strongly Agree Agree Uncertain Disagree Strongly Disagree

58) I would prefer to do an experiment on a topic than to read about it in science magazines.
Strongly Agree Agree Uncertain Disagree Strongly Disagree

59) It is better to be told scientific facts than to find them out from experiments.
Strongly Agree Agree Uncertain Disagree Strongly Disagree

Self-efficacy in robotics

Reference: G. Nugent, B. S. Barker, N. Grandgenett, V. I. Adamchuk, Impact of Robotics and Geospatial Technology Interventions on Youth STEM Learning and Attitudes, JRTE; Teacher Education Faculty Publications, University of Nebraska 42 (3) (2010) 391-408.

60) I am confident that I can program a robot to move forward two wheel rotations (i.e. 720 degrees) and then stop.
Strongly Agree Agree Uncertain Disagree Strongly Disagree

61) I am certain that I can build a LEGO or similar robot by following design instructions.
Strongly Agree Agree Uncertain Disagree Strongly Disagree

62) I am certain that I can fix the software program for a robot that does not behave as expected.
Strongly Agree Agree Uncertain Disagree Strongly Disagree

63) I am confident that I can program a LEGO or similar robot to follow a black line using a light sensor.
Strongly Agree Agree Uncertain Disagree Strongly Disagree

Problem solving skills

Reference: G. Nugent, B. S. Barker, N. Grandgenett, V. I. Adamchuk, Impact of Robotics and Geospatial Technology Interventions on Youth STEM Learning and Attitudes, JRTE; Teacher Education Faculty Publications, University of Nebraska 42 (3) (2010) 391-408.

64) I use a step by step process to solve problems.
Strongly Agree Agree Uncertain Disagree Strongly Disagree

65) I make a plan before I start to solve a problem
Strongly Agree Agree Uncertain Disagree Strongly Disagree

66) I try new methods to solve a problem when a known method does not work.
Strongly Agree Agree Uncertain Disagree Strongly Disagree

67) I carefully analyze a problem before I begin to develop a solution.
Strongly Agree Agree Uncertain Disagree Strongly Disagree

68) In order to solve a complex problem, I break it down into smaller steps.
Strongly Agree Agree Uncertain Disagree Strongly Disagree

Teamwork

Reference: G. Nugent, B. S. Barker, N. Grandgenett, V. I. Adamchuk, Impact of Robotics and Geospatial Technology Interventions on Youth STEM Learning and Attitudes, JRTE; Teacher Education Faculty Publications, University of Nebraska 42 (3) (2010) 391-408.

69) I like listening to others when trying to decide how to approach a task or problem.
Strongly Agree Agree Uncertain Disagree Strongly Disagree

70) I like being part of a team that is trying to solve a problem.
Strongly Agree Agree Uncertain Disagree Strongly Disagree

71) When working in teams, I ask my teammates for help when I run into a problem or don't understand something.
Strongly Agree Agree Uncertain Disagree Strongly Disagree

72) I like to work with others to complete projects.
Strongly Agree Agree Uncertain Disagree Strongly Disagree

Social skills

Reference: Social Skills: W. Hansen, R. McNeal, How D.A.R.E. works: An examination of program effects on mediating variables., Health Education & Behavior 24 (2).

73) I know how to make friends with people of the opposite sex
Strongly Agree Agree Disagree Strongly Disagree

74) If I want my friends to go along with me, I know what to say to them.
Strongly Agree Agree Disagree Strongly Disagree

75) It is easy for me to make new friends.
Strongly Agree Agree Disagree Strongly Disagree

76) It is easy for me to ask my friends for favors and help when I need to.
Strongly Agree Agree Disagree Strongly Disagree

77) How hard or easy is it for you to get along with other people?
Very easy Pretty easy Pretty hard Very hard

Goal setting skills

Reference: Social Skills: W. Hansen, R. McNeal, How D.A.R.E. works: An examination of program effects on mediating variables., Health Education & Behavior 24 (2).

78) How often do you work on goals that you have set for yourself?
Never Sometimes but not often Often All the time

79) Once I set a goal, I don't give up until I achieve it.
Strongly Agree Agree Disagree Strongly Disagree

80) Whenever I do something, I always give it my best.
Strongly Agree Agree Disagree Strongly Disagree

81) I think about what I would like to be when I become an adult.
Never Sometimes but not often Often All the time

82) When I set a goal, I think about what I need to do to achieve that goal.
Never Sometimes but not often Often All the time

Careers

83) Career interests: How interested are you in each of the fields below for possible future careers?

	very interested	somewhat interested	neither interested nor uninterested	somewhat uninterested	very uninterested
Business, Finance					
Engineering					
Entertainment, Media					
Computers					
Science and Technology					
Law					
Sports					
Math					
Medicine, Healthcare					
Education					
Architecture, Arts, Design					
Others:					

Teacher

Reference: Gruehn, S. (2000): Unterricht und schulisches Lernen. Waxmann: Münster

84) Our teacher…

	Strongly agree	Agree	Disagree	Strongly disagree
… often organizes the lessons in an exciting way.				
… can make even dry learning content really interesting.				
… sometimes really can enthuse pupils.				
… supports pupils implementing their own projects				
… inspires pupils for science/technology.				

EUROPEAN TERRITORIAL COOPERATION
Investing in your future
Operation part financed by the European Union
European Regional Development Fund
REPUBLIC OF SLOVENIA
MINISTRY OF ECONOMIC DEVELOPMENT AND TECHNOLOGY
University of Maribor
Das Land Steiermark

Personal interests

Reference: PISA 2009 Questionnaire for pupils

85) How interested are you in each of the following activities?

	very interested	somewhat interested	neither interested nor uninterested	somewhat uninterested	very uninterested
Working with machines or technical equipment					
Investigating how things work					
Doing things where creativity and imagination are important					
Adding new parts to a computer					
Seeking a solution to a problem for a longer time					
Learning a foreign language					
Establishing contacts, starting a conversation with other people					
Developing a computer program					
Investigating the cause of a problem					

SI-AT European Territorial Cooperation
Investing in your future
Operation part financed by the European Union
European Regional Development Fund
REPUBLIC OF SLOVENIA
MINISTRY OF ECONOMIC DEVELOPMENT AND TECHNOLOGY
University of Maribor
Das Land Steiermark

IV. Feedback

Finally we would like to ask you to provide some feedback regarding this questionnaire.

86) Please rate the overall difficulty of the questions.
Too Easy *Pretty Easy* *Exactly appropriate* *Pretty Difficult* *Too Difficult*

87) Please rate the overall clarity of the questions.
Very clear *Pretty Clear* *Exactly appropriate* *Pretty Unclear* *Very Unclear*

88) Please rate whether or not the time for filling in the questionnaire was enough.
Absolutely enough *Pretty Enough* *Exactly appropriate* *Not Really Enough* *Absolutely not Enough*

89) What do you think about the length (amount of questions + time required for filling in) of this questionnaire?
Way Too Short *Too Short* *Appropriate* *Too Long* *Way Too Long*

90) Do you have any further comments, feedback or suggestions?

____

To finalize this questionnaire please click on the 'Done' button below.

Thank you very much for your help!

A.11. Authors' Permissions to use Study Instruments

Subject: Re: Question regarding 'Impact of Robotics and Geospatial Technology Interventions on Youth STEM Learning and Attitudes'

Date: Tue, 2 Jul 2013 15:39:05 +0000

From: Bradley Barker <bbarker1@unl.edu>

To: Martin Kandlhofer <mkandlho@ist.tugraz.at>, Nealy Grandgenett <ngrandgenett@unomaha.edu>, bbarker@unl.edu <bbarker@unl.edu>, Viacheslav Adamchuk <vadamchuk2@unl.edu>

Hi Martin,

I have attached the instruments - the attitude questionnaire will probably work better for your needs. Also, you may want to find a copy of our book "Robotics in K-12 Education: A New Technology for Learning (2012)." Hershey, Pennsylvania: IGI Global. Amy Eguchi from Bloomfield College has done a lot of work in this area as well.

Good luck with your research,

Brad

Subject: Re: Question regarding thesis 'Robotics as a means of increasing student achievement'

Date: Sat, 27 Jul 2013 22:31:34 -0500

From: Ingrid Cruz <ingridjomento@gmail.com>

To: mkandlho@ist.tugraz.at

Hello Sir,

I have received your inquiry to use some of the questions from my Master's thesis for your dissertation and I would like to let you know that I'm giving you permission to use them.

I am also currently working on my PhD in Math and Science Education at Southern University and I'm considering to work on LEGO robotics again for my dissertation, I'm hoping we can collaborate. I hope you're willing to share with me the testing instrument you're developing and I can also invite you to review the online robotics class that I'm trying to put together for this coming school year.

Well, I wish you all the best in your endeavor. Let me know how else I can be of assistance.

INGRID CRUZ

Engineering Department Chair

Scotlandville Middle Pre-Engineering Magnet

2555 Desoto Drive,

Baton Rouge, LA 70807

(225) 775-7079

Subject: Re: Biber der Informatik

Date: Mon, 22 Sep 2014 15:18:46 +0200

From: Gerald Futschek <futschek@ifs.tuwien.ac.at>

To: Martin Kandlhofer <mkandlho@ist.tugraz.at>

Sg Herr Kandlhofer

Ja, sie können gerne die Aufgaben für wissenschaftliche oder pädagogische Zwecke verwenden (aber nicht kommerziell) und bitte geben Sie immer dazu die Quelle "Biber der Informatik" mit entsprechendem Wettbewerbsjahr an.

Aufgaben sind auf der Biber der Informatik Homepage der OCG.

mfG

Gerald Futschek

Subject: Re: Question regarding Beaver Computing Challenge

Date: Fri, 26 Jul 2013 13:13:37 +0000

From: J. P. Pretti <jpretti@uwaterloo.ca>

To: mkandlho@ist.tugraz.at mkandlho@ist.tugraz.at

Hello,

Thank you for inquiring and your interest in our Beaver Computing Challenge. We have released these problems under an Attribution-NonCommercial Creative Commons license (http://creativecommons.org/licenses/by-nc/3.0/) so you are welcome to use them as part of your research.

If you are able and willing, please send me any transcripts of your finished work that you are comfortable sharing.

Thank you again for asking.

Sincerely,

J.P. Pretti

Centre for Education in Mathematics and Computing

University of Waterloo

Subject: RE: Question regarding article 'Testing Programming Skills with Multiple Choice Questions'

Date: Sat, 27 Jul 2013 01:26:59 +0000

From: David.Clark <David.Clark@canberra.edu.au>

To: Martin Kandlhofer <mkandlho@ist.tugraz.at>

Hi Martin,

by all means. Go ahead.

I retired a few years ago, and am currently in Cairns but will be back in Canberra in September where I will have access to my old files, so if I can be of any help please feel free to contact me then.

cheers,

David

A.12. Confirmation Research Stay USA

THE HILL SCHOOL
THE FAMILY BOARDING SCHOOL

Confirmation of Stay

Official host institution: The Hill School; Pottstown, Pennsylvania, USA
Department: Engineering
Period of the stay: 11.04.2016 – 07.05.2016

We hereby confirm the above mentioned period of the research stay of **Mr. Martin Kandlhofer** (as part of his PhD programme).

Date: **May 20, 2016**

Signature: official Stamp:

717 East High Street • Pottstown, Pennsylvania 19464-5791 • 610-326-1000 • www.thehill.org