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Designing and assessing Educational Robotics Activities with the C4STEM framework

DISSERTATION

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Abstract

There is currently a lack of interest in STEM (Science, Technology, Engineering and Maths) subjects at schools and universities although there is increasing demand for STEM staff in Austria. Educational Robotics has proven to be a valuable tool for practical learning, not only about robotics but also about STEM topics in general. There are several programs and projects which are designed to promote young people in the field of STEM and to increase their interest in STEM, but there is a need for a concept with practical guidelines and a validation mechanism to ensure the effective use of educational robotics in STEM. This thesis has developed a concept (C4STEM) with the goals of increasing interest in the field of STEM, increase self-efficacy during workshops, provide students with role models, and motivate them with hands-on activities. The success in achieving these goals will be assessed using questionnaires before and after the workshops. To this end, data from 3417 participants aged from 6 to 18 years were evaluated. The concept includes a framework, templates and an evaluation tool for designing and validating different educational robotics activities on the basis of the same standards. The framework is based on a constructionism approach, problem-based learning, the AVIVA model and design-based research. The framework enables a comparison of the quality of different robotic activities and their implementation in repositories. The evaluation tool validates four necessary factors: interest in STEM, the positive relationship with tutors, the impact of out-of-school activities and the self-efficacy score for checking the quality of educational robotics activities. The thesis presents one case study (as best of) with an innovative design. The results of the validation report on the different quality of the four factors and what has to be optimized in educational robotics activities in order to foster the interest in STEM. The C4STEM framework offers a shareable methodological background for ERA for the purpose of simplifying comparisons, which is underlined with cases in this thesis.

Kurzzusammenfassung

MINT (Mathematik, Informatik, Naturwissenschaften und Technik) Fächern fehlt es an Aufmerksamkeit im Bereich der Schulen und Hochschulen, obwohl in Österreich MINT-Personal immer gefragt ist. Educational Robotics ist nachweislich ein wertvolles Werkzeug für das praktische Lernen von MINT-Themen. Um einen effektiven Einsatz von Educational Robotics für MINT zu gewährleisten, fehlt den verschiedenen Programmen und Projekten, ein Framework mit Richtlinien für die Praxis und einem Validierungsinstrument, um junge Menschen für MINT zu interessieren und im MINT-Bereich zu fördern. In dieser Arbeit wird ein solches Framework (C4STEM) generiert mit den Zielen, das Interesse am MINT-Bereich zu steigern, die Selbstwirksamkeit zu erhöhen, den Kindern und Jugendlichen Vorbilder zu bieten und sie mit Hilfe praktischer Aktivitäten zu motivieren. Der Erfolg von Educational Robotics-Workshops zur Erreichung dieser Ziele wird unmittelbar überprüft. Insgesamt wurden Daten von 3417 Probanden im Alter von 6 bis 18 Jahren ausgewertet. Das Framework beinhaltet einen Rahmen, Vorlagen und ein Evaluierungsinstrument für die Gestaltung sowie Validierung verschiedener pädagogischer Robotik-Aktivitäten nach den gleichen Standards. Der Rahmen basiert auf einem konstruktivistischen Ansatz, dem problembasierten Lernen, dem AVIVA-Modell und der Design Based Research Methode. Das Framework ermöglicht es, die Qualität verschiedener Robotik-Aktivitäten zu vergleichen und in Repositories (Datenbanken) zu implementieren. Das Evaluationstool validiert 4 zentrale Faktoren: das Interesse in MINT, die positive Beziehung zu den Tutoren, die Auswirkung der außerschulischen Aktivitäten und die Bewertung der Selbstwirksamkeit, um die Qualität der Robotik-Aktivitäten im Unterricht zu Überprüfen. Die Ergebnisse der Validierung zeigen die unterschiedliche Relevanz der 4 Faktoren und verweisen auf den Optimierungsbedarf bei den pädagogischen Robotik-Aktivitäten, um das Interesse an MINT besser zu fördern. Das C4STEM-Framework bietet einen gemeinsam nutzbaren methodischen Hintergrund für Bildungsrobotik Aktivitäten. Dies erleichtert Vergleiche, um Praxis zu optimieren, welche anhand von Fallbeispielen in der Arbeit dokumentiert wird.

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1 Introduction

„When the wind of change blows, some build walls and others windmills.“
(Chinese Wisdom)

STEM (Science, Technology, Engineering and Maths) careers are of little interest to students in most EU countries [1]. However, STEM is important because it is part of our whole life. Science and Technology are around us and continuously expanding in our life. Engineering is a basic for designing machines and solving problems. Without increasing the interest in STEM subjects, no progress will be made in the achievement of the 17 Sustainable Development Goals (SDGs) of the 2030 Agenda for Sustainable Development[1]. Most EU countries are facing a low number of students interested in STEM careers [1], although some economic projections forecast that the demand for STEM-skilled labour is expected to rise and there will be around 7 million job openings until 2025 in the European Union [2]. Austria, like many other EU countries, lacks students interested in pursuing degrees in STEM fields [3], [4]. Even now, eight out of ten industrial companies in Austria have problems finding qualified personnel in the fields of engineering, production, research and development [5]. Consequently, inspiring interest in STEM among children and young people is increasingly more significant. One means to raise interest in STEM could be robots.

The topic of robotics had been subject to a significant transformation in scope and dimensions by the beginning of the new millennium. Robotics has rapidly expanded from an industrial focus to the challenges of the human world, like human-centred and life-like robotics. The new generation of robots is expected to safely and dependably co-habit with humans in homes, workplaces, entertainment, education and healthcare [6]. Educational robotics programs are prevalent in most developed countries and are becoming more relevant in the field of education. Robotics is used to teach problem-solving, programming, 21st skills or product development, but also to generate enthusiasm for science and engineering. Educational robotics has increased the interest in STEM by giving students an active role in solving their problems with robots [6]. Educational robotics is one element in creating enthusiasm among young people for the STEM and engineering field. Research has demonstrated significant gains in interest when robot hardware, software, the

[1] https://sdgs.un.org/goals

classroom curriculum and evaluation instruments are all designed and aligned to yield the best possible learning ecology [7]. Furthermore element is a framework with a common theoretical background, teaching strategies and pedagogical intervention with an evaluation package, which is developed in this thesis. One example (see Figure 1.1) shows the impact of educational robotics activities designed with this framework to empowering students to solve problems with robots and increasing their interest in STEM.

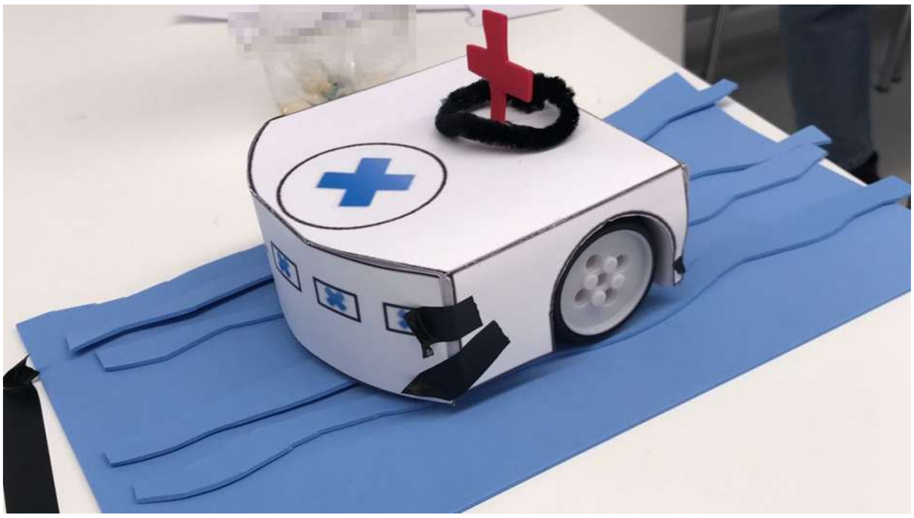


Figure 1.1: The students' task was to solve a problem in the water with a robot. The solution presents this robot prototype which scans the area with its sensors and rescues people in an emergency. The result shows that the combination of a constructionism approach and hands-on-activities with a design thinking process foster problem-solving and increase students' interest in STEM.

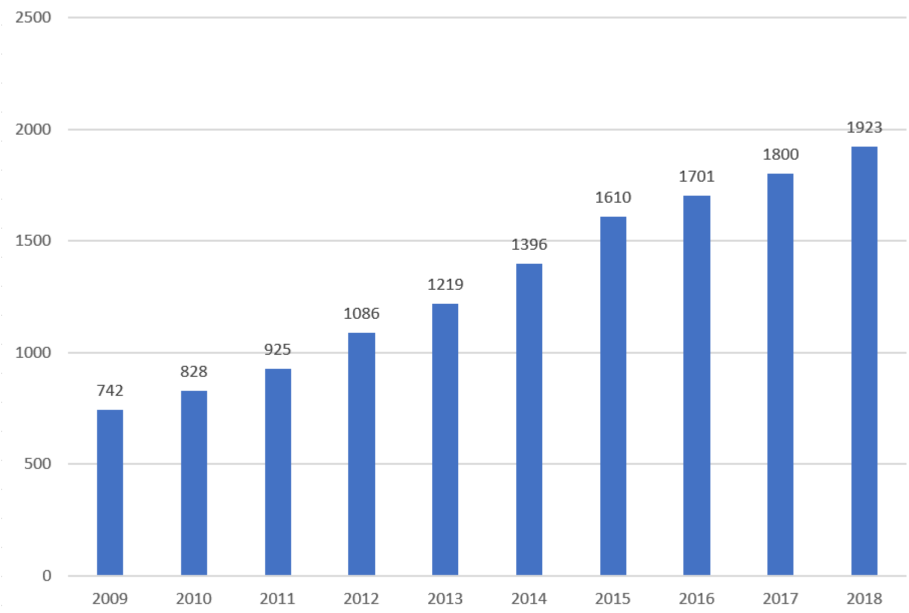
The development of this framework and evaluation tool was done with the data from 3417 participants in educational robotics workshops. These data were evaluated and assessed to gauge the impact of the workshops and related improvements and recommendations for the best means of increasing the interest in STEM.

1.1 Motivation and problem statement

The interest in applying robotics in educational activities has increased over the past few years. There have been attempts to introduce robotics in schools ranging from kindergarten to secondary (high) schools, mostly for STEM [8]. Robotics has attracted great interest among teachers and researchers as a valuable tool to develop cognitive and social skills in students from pre-school to high school and to support learning in science, mathematics, technology, informatics and other school subjects or interdisciplinary learning activities [9].

The use of robots in education is known as educational robotics, which is a growing field with the potential to significantly impact the nature of science and technology education at all levels, from kindergarten to university. Educational robotics has emerged as a unique learning tool that offers hands-on and fun activities in an attractive learning environment, which promotes the students' interest and curiosity [10]. The results obtained by searching for the keywords 'robotics' and 'education' in Science Direct, a leading platform of peer-reviewed scholarly literature, underline this statement with continuous growth, see in Table 1.1 [11]. Several studies have come to the conclusion that educational robotics can provide a constructionism learning experience that promotes students' creative thinking, teamwork, and problem solving skills: the essential skills necessary in the workplace of the 21st century [12]–[14].

Table 1.1: The continuous growth of hits with the keywords 'robotics' and 'education' in Science Direct, a leading platform of peer-reviewed scholarly literature, since 2009.



Criticism has emerged within the robotics community in recent years claiming an evident lack of quantitative research on how robotics increases students' learning achievements. Bredenfeld and Leimbach (2010) point out the lack of a systematic examination of robotics projects and a significant evaluation of the approaches' impact or success in meeting their goals [15]. In other cases, the expected benefits have not been measured and defined because there is no system of indicators or a standardized evaluation methodology for them [16]. Despite the usually positive educational and motivational effects, studies suggest that rigorous quantitative research is lacking in the literature. Research needs to assess whether the learning goals were reached in robotic projects or courses, and whether more students are becoming interested in science and technology or developing significantly better cognitive or social skills [9].

Because robotics may be of benefit to many students, evaluating how robots impact student learning and perceived levels of interest in science and technology is a common focus in the assessment of educational robotics. This trend is exacerbated because tens or even hundreds of thousands of students participate in educational robotics activities organized by non-profit companies and volunteers that lack specific funds and training for formal assessment [17]. The next necessary step is a practical framework for the development of educational robotics activities so that instructional designers and educators can implement it consistently and at large scale [18]. Independent of the framework, there is the need to validate the impact of robotics in promoting student learning and developing skills using scientific evidence. Without the validation of robotics' direct impact on students' learning and personal development, robotics activities might be just a fashion or trend. Furthermore, there is a lack of systematic evaluations and reliable experimental designs in educational robotics. An iterative plan is necessary to validate the different strategies and methodologies and to ensure that the realisation of the robotics curricula in practice is followed by testing, refinement and continuous improvements. Testing should be based on a system of indicators and a standardized evaluation methodology for measured and defined benefits [9].

In recent years, Austria and the European Union have introduced a strategy to increase the number of graduates in the STEM field to fight an existing shortage. In most European countries, interest in the STEM field is declining, and more than eight-hundred thousands technology posts were unfilled as recently as 2020, and the trend is increasing. Lower-level positions will increasingly require higher-level STEM knowledge and competence. This mismatch between demand and supply for qualified STEM professionals in the European Union, combined with decreased interest in STEM degree courses and careers results from low graduation rates in the STEM fields. The European Union's problem is the growing gap between recruitment for the STEM sector and the declining number of STEM graduates. Multiple studies show an increasing disengagement among young people from STEM subjects in school. The number of STEM graduates in Europe has been declining in recent years, from 24.3% in 2002 to 22.6% in 2011 according to Eurostat [4]. However, educational robotics has proven to be a very useful educational tool to increase the interest in STEM and thus the numbers of graduates in the STEM field [9]. The recommendations to bring all the main stakeholders in the field of educational robotics (teachers, educational researchers and organizations offering educational robotics activities) together to design educational robotics activities are an open and conceptual framework and a user- and activity-centered repository. A structured conceptual framework will form the basis for the design of all educational robotics activities [19].

The first development of this conceptual framework took place in a Horizon2020 project entitled ER4STEM [2]. The framework of ER4STEM was divided into workshops and curricula, conferences and competitions, educational technologies and repositories, and pedagogical design and innovations [20]. All of the educational robotics activities of the project were evaluated with an evaluation toolkit which is based on a mixed-methods approach. The qualitative data were used for a in-depth analysis required to identify areas for the framework's development, because quantitative data cannot begin to explain what works or does not work among pedagogical designs and innovations. The evaluation kit for educational robotics workshops included pre- and post-questionnaires, tutor reflections, draw-a-scientist, student reflections, artefacts of learning, observations, interviews and a structured protocol [19]. All of the educational robotics workshops were designed with a standardised activity plan template which was structured in seven steps [21]. All of the documents and collected data were finally uploaded to an open access repository from Zenodo [3].

The results of ER4STEM offer the first conceptual framework with an evaluation package to assess educational robotics activities on a large scale. The evaluation package assesses the 4Cs (Communication, Collaboration, Creativity, Critical Thinking) and the level of interest in STEM with a mixed-methods approach. The problem is that the effect of the factors which influence students' interest in STEM during educational robotics activities have not yet been researched. Furthermore, the evaluation package includes a large number of items which are too difficult for young students to fill in; thus these items are not practical in terms of their use and the context is not clear. This thesis identifies factors which positively influence the level of interest in STEM during educational robotics activities and are thus given the name 4STEM factors. The current framework is improved with extensions including interventions related to these factors and clear standardization based on the AVIVA model in the activity plan. The thesis analyzes the quantitative data from the pre- and post questionnaires in the context of levels of interest in STEM in order to reduce the number of items. Subsequently, the relevant items were combined to form a STEM index for an assessment of interest in STEM before and

[2]https://www.acin.tuwien.ac.at/project/er4stem/
[3]https://www.zenodo.org/

after educational robotics activities. Additional indices were developed in relation to the 4STEM factors and STEM careers and thus modified the evaluation package.

> The motivation is to minimize the gap between the recruitment needs in the STEM sector and the declining number of STEM graduates by using educational robotics activities. One project with this goal was the ER4STEM with the approach of developing a framework for all educational robotics activities in STEM with an evaluation package. The framework includes several goals such as fostering 21st century skills and the interest in STEM with the evaluation package including 92 items. For children this number of items is hard to complete with full concentration. The challenge is to develop a conceptual framework with common teacher strategies, pedagogical interventions and a minimal evaluation package to assess the effect of educational robotics activities to increase the level of interest in STEM. This conceptual framework is designed to be the basis for all of the activities. These activities will be developed by using the same theoretical background, teacher strategies and guidelines with a standardized evaluation methodology for assessing the relevant factors for increasing the interest in STEM.

1.2 Research overview

Regarding the problem statement in the previous section, the thesis has the following objectives. These objectives are derived from the problem statement in two significant parts, which are a) development a theoretical framework and b) an empirical evaluation tool:

a) a framework for sharing and comparing educational robotics activities in the STEM field,

b) an evaluation tool to assess the impact of factors which positively influence the interest in the STEM field.

The following research questions ($RQ[a,b]_x$) are derived from these objectives.

- RQa_1: What does a framework need to be able to compare and share educational robotics activities in the STEM field?
- RQa_2: Which factors positively influence the interest in STEM of educational robotics activities?
- RQb_1: Which evaluation tool can assess the impact of these factors to influence the interest in STEM positively by educational robotics activities?

- RQb_2: How does a comparison of educational robotics activities look like with this evaluation tool?

The thesis is based on a mixed-methods approach with an empirical evaluation of qualitative and quantitative methods to answer these research questions.

1.3 Contribution

This thesis aims to counteract the lack of interest in STEM subjects at schools with the help of educational robotics activities. There is currently no standardized evaluation methodology with clear teaching strategies to assess the impact of pedagogical interventions and interest in STEM. The first phase of the thesis was to evaluate the framework and data of an open access repository [4] in a pilot study with the aim of identifying the weaknesses and strengths of the tools. The first results showed that a broad framework has been developed with different aspects and the fostering of skills, but that there is no readily available and standardized framework with an evaluation tool in the context of the STEM field. The challenge is to develop a framework for designing and assessing educational robotics activities specifically for the interest in STEM and careers in STEM. For this purpose, a design-based study combined with concurrent triangulation mixed methods designed to investigate the didactic interventions in educational robotics activities was used [22]. This process of design-based research is seen in Figure 1.2.

A mixed method was chosen because it can take advantage of both quantitative methods (large sample size, trends, generalization) and qualitative methods (small sample size, details, in depth) and offset the non-overlapping weaknesses of one method with the strengths of the other method [23]. Quantitative and qualitative data were collected from multiple sources. These are an activity plan, questionnaires filled in by the students before and after robotics activities, photos of robotics activities and student interviews. Priority was equally distributed between the quantitative and qualitative methods. Data mixing occurred during interpretation in order to confirm findings from the quantitative and qualitative methods.

1.3.1 A standardized structure for designing educational robotics activities in the STEM field

The educational robotics community needs a standardized structured framework for sharing and comparing their educational robotics activity designs. The current framework was developed to foster entrepreneurship skills, 21st century skills, interest in STEM and more. This framework is extended with a standardized

[4] https://www.zenodo.org/

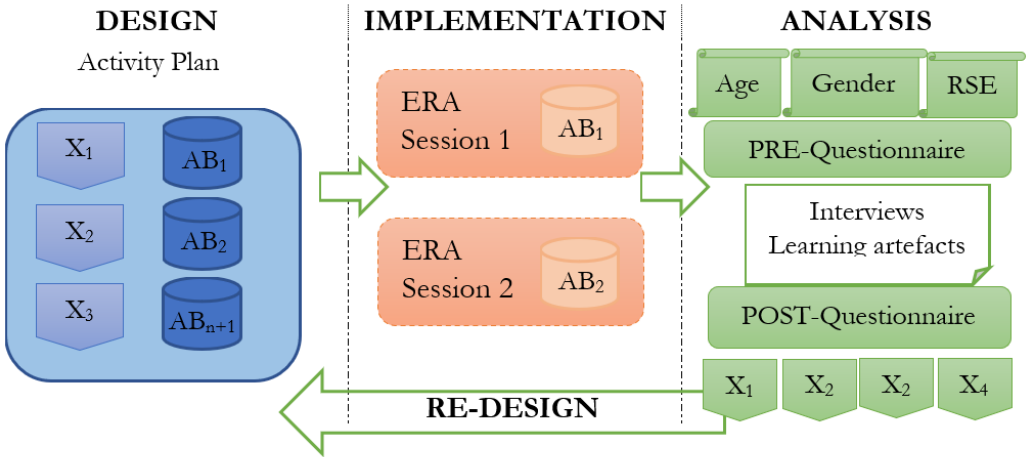


Figure 1.2: The design-based research follows a three-step process. The first step is that the design of an educational robotics activity is guided by an activity plan with activity blocks (AB_n) which include the pedagogical interventions (X_n). The next step is to implement the design in several sessions of educational robotics activities (e.g.: Educational Robotics Activity (ERA) Session 1) and the final step is to analyse the impact of the didactic factors (X_n) with an evaluation tool. The analysis shows the weaknesses and strengths of the design and offers recommendations for a re-design.

structure for all educational robotics activities and offers an option to implement the designs in a repository. The operation follows the standardized phases of the AVIVA model. It begins with the presentation of the tasks and schedule of the educational robotics activity called a session, followed by activating the previous knowledge of students, an instruction phase lead by a tutor and a construction phase with hands-on activities for students, and ends with an analysis of the learning artefacts together with the students. This standardized structure enables a comparison of the results, sharing the designs with other stakeholders and the option to implement the designs in a repository. It will be involved in all future designs of educational robotics activities as standard and gives answer to the research question RQa_1 [Jäggle, RiE 2018].

1.3.2 Designing educational robotics activities with a structured activity plan and activity blocks

The conceptual framework has a structure with an activity plan and activity blocks. Together, the activity blocks make a session, and several sessions make an educational robotics activity. The activity plan collects data about the title, authors, a short description, the duration, learning materials and the necessary space or room for the educational robotics activities. The activity blocks contain seven parameters. They are a code number, the duration in minutes, the name of the block, the targets, student activities, tutor activities and materials for learning or teaching. This information helps those involved to understand the framework conditions of educational robotics activities in detail and gives answer to the research question RQa_1 [Jäggle, IGI-Global 2021].

1.3.3 The 4-STEM factors which influence interest in STEM positively

Educational robotics has obtained increased importance and gained attention worldwide as an excellent teaching tool for STEM. However, awakening the enthusiasm of young learners who are not already interested in STEM remains challenging. One factor in influencing learners to pursue a STEM career is to increase interest in STEM through learning via hands-on exercises during lessons [24]. In this way, the opportunities for experiential learning are increased, resulting in the pupils broadening their horizons through learning by doing [25]. Another factor that positively influences the pursuit of a STEM career is increasing a person's self-efficacy [26], which is linked to positive STEM task performance [27]. Practical hands-on activities increase the students' self-efficacy and influence their positive attitude towards STEM [28], [29]. Also, it is necessary to participate in out-of-school activities to increase the level of interest in STEM [30], [31]. Educational robotics activities start with a lecture and repeat key elements as activity blocks throughout the whole visit to enhance the learning process. The tutors from different backgrounds (students of engineering, architecture, psychology or literature studies, or retired electrical engineers) act as role models.

For the design of the activities a concept that considers all the above-mentioned factors was used. For example, young learners come to the technical university to become researchers and investigate robots and robot behaviour. Theory and hands-on activities are combined in an age-appropriate concept based on constructivism approach. This approach has the focus on the art of learning, suggests that learners are more likely to develop new ideas and constructing artefacts (e.g.:robots) in hands-on activities. It tends to increase the interest in STEM through increasing the self-efficacy of solving problems in the field of robotics. The educational robotics activities were split into different activity blocks and started with the activity block "lecture about robots" for the whole class, which was then divided into groups. Each group visits each of the hands-on activity stations "explore a robot", "innovation lab", and "interaction with a humanoid robot". Important elements such as the children acting an scientists or sensors being an important part of a robot are repeated throughout all of the activity blocks. In order to evaluate this approach, a short post-questionnaire was developed. The results with 255 young people aged 7 to 17 show that after the visit 84% are more interested in technology and 80% are more interested in robotics. 85% of the young learners are of the opinion that robots are complex machines after the visit. Despite that fact, 85% of those who find robots complex are more interested in robotics after the visit, 85% want to come back to learn more about robotics, and 91% will tell their families about these activities.

These results show that the combination of hands-on activities with out-of-school activities in an educational robotics context creates more interest in STEM and influences self-efficacy in particular. The approach of constructivist learning in out-of-school workshops increases interest in STEM among young students. The evaluation shows that after the workshops most of the students have a greater interest in STEM and will share their experience with others. The factors which play a role in increasing their interest in STEM are hands-on activities, self-efficacy, a positive relationship with tutors as role-models, and out-of-school activities. These factors are necessary to increase students' interest in STEM and are called the 4-STEM factors. These factors will be implemented in all educational robotics activities and gives answer to the research question RQa_2 [Jäggle, RiE 2019b].

1.3.4 An evaluation tool to assess self-efficacy in the field of robotics

The goals of the educational robotics activities include engaging young children in the world of robotics so that they play an active part in hands-on activities in designing a robot, fostering scientific and technological literacy, and increasing their perceived self-efficacy in robotics. On the one hand it is necessary to increase and assess their self-efficacy because it is about the belief in their own capabilities to organize and execute courses of action required to produce given attainments [32]. On the other hand, the evaluation and fostering of self-efficacy in educational robotics is an extension to empower students in problem-solving in the field of robotics and to increase their interest in STEM. Therefore, the self-efficacy measurement of robotic activities could improve the understanding between impact of educational robotics activities and students' performance. We developed a Robotics Self-Efficacy questionnaire with 10 items and 5 scales to measure self-efficacy in educational robotics activities. The entire evaluation design is based on mixed methods with quantitative and qualitative analysis and gives answer to the research question RQb_1. [Jäggle, Constructionism 2020]

1.3.5 An evaluation tool to assess the 4-STEM factors with results about a comparison of different educational robotics activities

Educational robotics activities introduce the world of robots to students and foster their interest in STEM. A comprehensive quantitative and qualitative evaluation of all workshop activities is intended to allow the identification of best practice activities for all stakeholders in order to ensure the systematic and long-term realisation of educational robotics activities. The corresponding evaluation tool is introduced and the results of 352 students of the secondary school are presented. The evaluation tool considered quantitative questionnaires with a 5-point Likert scale. Interest in STEM was evaluated with questionnaires before and after the educational robotics activities. The 4-STEM factors of the role-model, self-efficacy and hands-on activities were evaluated after the educational robotics activities. The comparison of the results shows the strengths and weaknesses of the different activities and provides information on what works for whom, such as for girls or for participants with more or less previous knowledge about programming before the workshops and gives answer to the research question RQb_2. [Jäggle, RiE 2020]

1.3.6 Scientific Papers

This thesis has led to several scientific papers. These papers were published in peer review conference and journals.

[Jäggle, ICEED 2018] G., Jäggle, W., Lepuschitz, C., Girvan, L., Schuster, I., Ayatollahi, and M., Vincze **Overview and Evaluation of a Workshop Series for Fostering the Interest in Entrepreneurship and STEM.** in IEEE International Conference on Engineering Education (ICEED), pp. 89-94, 2018.

[Jäggle, RiE 2018] G., Jäggle, M., Vincze, A., Weiss, G., Koppensteiner, W., Lepuschitz and M., Merdan **iBridge-Participative Cross-Generational Approach with Educational Robotics.** in International Conference on Robotics in Education (RiE), pp. 263-274, 2018.

[Jäggle, ICL 2018] G., Jäggle, M. Vincze, A., Weiss, G., Koppensteiner, W., Lepuschitz, Z., Stefan, and M., Merdan **Educational Robotics-Engage Young Students in Project-Based Learning.** in International Conference on Interactive Collaborative Learning (ICL) pp. 360-371, 2018.

[Jäggle, RiE 2019a] G., Jäggle, M., Merdan, G., Koppensteiner, C., Brein, B., Wallisch, P., Marakovits, M., Brunn, W., Lepuschitz and M., Vincze **Project-Based Learning Focused on Cross-Generational Challenges.** in International Conference on Robotics in Education (RiE), pp. 145-155, 2019a.

[Jäggle, RiE 2019b] G., Jäggle, L., Lammer, H., Hieber and M., Vincze **Technological Literacy Through Outreach with Educational Robotics.** in International Conference on Robotics in Education (RiE) pp. 114-125, 2019b.

[Jäggle, ICL 2019] G., Jäggle, M., Merdan, G., Koppensteiner, W., Lepuschitz, A., Posekany and M., Vincze **A Study on Pupils' Motivation to Pursue a STEM Career.** in International Conference on Interactive Collaborative Learning (ICL) pp. 696-706, 2019.

[Jäggle, ESERA 2019] G., Jäggle and M. Vincze **Educational Robotics and Interest in STEM** in European Science Education Research Association Summer School (ESERA) pp. 36-39, 2019.

[Jäggle, RiE 2020] G., Jäggle, W., Lepuschitz, T., Tomitsch, P., Wachter and M., Vincze **Towards a conceptual and methodological framework for the evaluation of educational robotics activities.** in International Conference on Robotics in Education (RiE) pp. 221-233, 2020.

[Jäggle, Constructionism 2020] G., Jäggle, L., Lammer, W., Jan-Ove and M., Vincze **Towards a Robotics Self-Efficacy Test in Educational Robotics.** in International Constructionism Conference (Constructionism), pp. 537-550, 2020.

[Jäggle, IGI-Global 2021] G., Jäggle and M., Vincze **A Conceptual Framework for Educational Robotics Activities C4STEM: A Virtual Educational Robotics Workshop.** a chapter in Handbook of Research on Using Educational Robotics to Facilitate Student Learning (IGI-Global), pp. 274-298, 2021.

1.4 Outline of the thesis

The research work is organized in the following chapters. Chapter 2 defines the context and state of the art in educational robotics activities and interest in the STEM field, the factors (4STEM) to positively influence the interest in STEM, the framework development, an activity plan template and an evaluation package to assess the interest in STEM for educational robotics activities. Chapter 3 covers the design of the C4STEM framework developed for educational robotics activities in the STEM field, and subsequently the C4STEM activity plan template with an activity blocks template and the evaluation package. This framework is based on the theoretical background of the constructionism approach and a teaching strategy with problem-based learning and pedagogical interventions with 4STEM-factors to positively influence the students' interest in STEM. This combination enables the comparison and sharing of educational robotics activities and increases the students' interest in STEM. Chapter 4 presents the development of the evaluation tool in three study phases. The pilot study analysed the activity plan template of Yiannoutsou et al. (2018) with activity blocks and an evaluation tool kit by Girvan Carina and Todorova (2018). The focus is to assess the students' interest in STEM and the pedagogical interventions of the educational robotics activities. The results are shown as a recommendation for the Phase 1 (see Chapter 4.4). In the Phase 1, the activity blocks and evaluation tool were extended with 4STEM factors according to the pilot-study recommendations (see Chapter 4.5). In the Phase 2, educational robotics activities were designed and assessed within the modified framework called the C4STEM framework and provide a comparison of educational robotics activities (see Chapter 4.6). Chapter 5 includes a discussion of the study and an outlook on the future work.

2 Related studies about educational robotics activities in the STEM field

This chapter presents the relevant literature and theoretical background of educational robotics activities in the STEM field for this thesis (Section 2.1 and 2.2.). Section 2.3 summarizes findings on positively influencing the interest in STEM (4STEM) related to the objectives from section 1.2 and gives an answer to the RQa_2. Section 2.4 presents the framework development and provides a response to the RQa_1.

2.1 The interest in STEM

Many countries worldwide face the task of recruiting more individuals into industries involving science, technology, engineering, and mathematics (STEM) [33]. Countries such as Austria, France, Germany, the Netherlands, and Switzerland have struggled during the recent economic recovery with few individuals trained in using and creating the technologies capable of improving domestic production [34].

The European Commission reported that one of the aims of the agenda for improving the relevance of skills in the EU was to strengthen sustainable competitiveness by increasing the number of STEM graduates. Despite rising demand, the number of students completing a STEM program is decreasing [35]. A study from 2016 explicitly details secondary-school students' opinions about the STEM industry and associated careers [36]. The researchers tried to measure the level of students' interest in and enjoyment of science, mathematics and technology in and out of school. They ascertained that while more than 70% of the students were interested in science and technology, just 60% of the boys and 44% of the girls stated that they were learning science and technology. This reveals that students' primary exposure to and experience of STEM is in school. Therefore, policy institutions are offering several international co-operation endeavours to learn more about the STEM disciplines in modern ways. The realm outside of school is rife with opportunities to increase the interest of young students in STEM. Students' social views and personal understanding of the relevance of STEM as a career are also factors that play a role in cultivating interest in STEM [36].

The theory of interest interprets the construct of interest as a specific person-object relationship. Thus, a basic theoretical concept would be established that from the very beginning would allow simultaneous analyses from varying perspectives of proven relationships between person and object, of the course of action and the result of action. Human activity and human development is only analyzable and understandable in the interaction and engagement between man and the environment. The environment can refer to either the objective environment or subjective environment. The subjective environment can be labelled the social and objective environment. The social environment includes other people as elements. The objective environment is the non-personal environment, such as cultural values and ideas. In interest-orientated action performance, the individual has an effect upon the object, does something with it and changes it. Overall, a positive object conception is postulated for the action of interest in regard to the emotional aspect. The action process performance of action is accompanied by positive feelings. The action of interest is aimed at results that lie in the field of the objects of interest, which, for example, can mean that a change in the objective fields of interest can be aspired to, or that one can strive for the performance of actions with the object of interest. Because the constituting characteristics of interest represent subject-internal processes that cannot be immediately observed in a person's behavior, and because many fields of actions of interest are not accessible to a participating observer because of their "non-public" nature (e.g. reading), particularly those measurement procedures must be applied which enable the recording of subjective conditions, evaluations and estimations [37].

Thus, an evaluation tool will be developed which makes the subject-internal processes, such as interest in STEM, observable. The realization of an interest requires a situation-specific interaction between the person and the object. The term object refers to concrete, hands- on engagement with the object (e.g., a child playing with a robot) and also to abstract cognitive work on a specific problem (e.g., the analysis of a scientific question, the discovery of and research into the world of robots) [38]. In the Person-Object-Interaction Theory, interest is mostly understood as a phenomenon that emerges from an individual's interaction with his or her environment (e.g., students solve problems or tasks in the context of educational robotics). An important aim of applied research has been to develop and examine the quality of tests which enable the measurement of general or specific individual interests with a minimum of efforts [39]. One aim of the thesis is to develop an instrument to measure the interest in STEM of students with a minimum of effort. Most interests that are relevant for learning and work exist only for a limited period of time and are triggered by external incentives (situational interests). The interest construct is conceptualised as a relational concept: an interest represents or describes a more or less enduring specific relationship between a person and an object in his or her life-space. Within the entirety of the available and possible personal object relationships, a person will develop a closer relationship only to a few objects for a longer period of time. Under certain conditions such a relationship will become a longer-lasting personal interest. An interest that is primarily caused by external factors is called a situational interest. It may be transitory or may provide the basis of a longer-lasting situational or individual interest (see in Figure 4.2)

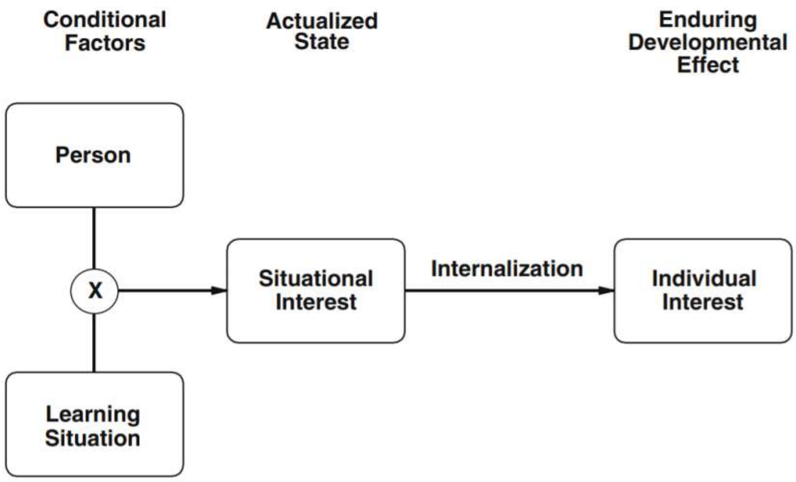


Figure 2.1: One conditional factor in transforming a situational interest into the development of a longer lasting individual interest (an interest in STEM) is a closer relationship to an object like educational robotics equipment with specific tasks in an educational robotics activity.

The experience of being interested in a concrete learning situation is always the result of an interaction between personal and situational factors. The prototypical case of a situational interest is primarily initiated by external factors in a given learning environment. In vocational training, for example, a situational interest can be created by an "interesting" presentation of a vocation-related topic or by the opportunity to learn how to solve a subjectively meaningful problem. The lecture about robots is related to this theory.

On the whole, many aspects of an interest-triggered action are connected with positive emotional experiences. In a person's cognitive-emotional representation system, experiences that precede, accompany, or follow an interest-triggered activity are stored in their specific quality for a longer period of time and can to some degree be remembered as positive "feeling-related valences". Many values, attitudes and interests were measured on the basis of survey data; for example whether or not subject-related interest in certain areas (e.g. natural sciences) has decreased within the last decade. This positive feeling is initiated in Educational Robotics Activities and assessed with a measuring instrument. The measurement instrument relates to the interest in the content (e.g.: maths and science) and the required skills (e.g.: programming, discovery and research) in the STEM field.

Internationally, efforts to increase student interest in science, technology, engineering and mathematics careers have been on the rise. It is often the goal of such efforts that increased interest in STEM careers should stimulate economic growth and enhance innovation. Scientific and educational organizations recommend that efforts to interest students in STEM majors and careers begin at middle school level, a time when students are developing their interests and recognizing their academic strengths. These factors have led scholars to call for instruments that effectively measure interest in STEM classes and careers, particularly for middle school students. One study published several reasons for the loss of interest in STEM: there is too much content in several curricula. The teacher uses the wrong teaching methods. The reputation of the discipline is not so popular in peer groups. The learning process dissuades students from pursuing the field, as most of the students receive bad marks in STEM subjects and think STEM disciplines are too difficult. The wrong teaching methods are reading instructional texts which are too theoretical [40].

This thesis supports the recommendation that a modern learning environment with educational robots is needed. An understanding of the relevance of STEM as a career can be developed in educational robotics activities. The interaction between students and the robots offers an emotional aspect with a positive feeling derived from achievements with hands-on activities. These activities with robots combined with discovering and researching the world of robots extend the field of interest of students. The effect of these activities have to be measured with an instrument with a minimum of costs. The measurement will evaluate the students' interest in using computers, in research and discovery, in science, maths, and understanding how technical things work. The next chapter 2.2 provides an overview of educational robotics activities in the STEM field.

2.2 Educational robotics activities in the STEM field

Educational robotics has proven to be a valuable tool for practical learning, not only of robotics but also of STEM topics in general [41]. It has again proven to be effective when students decide to go in for further STEM education, even sometimes against the will of their parents [42]. Several robotics activities are challenges or competitions and are classified in navigational contests, duels, crusades, line follower, micro mouse or climbing contests [43]. Several projects have the goal of reaching all young people with multiple entry points like ER4STEM [20], First

Lego League [13], Robot League [44], RoboCup [45] and Summer League [46].

The interest in robotics has greatly increased with the advances in modern technology and along with that the interest in robotics educational courses [47]–[49]. Since the year 2000 the number of studies on Educational Robotics has increased significantly [50]. Most countries plan to rework their curricula to increase students' competence in Science, Technology, Engineering and Mathematics. The reason for the change is the lack of STEM skills of students on the one hand and the needs of the 21st century such as critical thinking and problem solving on the other [51].

Many schools offer activities to teach students about coding and building robots. Thousands of educational robotics programs teach them how a robot follows a line on the floor or how they can guide a robot and how they can control sensors or actors with coding. The range of activities in this context is endless. All these activities are seen as an investment in the student's future. They learn content knowledge and skills which are needed to solve problems by the labour market and in daily life. They are the next generations of workers and citizens. Educational Robotics engages students in activities involving building and controlling robots by using programming tools [52], and supports students to become active learners and create new knowledge and developmental skills by working as scientists [53]. Students have to learn how robots interact in the real world, taking into account the sensor's value and the reaction of its actuators. The students transform complex concepts into a more concrete real-world understanding with hands-on experimentation with mechanical and scientific principles [54]. Previous studies have showed that educational robotics positively influence students' motivation [55], problem-solving skills, collaboration [54] and their interest in math and science careers [56]. Robotics has also been effectively used for industrial purposes to increase productivity, and at the same time the interest in applying robotics in educational activities has also increased over the past few years. There have been attempts to introduce robotics in schools ranging from kindergarten to secondary (high) schools, mostly for Science, Technology, Engineering and Mathematics subjects [8]. Educational robotics activities are for children, and programmes for adolescents are increasingly being implemented in the curriculum in Europe. Sixteen countries have integrated robotics into their curriculum: Austria, Bulgaria, the Czech Republic, Denmark, Estonia, France, Hungary, Ireland, Israel, Lithuania, Malta, Spain, Poland, Portugal, Slovakia, and the UK [34]. Educational Robotics offers the required content knowledge for all STEM disciplines and engineering, increases the students' level of interest and promotes real-world problem solving and other STEM skills [57], [58].

Different approaches are reported in the literature on STEM skills. Governmental reports mostly focus on STEM education outcomes in relation to industrial needs. Other researchers prefer a more generalized definition of STEM for all citizens [59].

The standard report on STEM skills includes creativity,critical thinking, designing, problem-solving and the application of these skills to solve challenging real-world problems. Educational Robotics offers a framework for students and teachers to improve students' learning outcomes and their STEM skills [60]. Several projects and competitions with an Educational Robotics approach have significantly enhanced students' views of STEM disciplines [61].

One evaluation was carried out on the impact of educational robotics in the form of the RoboCup on the students' technical and social skills and the influence on their attitudes towards and interest in science and technology. The results suggest that it is mainly students who are already interested in science and technology who decide to participate in educational robotics activities. Consequently, the question is how we can also attract students who are not already interested in science and technology. The concept of educational robotics should not only focus on separate, isolated topics but should be applied as an integrated approach, fostering a holistic understanding and acceptance of different areas and fields [41]. One answer could be a holistic approach to interesting children in future robotic products with an innovative five-step plan [62].

Figure 2.2: The educational robotics equipment Thymio is a small mobile robot with the dimensions approximately 15 cm wide, 12 cm long and 4 cm high and has three different actions, all based on obstacle detection by the infrared sensors and presented as moods such friendly, curious and shy. A series of LEDs and sound effects enhance those moods. The robot is gender-neutral and in a mantle of a white box also as a playground to added the construction with possible lego brix. The robot is useful for workshops for all young students.

Educational robotics includes not just assembly activities in a STEM context, but also involves students actively in thinking about how to solve real-world problems through experimentation and hands-on activities. A possible combination is to upgrade robots with a platform to operate with them. This educational tool engages students to interact with robots by coding the medium [17]. A practical example of how to control robots with an interface platform in an educational robot environment is the robot Thymio mentioned above (see in Figure 2.2) with the primary goal of encouraging creativity and promoting young people's understanding of technology with some non-trivial behaviours [63]. The argument for using educational robotics is that it can increase students' interest in these subjects and even influence their STEM future career positively [64].

This section underlines the impact of educational robotics activities in the STEM field with offers to promote problem-solving, STEM skills and to increase levels of interest in STEM with hands-on activities. It outlines the trend towards the increasing inclusion of educational robotics activities in the curriculum. The studies show that the educational robot environment called Thymio has a positive impact on students' interest in STEM and their STEM careers. The focus is also on a holistic approach and not on isolated topics. All educational robotics activities are based on Thymio. Chapter 2.3 will provide an answer to questions about the necessary external factors for situational learning to increase the interest in STEM.

2.3 Factors in positively influencing the interest in STEM

Several studies have identified and addressed different factors which are influential in motivating students towards STEM, such as their parents, teachers, and hands-on activities (e.g. laboratory, experiments), out-of-school activities (e.g. open days, lectures at a university, workshops, summer camps), as well as role models and mentoring programs [65]–[69].

Studies show that parental involvement could be an influencing factor in their children's career path [70], but also role models, such as teachers or tutors, can significantly influence students to pursue STEM careers [71]. A positive impact was shown in a study of fifth grade students. They performed better in a math test if they were exposed to a role model who emphasized hard work rather than to a role model who was described as being naturally gifted in math [68].

Hands-on activities are supported by theoreticians such as Piaget, Dewey and Bruner who support a constructivist view of knowledge and learning. Constructivism contrasts with the traditional methods of talking and demonstrating. It holds that students acquire new knowledge by associating careful observations with new terms. Hands-on activities mean that students, whether individually or in groups, manipulate objects or events in the natural environment [72].

Further studies suggest that out-of-school activities have a positive effect on students' interest in STEM. Also, more work is necessary to understand better how out-of-school activities can support interest in STEM through Educational Robotics

Activities. Information of this kind would help educators and researchers. Students tend to be more motivated if they have participated in STEM-related out-of-school activities such as after-school events, field trips, summer camps, competitions or mentoring programs [73].

Besides, the results of several studies point out that self-efficacy along with a knowledge of STEM careers are essential factors in whether or not young people will pursue a STEM career [74]. Considering that there has been only limited research on the influence of robotics, the focus of this thesis will be to investigate how participation in educational robotics activities, as well as students' attitude to robotics in general, correlate with their interest in STEM and their motivation to pursue a STEM career. Table 2.1 has been developed in relation to the studies and forms a basis for the thesis. The Table illustrates the factors that influence students' interest in the STEM field.

Table 2.1: The relevant factors, which positive influence the interest in STEM.

Factors	Description
Role-model	Parents, teachers and tutors have the most decisive influence on student's STEM orientation.
Hands-on-activities	Students want to understand a problem in practical activities (laboratory, hands-on, experiments). Students like more welcome practical activities than theoretical approach.
Out-of-school-activities	Students are open to open days, lectures at the university, workshops, meeting with experts, in general, all kind of out-of-school-activities are welcomed.
Job perspectives	Students motivation is linked with self-efficacy and with future carriers by future job perspectives.

Additional studies also indicate that school science practices are restricted to memorizing and replicating science content, and that there is a need to redesign and reshape science learning to improve STEM learning [75]. To improve perceptions of STEM, more awareness of career options and direct contact opportunities are needed to ensure students have enough knowledge to make informed career choices [76]. It is of vital importance to investigate key factors such as family influences, teachers and school curricula, or out-of-school activities that can motivate young people to target STEM careers [77]. It is in this context that the STEM career interest survey was developed, in which the effects of STEM programs on changes in students' interest in STEM subjects and careers were measured using 28 items. The study revealed four factors: the personal and social implications of STEM, the learning of science and engineering and their relationship to STEM, the learning of mathematics and its relationship to STEM, and the learning and use of technology. The teaching approaches used by teachers to teach STEM subjects play a critical role in student learning in STEM subjects and in their developing an interest in STEM careers. The teachers in this study were not observed when teaching STEM subjects [78], [79].The survey in this thesis focuses on personal and social implications (e.g.: I like maths) and learning about technology and its uses (e.g.: I like using a computer). The focus is also on assessing the impact of teachers on their students in the context of a common teaching strategy.

A further impact is the concept of self-efficacy in relation to the career development literature, noting its potential to help understand the complexity of career decision-making such as the under-representation of women in traditionally male-dominated career fields [80]. Self-efficacy refers to the belief that a person has in their own ability to successfully perform a particular task based on their perception of their capability and the likelihood of their achieving success in that activity. Self-efficacy beliefs are an essential aspect of human motivation and behaviour as an action that can affect one's life.

Self-efficacy refers to beliefs in one's capabilities to organize and execute the courses of action required to manage prospective situations. More simply, self-efficacy is what an individual believes he or she can accomplish using his or her skills under certain circumstances [81]. The basic principle of self-efficacy theory is that people are more likely to engage in activities in which they have a high level of self-efficacy, and less likely to do so in those where they do not [82]. Research has also shown that individuals with high levels of self-efficacy tend to set loftier goals than individuals with lower self-efficacy [83]. Self-efficacy is influenced by four essential sources of information: mastery experience, vicarious experience, verbal persuasion, and physiological information. The degree of change in self-efficacy is partly a function of the variability and the controllability of its determinants. A level of self-efficacy predicts how people function, in terms of choice behaviour, effort expenditure and persistence, thought patterns and emotional reactions [80].

Therefore, all designed educational robotics activities which influence students and change their beliefs about solving problems with educational robotic environments foster their problem-solving skills in the context of robotics and increase their interest in STEM. Table 2.2 shows how the four resources are linked to educational robotics activities in strategies and missions according to Rittmayer and Beier (2008) [84]. The four resources of self-efficacy support the interest of students in STEM and foster their level of achievement with hands-on activities and problem solving. The related work shows that the C4STEM framework has to consider four

Table 2.2: The four sources of self-efficacy with their general explanation, strategy for educational robotics activities and mission for educational robotics activities. That means that the self-efficacy is increasing if the activities have part of hands-on activities, the students get positive feedback to their performance and the students are empowered to dedicate themselves fully to the tasks at hand.

Sources	Description	Strategy	Mission
Mastery experience	Mastery experiences are openings to memorize and hone the rules and methodologies essential to perform successfully.	Many tutors have mastery experiences such as lab work, experiments and other applied activities that are part of hands-on activities.	The ERA incorporated hands-on activities in several ERA designs.
Vicarious experience	Role-models are particularly formative when they are perceived as similar to the viewer.	Tutors present their STEM background and collaborate with students or share their STEM experiences and achievements.	Role-models lead the ERA. The team introduce themselves and their different technological backgrounds.
Verbal persuasion	Positive feedback and encouragement, especially from tutors, teachers or parents, increase self-efficacy.	Tutors give feedback and support which is positive but also genuine and realistic.	Tutors give positive feedback on the performance outcome of the students.
Physiological reaction	A person disentangle his or her enthusiastic and physical states to decide his or her self-efficacy convictions.	Feeling calm and composed instead of anxious and stressed when planning for and performing an assignment leads to higher self-efficacy.	Empowering students to focus completely on the task at hand, which ought to diminish any misgivings.

factors to positively influence students' interest in STEM. Table 2.3 shows the link between the four factors (4STEM) and pedagogical interventions.

This conclusion stems from the fact that we implement these factors (4STEM) in the educational robotics activities, we will sustainably increase the interest in STEM by students. The assessment of self-efficacy is one of the main factors in identifying best practice in educational robotics activities. Given this evidence for 4STEM factors, an examination of the factors that impact upon educational robotics activities seems warranted and necessary. The evaluation package to assess these 4STEM factors is developed and reported on in chapter 3.

Table 2.3: The relevant factors for increasing interest in STEM linked with pedagogical interventions for educational robotics activities. These factors are called 4STEM factors and are the basis for evaluating and improving educational robotics activities.

Factors	Pedagogical Interventions
Out-of-school-activities	ERAs take place in universities or labs.
Relationship	Tutors or educators introduce their positive background in STEM and are role models for students. They give them the feeling that success in STEM is a result of their interest and not of their natural skills.
Hands-on activities	The students learn through experience and "trail and error".
Self-Efficacy	The first tasks are easy to solve and offer multiple entry points. The students get positive feedback on their results and given space to present them the whole group.

Several factors positively influence students' interest in STEM. Increasing the students' self-efficacy through more practical, hands-on lessons and establishing a good relationship between teachers and students will foster learning and will give students a feeling of success. It is necessary to coordinate in- and out-of-school activities with shared spaces for the different disciplines of STEM, and it is also advisable to implement constructionist activities in those shared spaces to allow the students to express their results and ideas in and outside of classrooms. These 4STEM factors were applied in all educational robotics activities to increase students' interest in the STEM field.

2.4 Framework development for educational robotics activities

Educational robotics activities need to validate educational robotics curricula, valid and reliable assessment instruments, and trained and motivated educators and teachers. Educational robotics methodologies and tools also enter the education system and impact future citizens [85]. This chapter provides an overview of frameworks for educational robotics activities in general and those with a special focus on the STEM field. The first section includes a development circle of frameworks and designing processes for educational robotics activities in this thesis, the related theoretical background with robotics methodologies, then a description of a current activity plan and finally the assessment of interest in STEM with a current evaluation package. This chapter forms the background for the homogeneous design of educational robotics activities with structured documentation and a measurement instrument as evaluation package in the STEM field.

2.4.1 Framework development

A literature review of educational robotics shows limited references for implemented educational robotics activities with a systematic educational design. In some cases, there is a framework with activity plans and a non-detailed structure with an added evaluation tool. The primary aim of this section is to provide an overview of frameworks in educational robotics and their weaknesses. The goal is an appropriate educational framework for organizing the design-based research process for educational robotics activities, and a structure for developing educational robotics activities and their assessment and comparison. The framework of this thesis uses design-based research and mixed research and applies the method of multiple case studies for collecting qualitative and quantitative development data [86].

Design-based research is a development process in iterate cycles of design, testing, analyses, and redesign. Optimization of the design takes place within these cycles, and the development processes and principles are documented [87]. This development process will be linked with structured documentation in a framework and offers a homogeneity framework for the development cycle of all educational robotics activities (see in Figure 2.3). The specific problem is to increase the interest in STEM among students with educational robotics activities. The theoretical framework is defined in chapter 2.4.2 and the educational robotics activities are designed with 4STEM factors and were evaluated and tested with an evaluation package. The general design is a structured framework with an evaluation package

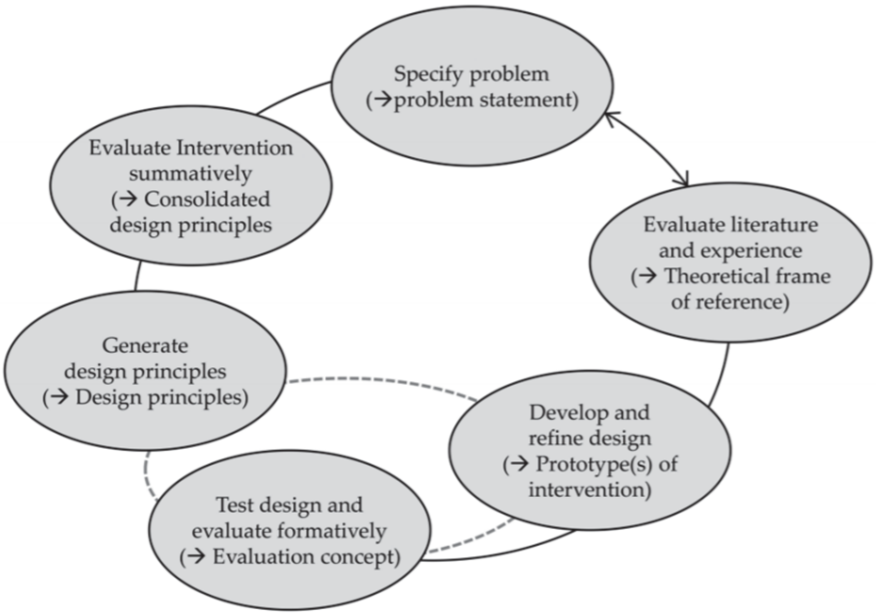


Figure 2.3: The design-based research and developmental process will identify target results for the individual process phases.

to test and evaluate educational robotics activities with the same standards in order to solve the problem of creating more interest in STEM among students.

The ER4STEM Framework for educational robotics activities is state of the art and was developed within the ER4STEM project. The aim of the framework is to help stakeholders in designing, developing and implementing activities in educational robotics [88]. The framework rests on three main goals: providing multiple entry-points to educational robotics and creative STEM, empowering children to solve real-world problems, and addressing all young learners and providing a continuous STEM schedule. The framework is informed from different perspectives, i.e. workshops and curricula, conferences, pedagogical activities and innovations and educational technologies, and a rigorous evaluation [89], and provides the following values: creativity, collaboration, communication, critical thinking, evidence of learning, mixed gender teams, multiple entry points, changing and sustaining attitudes to STEM [88]. The ER4STEM framework has a broad framework and is the basis for the development of a framework to foster interest in STEM with educational robotics activities. A comparison of the impact of different educational robotics activities in the STEM field could improve the success of teachers, educators and stakeholders in the educational robotics field. Based on this, there is a need for a homogeneity protocol to reflect and assess the individual educational robotics activities [90]. Therefore, standardization of the design and evaluation of all educational robotics activities is necessary and is a goal of this thesis. The phases of Figure 2.4 show the process of successfully designing an educational robotics activity the C4STEM Framework. A detailed description of the C4STEM framework tools is provided in chapter 3.

2.4.2 Theoretical background

The theoretical background is the framework for designing and assessing all educational robotics activities in this thesis. The trend of using a framework with a constructivist approach to teaching and learning sciences is extended here to the field of educational robotics, and features activity-based and problem-based learning [91].

Alimisis (2013) stated that an appropriate educational philosophy, namely constructivism and constructionism, along with the curriculum and the learning environment, are some of the important elements that can lead innovation in robotics to success [9]. Construcionism is defined as follows:

„Constructionism -the N word as opposed to the V word- shares constructivism's view of learning as ‚building knowledge structures' through progressive internalization of actions... 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.“

The constructionism approach was developed in 1980 by Papert in his research based on the Logo programming language, based on constructivism that conveys the idea that the student actively builds knowledge through experience and the related 'learning-by-doing' approach to education. One of the implicit purposes of the constructionism approach is to increase the self-efficacy of solving problems in the field of robotics. Self-efficacy belief is one of the fundamental concepts of Bandura's Social Learning Theory. According to Bandura, individuals' motivations, their responses to events, and their actions depend on what they believe rather than what is real [92]. Schunk (1990) added that belief in one's self-efficacy is the most important predictor of human behaviours. Suppose students believe that they have the necessary ability and self-monitoring capacities to perform a task. In that case, they become more willing to choose this task, reflect their decisiveness, and present the required behaviours [93]. In the constructivist learning approach, the essential task for establishing a learning environment is providing an opportunity for students to create their own meanings, tasks and problems. The teacher interacts with students in the constructivist learning environment [94].

The constructionism approach focuses on the art of learning and on the importance of constructing artefacts in learning. The essential priority is the learner's conversation with others about the artefact, and how these dialogues facilitate new knowledge building. This is the reason why tools (e.g. educational robotics) and media are essential to influence human development. This knowledge is actively constructed by the children in interaction with their world; to this end, it tempted to offer opportunities for children to engage in hands-on explorations that fuel the constructive process to get a personal experience [95]. A further and optimized understanding for our educational robotics context is that knowledge is not simply transferred from the teacher to the student, but actively constructed by the learner's mind. Children do not get ideas; they make ideas. In addition, constructivism suggests that learners are more likely to develop new ideas if they are actively involved in producing a type of external artefact that they can think about and share with others [96].

The relationship between AVIVA and competence-oriented teaching and the use of methods creates specific learning situations which have much more to do with reality. Competence-oriented teaching provides learning resources and opportunities for learners to prove their competencies [97]. The AVIVA model is a didactic design with five phases for all educational robotics activities and contains both constructionism-oriented and instructionism-oriented approaches to foster problem solving and the constructivist learning approach with a step-by-step process leading to a 'construction phase', which facilitates learning by doing and learning by 'trial and error' and finally an analysis of the new knowledge or competences with the other students [98]. To improve the structure of the Activity Plan, an AVIVA model (Ankommen, Vorwissen aktivieren, Informieren, Verarbeiten und Auswerten) will be implemented in the current version.

Table 2.4 below depicts the five phases which illustrate the course of this learning process. Learning assumes first of all a special basic feeling, an openness to new things (Arrive). The actual learning (instruction phase) begins with the existing knowledge (activating previous knowledge) and builds on it. For new knowledge to be internalized, it requires the opportunity to be applied, deepened, and practiced until it is solidly embedded (construction phase). In the end, the new knowledge or competence is analysed (analysis) [97].

A necessary teaching strategy is problem-based learning. It leads to positive learning outcomes and is a pedagogical approach that enables students to learn while engaging actively with problems. The learning process is self-directed through practice and reflection. The typical problem-based learning setting is based on the belief that effective learning takes place when students both construct and co-construct ideas through social interactions [99]. This setting will be implemented in the activity plan as the activity block called 'Discussion in the plenum'.

The related work reports the link between the constructionism approach, self-efficacy and the necessary implementation of tools such as an educational robot

Table 2.4: The AVIVA model with a standardized structure for designing all educational robotics activities in five phases.

Phases	Description
(A) Arrive	Task and schedule are presented.
(V) Activate previous knowledge	The students activate their previous knowledge under instruction.
(I) Instruction phase	The students follow a lecture from a teacher about the information and knowledge needed to solve a problem.
(V) Construction phase	The students work actively on different robotics topics and solve problems in the field of robotics.
(A) Analysis	The students check their learning during a presentation about their solutions, the process of solving the problem and learning artefacts as code, a simulation or a robot which has been developed.

environment. The constructionism theory as a design theory it has lent itself to a range of contexts such as the design of constructionist-minded interventions [100]. The problem-based learning leads to positive learning outcomes and is a pedagogical approach that enables students to learn while engaging actively with problems. The learning process is self-directed through practice and reflection. Therefore the constructionism approach is the theoretical background and the teaching strategy problem-based learning for all educational robotics activities in this thesis. The AVIVA model helps to integrate the activities into a standardized structure and to implement activity blocks with the teaching strategy of problem-based learning.

2.4.3 Activity plan template

Yiannoutsou et al. (2018) designed an activity plan template as a design instrument for teachers and stakeholders who are interested in designing educational robotics activities. It is a documentation tool for sharing and reflecting on educational robotics activities. The activity plan has a hierarchy: 1st level Activity Template, 2nd level Activity Plan and 3rd level Activity Blocks. The focus of the thesis' framework development is to extend and redesign the 2nd and 3rd level.

The activity plan has a structure with seven steps and includes activity blocks. The activity blocks can be accompanied by relevant worksheets, are adjustable, can be combined with other activity blocks or can be integrated into an existing activity plan. The activity plan has the aim of fostering the goals of the framework.

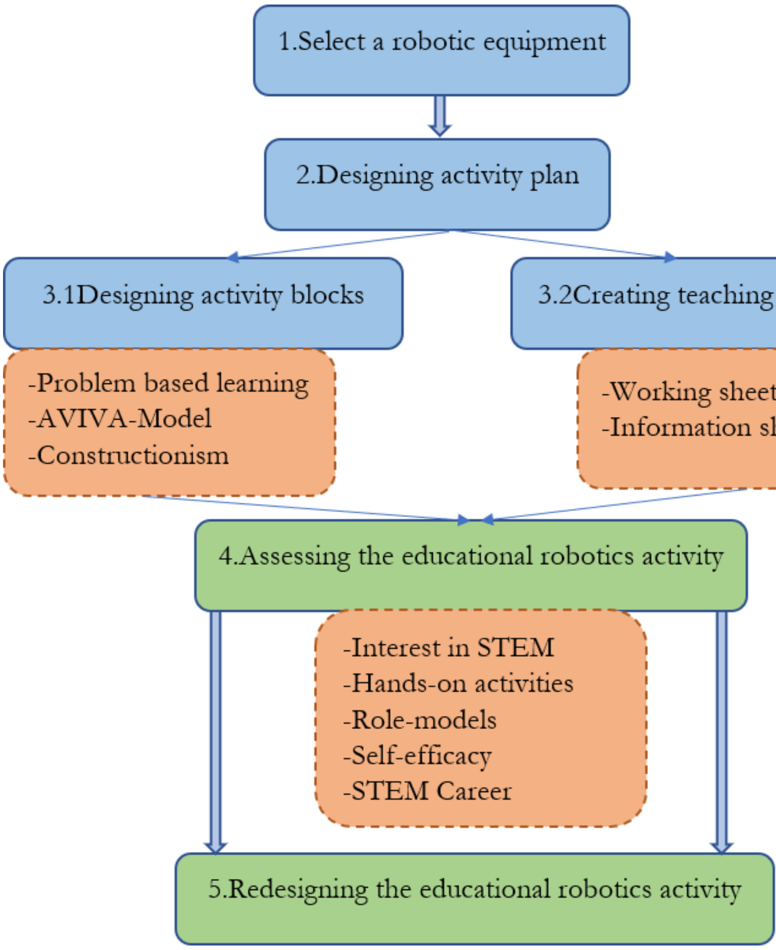


Figure 2.4: All educational robotics activities have to be designed with a standardized process. The figure shows a guideline with five steps. The first step selects robotic equipment; afterwards, the designing of educational robotics activities is carried out with an activity plan. The activity plan includes activity blocks with a theoretical background using a constructionism approach, a teaching strategy based on problem-based-learning, and a standardized structure with the AVIVA model. In parallel, the teaching materials are created. The fourth step is assessing the educational robotics activity in relation to the interest it creates in STEM and the relevant 4STEM factors. The last step is to carry out a redesign with the help of the assessment results, if necessary.

The next paragraph explains the activity plan in more detail. Step 1 is basic information about the author (designer, teacher, researcher, etc.), a short description of the activity (summary) and selecting the kind of educational robotics activities (workshop, competition, research or other). Step 2 includes the domains with the selectable alignment of the curriculum (NO; if the scenario is not aligned with the curriculum and YES if it is) and selectable domains (e.g. Science, Technology, Business, Engineering, Arts, Mathematics, and more) with weightings. Step 3 is called “Learning outcomes” with selectable objectives and skills, for example collaboration, creativity, teamwork, critical thinking or problem solving. Step 4 is called “Interaction during the activity” with fields for action, relationships, roles in the group and support by the tutors. Step 5 is called Artifacts, with a short description of digital and robotic artefacts. Step 6 is divided into two parts. The first part is called “Who? Where? How long?” and is divided into three sections. The first section includes information about the time required, the second section includes information about the students and the third section includes information about the space. The second section is called “Social Orchestration” and includes information about the population and grouping. The activity plan template is constructed with activity blocks from 10 minutes to 1 or 2 hours [101].

What has not been clarified is the process of the design. Therefore, five phases are being developed for designing educational robotics activities based on the related work and the framework. The first step in designing an activity is to select educational robotic equipment. The second step is to design an activity plan. Then the activity blocks as well as the necessary teaching materials are created in line with the AVIVA model, problem-based learning and the constructionism approach. The assessment of the educational robotics activities is carried out with an evaluation package which includes the 4STEM factors (see in Figure 2.4).

2.4.4 Evaluation package to assess the impact of educational robotics activities at the interest in STEM

Robotics offers a platform with the potential to excite students, encourage their STEM learning, and attract them into technological careers [102]. An improvement in educational robotics activities is needed along with a clarification of the evaluation package for educational robotics activities [85]. This approach includes an assessment with quantitative methods of the impact of educational robotics activities to encourage interest in STEM. Interest in STEM was assessed with the evaluation tool package from Girvan and Todorova (2018) [19]. This tool kit was used in educational robotics activities at workshops. Each student is randomly allocated a student number before the workshop and fills in the pre- and post-questionnaires. The participants fill in the pre-questionnaires before and the post- questionnaires after the workshops. The pre-questionnaires with a 5-point Likert scale (ordinal) contain 49 items and the pre-questionnaires with Yes and No answers (nominal) contain 2 items. The post-questionnaires with a 5-point

Likert scale (ordinal) contain 25 items and the post-questionnaires with multiple answers (Yes/Nominal) contain 16 items. The participants gave feedback after the workshop a feedback in the form of stars. The best score was five stars. The first step was to select the necessary items to measure the students' interest in STEM and the change which occurred in their interest in STEM.

Table 2.5: Pre-questionnaires with a 5-point Likert scale containing items to evaluate the students' interest in STEM before the educational robotics workshops.

No.	Items	No.	Items
1	I like science.	14	Maths is the most interesting subject in school.
2	I like maths.	15	Maths is important to learn.
3	I want to understand more about mechanical things.	16	Most of my friends are good at maths.
4	I like using computers.	17	Science is the most interesting subject in school.
5	I like learning about how things work.	18	In general I find science easy.
6	In general I find maths easy.	19	Science lessons are boring.
7	Maths lessons are boring.	20	We have fun in science lessons.
8	We have fun in maths lessons.	21	Science is important for the job I want to do.
9	Maths is important for the job I want to do.	22	My teacher thinks I am good at science.
10	My teacher thinks I am good at maths.	23	I think science is difficult.
11	I get good grades in maths.	24	Science is important to learn.
12	I think maths is difficult.	25	I get good grades in science.
13	I have to work on my own in maths.	26	Most of the students in my class are good at science.

Girvan (2018) identified 26 items from the PRE-questionnaires with a 5-point Likert scale to evaluate their interest in STEM (see Table 3.5) [103]. The selected items from the post-questionnaires are only from the multiple answers (nominal) and there are ten of them 3.4.

These selected items are the basis for the development of a useable evaluation package to assess the impact of educational robotics activities on the interest in STEM among students. The assessment the of best-of educational robotics activities will be evaluated in relation to these quantitative items and is defined by

Table 2.6: POST-questionnaire items with response options (Yes/No) for the evaluation of the students' interest in STEM after the educational robotics workshops.

No.	Items	No.	Items
1	I am now more interested in studying science.	6	I understand how important maths is.
2	I am now more interested in learning about how things work.	7	I understand how important science is.
3	I think I am good at maths.	8	I would like to learn more about programming.
4	I think I am good at science.	9	I would like to learn maths in robotics workshops like this one.
5	I like using computers.	10	I would like to learn about science in robotics workshops like this one.

the greatest change in students' interest in STEM, their interest in studying STEM in the future and the impact of the 4STEM factors. The number of items in the evaluation package will be reduced in order to have a practically usable evaluation package.

2.5 Conclusion

Educational robotics is a proven and innovative teaching tool and learning environment to foster interest in STEM. The related work provides the basis for a framework for sharing and comparing educational robotics activities in the STEM field. It answers the RQa_1 as follows: the framework needs to be based on a theoretical background with a constructionism approach, a teaching strategy with a problem-based learning approach and a standardized structure with the AVIVA model. All educational robotics activities in this thesis were designed against this background. RQa_2 is also answered with the factors (4STEM) which positively influence the interest in STEM. The thesis identifies four factors which are referred to as 4STEM factors, which are out-of-school activities, positive identification with role-models, hands-on activities and increasing self-efficacy. The current framework includes an activity plan, activity blocks and an evaluation package. These answers are recommendations for objective a, the development of a conceptual framework for sharing and comparing educational robotics activities in the STEM field. The necessary items about levels of interest in STEM before and after educational robotics activities were filtered out from the current evaluation package by Girvan and Todorova (2018) and form a basis for reducing them to form a practically usable evaluation package. This is the first step towards answering the research questions in objective b. The development of the framework to foster interest in STEM via educational robotics activities is based on this related work and is shown in chapter 5. An evaluation package focused on the 4STEM factors and with a minimum level of costs is shown in chapter 3.2. The conceptual framework (C4STEM) with an activity plan, activity blocks and a valid assessment is presented in the next chapter.

3 C4STEM framework with an evaluation package

This chapter presents a conceptual framework with an evaluation package for assessing educational robotics activities related to the objectives of chapter 2 within the C4STEM framework. The framework includes a theoretical background and relevant factors to positively increase students' interest in STEM. The theoretical background is based on a constructionism approach, a teaching strategy with problem- based learning, and for a standardized structure the AVIVA Model (see chapter 2). The relevant factors (4STEM) are out-of-school activities, positive identification with role models, hands-on activities and increasing self-efficacy (see in table 2.3). The framework is divided into two parts. The first part offers a structure with a standard template (see section 3.1). This template is an activity plan with an activity block template. The activity plan template provides a standardized structure for the comparison of different educational robotics activities and the activity block template a framework for comprehensible pedagogical interventions. The second part offers an evaluation package to assess the impact of educational robotics activities and gives an answer to the research question RQb_1 (see in section 3.2). This evaluation package evaluates the effect of educational robotics activities on interest in STEM, Robotics self-efficacy, role models, hands-on activities and the STEM careers of students.

The educational robotics activities in the Phase 2 (see section 5) are designed and assessed with this C4STEM framework. The assessment provides information about students' interest in STEM and STEM careers, and the results of these examples of educational robotics activities can be shared with the community.

The requirements for the C4STEM Evaluation Framework are:

- A standard template for developing educational robotics activities
- An evaluation tool to assess the effect of educational robotics activities

3.1 C4STEM activity plan template

This section presents a standard template for assessing and developing educational robotics activities. This standard template is the C4STEM activity plan including an activity plan template with activity blocks. It is a template for planning educational robotics activities with a standardized structure to compare the effect of different workshops with the option to implement them with different variables in a repository (seen Figure 3.1).

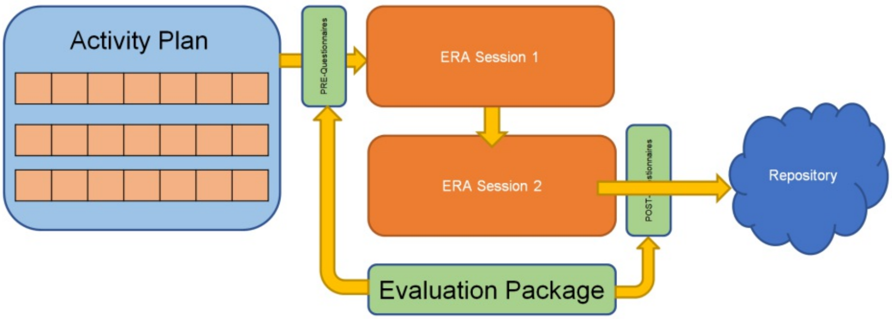


Figure 3.1: The C4STEM activity plan structure offers the possibility of implementation in a repository. The figure shows the process from the design to the evaluation and implementation in a repository.

The C4STEM activity plan template contains information about a title, the authors, a short description of the educational robotics activity, the time requirements, the learning materials and artefacts, and space info (see Table 3.1), activity blocks as a schedule of the session and an appendix of the workshop materials. The session can last 2 to 4 hours and the appendix includes work sheets, information sheets and presentation slides.

The requirements for the C4STEM template are that you can define and select different activity blocks in different rows, that you can implement the activity blocks in a repository and that you can change interventions by changing the row or the duration of the activity blocks. This enables a comparison of the performance of different workshop designs. The activity block template is a table with general information about tutors (teachers, trainers) who lead the educational robotics activities, the space info and the age group. Every line is divided into seven columns (parameters) for the detailed description of different activity blocks (see Table 3.2).

The seven parameters are an AB code number, the duration in minutes, the name of the block, the targets, student activities, tutor activities and materials. Every session is designed separately with an AB. The teachersâ€™ activities are seen as pedagogical interventions (see Table 3.3).

Table 3.1: The C4STEM Activity Plan is structured with six parameters and provides all necessary information about the educational robotics activity which have been developed.

Name	Description
Title	Include the title of the activity as it is presented to the students.
Author(s)	Name(s) of designer(s).
Short description of the ERA	Include a short description of the ERAs so that it becomes clear the theme of the activity, the problem to solve with robots and the fosters skills and interests.
Time	Duration (e.g. 4 weeks), Duration of Sessions (e.g. 2 hours per session), Number of sessions.
Learning Materials/Artifacts:	Digital Artifact: programming language (e.g.: Blockly, Python, Aseba), robot simulation (Thymio Suite, Scratch) Robotic artifact: kind of educational robots (e.g.: Thymio, HedgeHog) Student's workbook and manual: e.g.: Worksheets, Infosheets Teacher's instruction book and manual: e.g.: Presentations.
Space Info	e.g. computer lab, technology lab, robotic club, classroom.

Table 3.2: The C4STEM Activity Block Template includes information about the tutors, about the space, the age group, the date of the session, an Activity Block (AB) code, the duration of the AB in minutes, the name of the AB, a goal related to the 4STEM factors, student and tutor activity during the AB and materials.

	Tutors:			Space info:		
	Age Group:			Date:		
AB Code	Duration [min]	Name	Goal	Student Activity	Tutor Activity	Material

The different goals of the Activity Block Template are linked with pedagogical interventions. The C4STEM Activity Plan Template provides standardized documentation to compare the impact of different interventions on interest in STEM in educational robotics activities. The next section presents the C4STEM Evaluation Package to assess the impact of different interventions and the goal of increasing the interest in STEM through educational robotics activities.

Table 3.3: The figure shows a description of the parameters for activity block templates.

Parameters	Description
Activity Block Code	The code consists of two numbers. (E.g.: 0-2, 1-2, 2-3) The first number is the information about the kind of activity. 0 - Periodical activities with all people (e.g. breaks, discussion in plenum for construct and co-construct the student ideas, etc.) 1 - Instructionism-oriented activity. (e.g.: introduction, lectures, etc.) In this activity, the teachers more active than the students. 2 - Constructionism-oriented activity (e.g., solve problems, robots in a line, etc.) At this activity are the students more active than the teachers.
Duration	The activity blocks can be designed in intervals of five minutes (e.g., 5, 10, 15, 20).
Name of the AB	Every AB receives a specific name.
Goal	The selected goal should be linked with an quantitative or qualitative evaluation tool (e.g., positive achievement with robots, positive achievement in STEM field, increase the Robotics Self-Efficacy, positive relationship with a role model, positive attitude in robotics, etc.).
Student Activity	This parameter describes the activity of the student in this block.
Teacher Activity	This parameter describes the activity of the teacher in this block.
Material	The materials are teaching materials (e.g., PPT, Thymio Suite, Thymio, information sheets, worksheets, etc.).

3.2 C4STEM evaluation package

This section presents the C4STEM Evaluation Package for quantitative data with questionnaires before and after the educational robotics activities and for qualitative data with semi-structured interviews with focus groups. The evaluation employs a mixed methods approach which allows the activities to be analysed in depth. This makes it possible to identify best practice examples which can be used for activities in robotics workshops in the future to increase the interest in STEM. The evaluation process starts with questionnaires at the beginning of every workshop. Every student is anonymised with an ID number and fills out a questionnaire. After the workshops, the students fill out another questionnaire and a focus group of the students gives an interview. The data analysis is divided into the two fields of quantitative and qualitative data. The quantitative data from the questionnaires can be analysed with the SPSS 25 software program. The questionnaires at the beginning of the workshop provide information about gender, age, personal experience with robotics and programming, interest in STEM and the Robotics Self-Efficacy (RSE) score. The questionnaires after the workshop provide information about how the workshops increase the interest in STEM and robotics self-efficacy, how the role model fosters students' interest in a STEM career and the effect of hands-on activities on their interest in a STEM career. The interview gives in-depth information about what works during the educational robotics activities, how and why. All of the data will be analysed based on the approach of design-based research [104] and mixed methodology [105].

3.2.1 C4STEM evaluation package for quantitative data

The goal of the evaluation package is to assess the performance and the pedagogical interventions of different educational robotics activities with quantitative data. This evaluation provides a comparison of the results with similar age groups or previous experience in the field of robotics. The educational robotics activities are workshops and the quantitative data are collected with questionnaires before and after the workshops. The goals of the workshops are to increase the **interest in STEM**, the **robotics self-efficacy** and the **interest in STEM career**. The evaluation of the students' interest in STEM and Robotics self-efficacy takes place before and after the workshops. The evaluation of the interest in STEM careers occurs after the workshops. The pedagogical interventions in workshops are about **positive relationship** and **hands-on activities**. These pedagogical interventions are evaluated after the workshops. The section starts with an explanation of the meta-data with the PRE-questionnaires, followed by the items to evaluate the interest created in STEM and robotics self-efficacy by the workshops with the PRE and POST-questionnaire. The next explanation is about the items used to evaluate interest in a STEM career and pedagogical interventions with the POST-questionnaires.

Meta-Data

The PRE-questionnaire before the workshops evaluates the meta-data such as gender mix, age, school type and migration background. Experience with robots and programming are measured with yes and no. After the evaluation of the meta-data, the next step is to evaluate the students' interest in STEM with 5 items and their robotics self-efficacy with 10 items (see Table 3.4). These items can be answered on a 5-point Likert scale.

Table 3.4: The index measures the positive influence of educational robotics activities in interest in STEM and robotics self-efficacy.

Index	Description	No.Items
STEM-Index	The interest in STEM before the workshop.	5
RSE-Index	The robotics-self-efficacy before the workshop.	10

Interest in STEM

A STEM index is developed to compare students' interest in STEM before and after the workshops (see Table 3.5). The hypothesis is that the educational robotics workshops positively influence students' interest in STEM; therefore, the STEM index should be higher after the workshops than before the workshops.

Table 3.5: The STEM index measures students' interest in STEM.

Items	Statement	Datatype
STEM-1	I like using a computer.	Ordinal (5-Likert)
STEM-2	I like to research and discover.	Ordinal (5-Likert)
STEM-3	I like math.	Ordinal (5-Likert)
STEM-4	I like science.	Ordinal (5-Likert)
STEM-5	I want to understand how technical things work.	Ordinal (5-Likert)

The STEM index is the sum of the five items from Table 3.5 and informs about the change of students' interest in STEM. The next index measures the robotics self-efficacy.

Robotics self-efficacy

Robotics self-efficacy (RSE) is measured with a robotics self-efficacy scale related to the self-efficacy scale of from Beierlein [106] and is a standard test which measures the confidence and resilience of students when solving problems with robots. The goal is to increase this self-efficacy during the workshop sustainably in order to encourage students towards a more active interest in STEM fields and thus to empower them as makers and developers. The RSE has been developed to compare the value of RSE before and after the workshops. It assesses the changes in students' robotics self-efficacy through the workshops.

The Robotics self-efficacy index is the sum of the ten items from Table 3.6. The quality of the evaluation tool is proven with the Cronbach's Alpha value with a

Table 3.6: The Robotics self-efficacy index assesses the confidence and resilience of students in solving problems with robots.

Items	Statement	Datatype
RSE-1	I'm confident that I can program a robot.	Ordinal (5-Likert)
RSE-2	I'm sure I can build a robot.	Ordinal (5-Likert)
RSE-3	It's easy for me to understand the parts of a robot.	Ordinal (5-Likert)
RSE-4	It would not give me any difficulties to let a robot drive along a line.	Ordinal (5-Likert)
RSE-5	If I don't know what to do, I'll find a way to control the robot.	Ordinal (5-Likert)
RSE-6	I can create a robot that solves other people's problems if I effort.	Ordinal (5-Likert)
RSE-7	I will work well with robots when I have a chance.	Ordinal (5-Likert)
RSE-8	I am someone who immediately solves robotics tasks.	Ordinal (5-Likert)
RSE-9	I think that I will be able to do everything that a robotics researcher has to do.	Ordinal (5-Likert)
RSE-10	I'm the one who will explain how robots work.	Ordinal (5-Likert)

result of $\alpha > 0.8$ being good and $\alpha > 0.7$ still being acceptable [107]. The statistical analysis in one study shows that the internal consistency of the questionnaire is significant with an $\alpha = 0.842$ [108]. Self-efficacy is an important factor in students' beliefs about solving problems. The RSE index shows the influence of educational robotics activities on the robotics self-efficacy of students before and after educational robotics activities. It is a figure which illustrates the beliefs of students in their ability to solve problems in the field of robotics. The goal is to increase the value of RSE through educational robotics activities.

Positive relationship

The role model index measures the tutors' impact as role models regarding the students' thoughts on following a STEM career after the workshops.

The Role model index is the sum of the 3 items in Table 3.7. The statistical analysis shows an $\alpha = 0.782$. The tutors' task is to establish a positive relationship with students. This relationship is based on their technical background and

Table 3.7: The Role model index assesses the impact of tutors on students' STEM careers.

Items	Statement	Datatype
Rol-1	The tutor is a role model for me.	Ordinal (5-Likert)
Rol-2	The tutor has motivated me towards more interest in technology.	Ordinal (5-Likert)
Rol-3	The tutor motivated me to go for technical education.	Ordinal (5-Likert)

biographies. Students will learn about new biographies and entry points into the world of technology and robotics. Students come with a stereotypical image of engineers, but the introduction of the tutors and their positive relationship to them give students new impressions and biographies in the field of engineering. As role models, the tutors help students to imagine and achieve a future in the field of robotics and technology.

Positive Achievement with Hands-on Activities

The Robotic activity index assesses how it was for the students to work with robots after the workshops (see Table 3.8 and and shows the effect of hands-on activities in the educational robotics activity.).

Table 3.8: The Robotic activity index assesses the impact of hands-on activities with robots on students.

Items	Statement	Datatype
Rob-1	Working with robots during the workshop was interest.	Ordinal (5-Likert)
Rob-2	Working with robots during the workshop was difficult.	Ordinal (5-Likert)
Rob-3	Working with robots during the workshop was fun.	Ordinal (5-Likert)

The statistical analysis of the POST Robotic activity index shows an α=0.450. This Cronbach's alpha value is too weak to create an index with these items, which is why the items have to be evaluated separately (as in Section 4.5). The goal of educational robotics activities are that the students have fun and at the same time become interested in working with robots. The pedagogical intervention is to design tasks with hands-on activities and give students the space to have fun in the field of robotics. Students are guided towards engaging in robotics tasks in the future.

Interest in a STEM career

For a better understanding, the topic of interest in a STEM career is split into three different indices. The first index is the Study STEM index and assesses the effect of educational robotics activities on students' interest in studying subjects in the STEM field in the future after the workshop with three items. These items to evaluate students' interest in studying STEM in the future after the workshop can be seen in Table 3.9.

Table 3.9: The Study STEM index assess the interest to study in STEM after the educational robotics activities.

Items	Statement	Datatype
Study-1	I am now more interested than before in studying something with science.	Nominal (Yes/No)
Study-2	I am now more interested than before in studying something with computer science.	Nominal (Yes/No)
Study-3	I am now more interested than before in studying something with technology.	Nominal (Yes/No)

The Study STEM index is the mean of the three items from Table 3.9. The goal of educational robotics activities is to influence students to study subjects in the STEM field in the future. The second index is the STEM Imp index which assesses students' understanding of the importance of the STEM field with three items. The items can be seen in Table 3.10.

Table 3.10: The STEM Imp index assesses students' understanding of the importance of the STEM field after the educational robotics activities.

Items	Statement	Datatype
STEM-Imp-1	I understand how important mathematics is.	Nominal (Yes/No)
STEM-Imp-2	I understand how important natural sciences (physics, biology, chemistry) are.	Nominal (Yes/No)
STEM-Imp-3	I now understand better how important technology is.	Nominal (Yes/No)

The STEM Imp index is the mean of the three items from Table 3.10. The STEM Imp index shows the influence of the educational robotics activities on students' understanding of the importance of STEM. The third index is the Robotics Future index and assesses students' interest in building, programming and learning with robots, and in learning more about programming. This index assesses their motivation to work with robots in the future and is measured with three items as seen in Table 3.11. The third index is the Robotics Future index and assesses students' interest in building, programming and learning with robots in the future with three items. The items can be seen in Table 3.11.

Table 3.11: The Robotics Future index assesses students' interest in building, programming and learning with robots in the future after the educational robotics activities.

Items	Statement	Datatype
Rob-Fut-1	I would like to build and program robots in the future.	Nominal (Yes/No)
Rob-Fut-2	I want to use robots in the future to learn new things.	Nominal (Yes/No)
Rob-Fut-3	I would like to learn more about programming.	Nominal (Yes/No)

The Robotics Future index is the mean of the three items from Table 3.11. The index informs us about the effect of educational robotics activities on students working and learning with robots in the future. The next section offers an in-depth evaluation package for the case studies with qualitative data collected by means of semi-structured interviews.

3.2.2 C4STEM evaluation package for qualitative data

The qualitative data are collected by a focus group with a semi-structured interview after the educational robotics activities. A focus group consists of two or more students together in an interview setting. The first step is to turn on the recording device when meeting with all interviewees and informing them about anonymization and confidentiality. The interviewees will need time to reflect on and talk about their experiences. The question about whether anything is unclear is asked only after the conclusion of the narrative. The interview questions from Table 3.12 can be extended depending on the respective interview situation and interests of the student.

After the interview, the recording must be saved and will be sequentially transcribed for the case study. The results provide information about the effect of the activities during the workshop, the learning strategies of students and their interest in STEM after educational robotics activities.

Table 3.12: Questions for a semi-structured interview after the workshops.

Parameters	Description
Previous Experience	Did you visit a workshop like this one? Did you know these tasks?
Activities during the workshop	What did you do during the workshop?
	What was the biggest challenge for you?
	What was the most interesting thing for you?
	How was the work with the robot or program in the workshop?
	What would you change in this workshop?
Learning strategies	What did you need for solving the problems? (Skills, Content)
	How did you solve the problems?
Interest in STEM	Were you already interested in technical things or robotics before the workshop?
	Which STEM fields are you more interested in after this workshop? (Science, Technology, Engineering or Mathematic) Why you are more interested?
	How you are interested in technology and robotics after the workshop?
	Do you think that robotics workshops could also foster their interest in the STEM fields among other students? Why?
	Could you now imagine yourself more likely to work or study in the STEM field?

3.3 Conclusion

The C4STEM Framework with the evaluation package is developed on the basis of the results and answers to the research questions RQa_1 and RQa_2 and provides a standardized template for designing and assessing educational robotics activities. The current activity plan is extended with activity blocks and parameters. It enables the design of educational robotics activities with 4STEM factors that influence students' interest in STEM. The C4STEM evaluation package adopted several items from the current evaluation package in the context of interest in the STEM field. The thesis modified the items about interest in STEM in indices like the STEM index, and extended items for the Study STEM index, the STEM Imp index and the Robotics Future index. The newly-developed items are related to the 4STEM factors and are described as the as RSE index and the Role model index. The C4STEM evaluation package answers the research question RQb_1 with a different index to assess the impact of these factors quantitatively and qualitatively. This information supports a better understanding and optimization of educational robotics activities for the educational robotics community. The C4STEM evaluation package provides information on the results compared to another gender, age group or the previous knowledge of students. It offers information for redesigning and optimizing the different educational robotics activities. The next chapter illustrates a research design for developing a framework and evaluation tool for educational robotics activities in the STEM field in three phases. The first phase (pilot study) analyzes the current activity plan template and evaluation package in the STEM field and makes recommendations for the Phase 1 of the research results (see chapter 4). The Phase 1 develops the evaluation tool in relation to the recommendations of the pilot study. The last phase (Phase 2) assesses and compares educational robotics activities with the C4STEM framework and evaluation package (see chapter 5).

4 Research design

This chapter presents the research design for developing an evaluation tool to assess the impact of educational robotics activities on students' interest in STEM. The aim is, on the one hand, to modify the current activity plan and evaluation package from chapter 2.4 with the 4STEM factors from chapter 2.3 and to reduce the number of items, and on the other hand to reduce the effort required from students to fill in the questionnaires with a useful evaluation tool, and also to achieve a minimisation of costs for stakeholders. Section 4.1 provides an overview of the evaluation process and the data management. The different samplings for the different evaluation phases are explained in section 4.2. The research design is divided into three study phases see Figure 4.1. The pilot study (see section 4.3) analyzes the current activity plan template and evaluation package and gives recommendations for the development of a useful evaluation tool (see chapter 2.4), the Phase 1 (see section 5.1) develops a conceptual framework with a useful evaluation package and a minimum of costs, and the Phase 2 (see section 5.2) tests the package with a comparison of different educational robotics activities and gives an answer to the RQb_2.

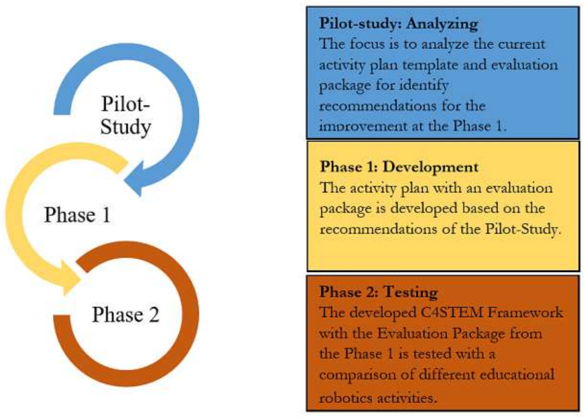


Figure 4.1: The research design is based on three phases. The Pilot study analyzes the current activity plan and evaluation package and gives recommendations for the Phase 1, which develops a conceptual framework and evaluation package. The Phase 2 compares different educational robotics activities and answers the RQb_2.

4.1 Evaluation Process and Data management

The evaluation process in all studies is based on the approach of design-based research [104] and mixed-methods [105] and is shown in Figure 4.2. Each evaluation provides meta-data from students. They are gender, age, native language, experience with robots and programming before the educational robotics activities. Additional data are modified to the specific sampling and explained in the different studies. Evaluations are obtained through multiple data sources, such as questionnaires, group interviews and learning artefacts. The evaluation process starts with questionnaires at the beginning of every workshop and ends with questionnaires. Every student is anonymized with an ID number and fills out a questionnaire.

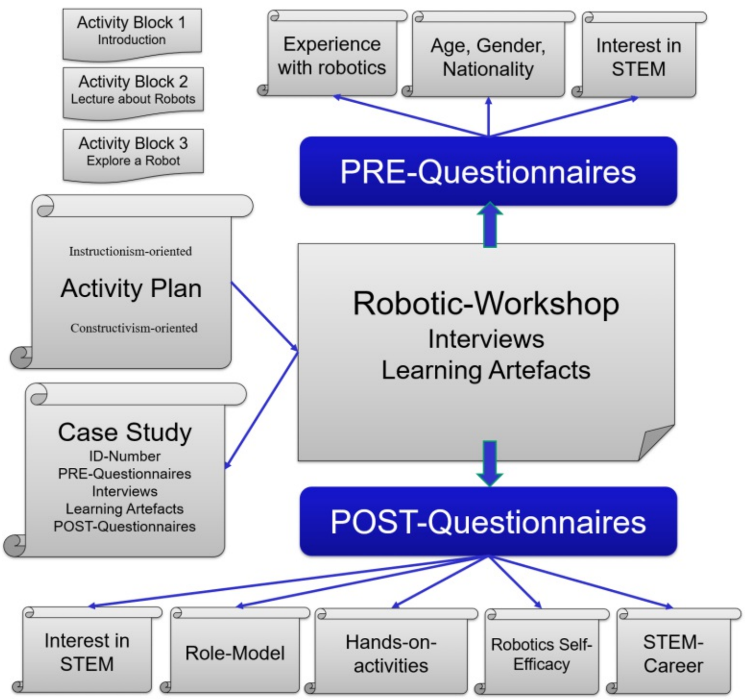


Figure 4.2: The evaluation process in all studies is based on quantitative methods with PRE- and POST-questionnaires and qualitative methods with interviews and learning artefacts.

The evaluation process follows a data management plan with ethical principles and data protection. The names of the students were not included in the raw data (for example on a questionnaire). Each participant was randomly assigned a student number (ID number) before the workshop and asked to use it on the questionnaire and other written materials. This ID list was recorded and kept separate from the assessment data according to the Austrian Data Protection Act for the processing of personal data. Students were given full anonymity with ID numbers. They have all given their voluntary consent to be a part of the study after their parents had been informed of its purpose and of the possibility to refuse to participate.

When the workshop was carried out in a school, the school gave its consent to carry out the research. Consent for data collection and storage were given by the parents. If a parent did not give consent, no data could be collected from their child. Parents had the opportunity to ask questions about the research before giving consent. Consent for data collection and storage was given by the students. There was an opportunity for students to ask questions about the research before they gave their consent. Consent for data collection and storage was given by the tutors (who conducted the workshop).

4.2 Samplings

All samplings were evaluated with the evaluation process and ethical principles of chapter 4.1. They started with a questionnaire collecting meta-data about the participants. All three study phases were evaluated and assessed in six different samplings in a multiple-case study. Table 4.1 shows these different samplings in different studies.

Table 4.1: Data samplings evaluated in the different phases of studies for developing a conceptual framework with the evaluation package.

Index	Data samplings	Pilot-Study	Phase 1	Phase 2
PS1	ER4STEM	x		
PS2	Makers@School	x		
PS3	iBridge		x	
PS4	Outreach with educational robotics		x	
PS5	Robotic Summer Camp		x	
PS5	RoboCoop		x	
MS1	RoboCoop			x

The next section introduces in detail the pilot study with analyzing the current activity plan template and evaluation package.

4.3 Pilot study: Analyzing the current activity plan and evaluation package

The aim of the Pilot study is to identify recommendations for the improved development of a conceptual framework with an evaluation package to assess the impact of educational robotics activities with a minimum of costs. The Pilot study is divided into three evaluation parts. The first part is to analyze the current activity plan template related to chapter 2.4.3. The second part is to analyze the current evaluation package from chapter 2.4.4 with SPSS 26. The third part evaluates the quantitative and qualitative data of one robotic workshop as a case study with multiple data sources (seen Figure 4.2). It assesses the effect in-depth with SPSS 26 and Maxqda 2018 software. This study formed the basis and makes recommendations for the improved development for the Phase 1 (chapter 5.1).

4.3.1 Pilot study: Samplings

The Pilot-Study use the quantitative data [1] from the workshop series from September 2015 to June 2017 in the ER4STEM Project (PS1) funded by HORIZON2020. The project's context was that many children lose their natural curiosity for how things function and interrelate to each other along the way into their lives as young adults. The Educational Robotics for STEM (ER4STEM) project aims to turn curious young children into young adults passionate about science and technology with a hands-on use case: robotics. The domain of robotics represents a multidisciplinary and highly innovative field encompassing physics, maths, IT and even industrial design as well as social sciences. Moreover, due to various application domains, teamwork, creativity and entrepreneurial skills are required for the design, programming and innovative exploitation of robots and robotic services. Children are fascinated by such autonomous machines. This fascination and the variety of fields and topics covered make robotics a powerful idea to engage with. Young girls as well as boys can easily connect robots to their personal interests and share their ideas through these tangible artefacts. ER4STEM will refine, unify and enhance current European approaches to STEM education through robotics in an open operational and conceptual framework. The concept is founded on three important pillars of constructionism: 1. engaging with powerful ideas, 2. building on personal interests, and 3. learning through making (or presenting ideas with tangible artefacts). The ER4STEM framework will coherently offer students aged 7 to 18 as well as their educators different perspectives and approaches to find their interests and strengths in robotics to pursue STEM careers through robotics and semi-autonomous smart devices. At the same time, students will learn

[1] https://zenodo.org/search?page=1size=20q=er4stem

about technology (e.g. circuits), about a domain (e.g. maths) and acquire skills (e.g. collaborating, coding). Innovative approaches will be developed to achieve an integrated and consistent concept that picks children up at different ages, beginning in primary school, and accompanies them until graduation from secondary school. [2]

Sample of data for the Pilot study PS1:

- Time frame: September 2015 to June 2017
- Type of study: Quantitative method
- Setting: Workshop series for students in a university lab
- Evaluation instruments: Questionnaires
- Participants: 2249
- Environments: Lego WeDO, Botball, Dash and Dot, Thymio, Hedgehog, SLurtles

The Pilot study using the data from the case study of the workshop series took place in June 2017 in the project FFG Makers@School (PS2). The Makers @ School project brings new technologies and the world of makers directly into schools, developing a sustainable environment and robots. The students can go through a complete innovation cycle up to the finished prototype, starting with their own ideas and developing and demonstrating creativity and potential with robots. The students have the opportunity to take a look at the world of research and create their own robots. The Makers@School project also provides a broad platform for the networking of companies and students. [3]

Sample of data for the Pilot-Study PS2:

- Time frame: Sept 2017 to May 2018
- Type of study: Case Study
- Evaluation instruments: Questionnaires, interviews
- Setting: Workshop series for students in PRIA lab
- Participants: 175
- Environment: Hedgehog

[2] https://www.acin.tuwien.ac.at/en/project/er4stem/
[3] https://pria.at/en/education/makersschool/?noredirect=en$_U S$

4.3.2 Pilot-Study: Methodology

The Pilot study is based on a case study with qualitative and quantitative data. This methodology provides a maximum amount of data for analysis and concepts in order to reach a conclusion on whether the claim that educational robotics activities increase students' interest in STEM is confirmed or disputed [109]. The quantitative data analysis uses the data from PRE- and POST questionnaires and for the case study part it uses interviews and questionnaires from a current evaluation package in the context of educational robotics activities [21]. All of the educational robotics activities were designed with the same Activity Plan Template. The questionnaires include meta-data from the participants about gender, nationality, age and experience with robots. The questionnaires for the quantitative part were answered by 2490 students. The students were 50.6% boys and 49.4% girls. Their ages ranged from 6 to 19 years. The questionnaires for the case study were answered by 173 students. The students were 47.4% boys and 52.6% girls. The age range was from 8 to 14 years old. The results confirm the claim that educational robotics activities influence levels of interest in STEM positively and provide recommendations for the Phase 1.

4.3.3 Pilot study: Analyzing the current activity plan template

The Activity Plan Template [21] should be a bridge between theory and practice, an expressive medium for stakeholders (i.e., industry, academia and organizers of educational activities) and an instrument for sharing and communication. It should also involve an understanding of related but different domains. (i.e. Science, Technology, Engineering, Arts and Mathematics). The Activity Plan Template helps members of different disciplines to understand each other's perspectives and knowledge.

The criteria for identifying the impact of the designs as best practice are divided into two categories. One category is prerequisites which should be considered in all educational robotics activities for a comparison. The second category is the main criteria that identify the common ground in educational robotics activities in order to achieve best practice.

The prerequisites criteria are:

- The topic considers concepts related to the subjects: Science, Technology, Business, Engineering, Art, Mathematics or something from another discipline are linked to robotics.
- The activity is designed with constructionist elements. (i.e.: not just presentations).

- The activity is linked to students' or participants' interests.
- The activity considers technology related to educational robotics.
- The main criteria assess the following parameters.

If the prerequisites criteria have been considered in the educational robotics activities, the next step is the main criteria which are defined in the following parameters for best practice:

- Context (place, participants description, theoretical framework).
- Educational activity (Connection with a curriculum, motivation for the activity, description of the activity).
- Tools (Criteria for used technology, type of artefacts produced).
- Evaluation.

The current activity plan offers criteria to design educational robotics activities with the same template and identify the impact as best practice with a context, educational activities, tools and evaluation. It lacks a framework with more details and visible pedagogical interventions and goals. An improvement for a better comparison of educational robotics activities is the extension of the template with activity blocks including pedagogical interventions to foster interest in STEM, plus a standardized structure. These recommendations have to be implemented in the current activity plan for the Phase 1. It has to develop a template with more details such as an activity block, pedagogical interventions and a standardized structure.

4.3.4 Pilot study: Analyzing the current evaluation package

At the beginning of the analysis process the quantitative evaluation with the current evaluation package is improved by reducing the items of the questionnaires in the STEM field and clustering them in sub-fields called tokens to develop a different index. This reduction creates a user-friendly tool for students. The development of different indices creates a user-friendly tool for scientists. The quality of the index is confirmed by the Cronbach's Alpha value with a result of $\alpha > 0.8$ being good, an $\alpha > 0.7$ being still acceptable an $\alpha > 0.6$ being questionable [107].

The responses from 2490 students who participated in robotics workshops are evaluated with these items. At the end a case study is evaluated in detail with questionnaires and interviews in mixed methods for information on how different designs work.

The Pilot study's lead question is "What is students' interest in STEM field before and after the robotic workshops?". The first step was to answer this question with the reducing of the select items from Table 3.5 and Table 3.4 to a minimum and to the relevant items in the STEM field. The selected and relevant items to evaluate interest in the STEM field before the robotics workshop can be seen in Table 4.2. These items are categorized in three subfields which are "Interest in STEM" with the token "PRE-STEM", "STEM for a job" with the token "PRE-STEM-Imp" and the "Study STEM" with the token "PRE-Study-STEM". The first subfield represents personal interest in STEM before the robotics workshops and the last two subfields represent students' interest in STEM career before the robotics workshops.

Table 4.2: Items to analyze the interest in STEM field before the robotics workshops at the Pilot study.

Kind of items	Items	Token
Likert Scale (1 to 5)	I like using computers	PRE-STEM-1
Likert Scale (1 to 5)	I like maths	PRE-STEM-2
Likert Scale (1 to 5)	I like science	PRE-STEM-3
Likert Scale (1 to 5)	I want to understand more about mechanical things.	PRE-STEM-4
Likert Scale (1 to 5)	I like learning about how things work.	PRE-STEM-5
Likert Scale (1 to 5)	Maths is important for the job I want to do.	PRE-STEM-Imp-1
Likert Scale (1 to 5)	Science is important for the job I want to do.	PRE-STEM-Imp-2
Closed-question (Yes/No)	Would you like to study maths when you are older?	PRE-Study-STEM-1
Closed-question (Yes/No)	Would you like to study science when you are older?	PRE-Study-STEM-2

The selected and relevant items to evaluate students' interest in STEM with a minimum of items after the robotics workshops can be viewed in Table 4.3. These items are categorized in four subfields which are "Interest in STEM" with the token "POST-STEM", "STEM for a job" with the token "POST-STEM-Imp", the "Study STEM" with the token "POST-Study-STEM" and the "Robots in the future" with the token "POST-Rob-Fut".The first subfield represents personal interest in STEM after the robotics workshops and the last three subfields represent students' interest in STEM careers after the robotics workshops.

Table 4.3: Items to analyze the interest in STEM field after the robotics workshops at the Pilot study.

Kind of items	Items	Token
Multiple-Answer (Yes)	I am now more interested in learning about how things work.	POST-STEM-1
Multiple-Answer (Yes)	I am good in maths.	POST-STEM-2
Multiple-Answer (Yes)	I am good at science.	POST-STEM-3
Multiple-Answer (Yes)	I understand how important maths is.	POST-STEM-Imp-1
Multiple-Answer (Yes)	I understand how important science is.	POST-STEM-Imp-2
Multiple-Answer (Yes)	I would like to build and program robots problems in the future.	POST-Rob-Fut-1
Multiple-Answer (Yes)	I would like to use robots to learn new things in the future.	POST-Rob-Fut-2
Multiple-Answer (Yes)	I would like to learn more about programming.	POST-Rob-Fut-3
Multiple-Answer (Yes)	I am now more interested in studying science.	POST-STEM-Study-1

The quantitative evaluation of interest in the STEM field is divided into two parts. The first part is the evaluation of the interest in the STEM field before the robotics workshops and the second part is the evaluation of the interest in STEM field after the robotics workshops.

4.3.5 Pilot study: Analyzing interest in STEM field before the robotics workshops

The first step is to analyze the personal interest in STEM in detail and subsequently as an iSTEM index. The next step is analyzing the students' STEM careers with the subfield "STEM for a job" (fSTEM) and "Study STEM" (sSTEM) before the robotics workshops. The analysis is initially in detail and subsequently as an fTSEM and an sSTEM index.

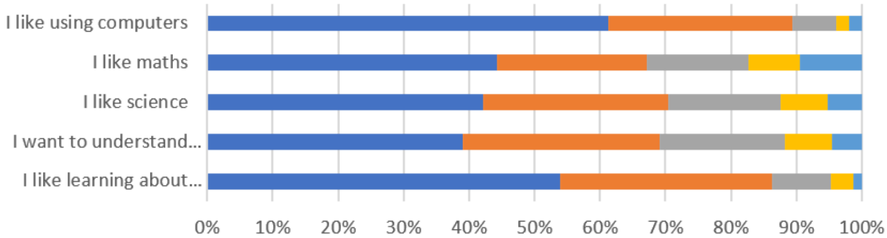
Analyzing personal interest in STEM before the robotics workshops

The first subfield is about personal interest in STEM related to the personal object theory (see chapter 2.1). It includes five items (see Table 4.4).

Table 4.4: The 5 relevant items to evaluate personal interest in STEM before the robotics workshops in the Pilot study.

Kind of items	Items	Token
Likert Scale (1 to 5)	I like using computers	PRE-STEM-1
Likert Scale (1 to 5)	I like maths	PRE-STEM-2
Likert Scale (1 to 5)	I like science	PRE-STEM-3
Likert Scale (1 to 5)	I want to understand more about mechanical things.	PRE-STEM-4
Likert Scale (1 to 5)	I like learning about how things work.	PRE-STEM-5

The items of the evaluation are "I like using computers.", "I like maths.", "I like science.", "I want to understand more about mechanical things." and "I like learning about how things work.". The evaluation in detail led to the following results (see Figure 4.3). Out of 2459 students who responded to "I like using computers.", 61.3% answered strongly agree and 28.1% answered agree. The results show that 89.4% of the students liked using their computer before the robotics workshops. Out of 2449 students who responded to "I like math", 44.3% responded strongly agree and 22.9% responded agree. The results show that 67.2% of the students liked maths before the educational robotics activities. Out of 2448 students who responded to "I like science", 42.2% responded strongly agree and 28.2% responded agree. The results show that 70.4% of the students liked science before the educational robotics activities. Out of 1785 students who responded to "I want to understand more about mechanical things.”, 39.0% responded strongly agree and 30.2% responded agree. The results show that 69.2% of the students want to understand more about mechanical things before the robotic workshops. Out of 1784 students who responded to “I like learning about how things work.”, 53.9% responded strongly agree and 32.3% responded agree. The results show that 86.2% of the students like to learn about how things work before the robotics workshops.



	I like learning about how things work.	I want to understand more about mechanical things.	I like science	I like maths	I like using computers
Strongly Agree	53,9	39,0	42,2	44,3	61,3
Agree	32,3	30,2	28,2	22,9	28,1
Neither	9,0	19,1	17,1	15,5	6,6
Disagree	3,4	7,1	7,2	7,8	2,1
Strongly Disagree	1,3	4,6	5,3	9,5	1,9

Strongly Agree ■ Agree ■ Neither ■ Disagree ■ Strongly Disagree

Figure 4.3: The personal interest in STEM in detail before the robotic workshops in [%] at the Pilot-Study.

The evaluation of the items in Figure 4.3 informs about the students’ personal interest in STEM in fragments. These results show that most students are interested in using a computer and like learning about how things work. Students liked science more than maths before the robotics workshops. The next step is to evaluate the data as an index.

Analyzing the index for personal interest in STEM; iSTEM

The index for interest in STEM (iSTEM) is developed from the items with the token “PRE-STEM” from Table 4.4 (see Table 4.5). The iSTEM index based on data from the sampling with 2490 students and is calculated with the following formula: iSTEM = (I like using computer + I like maths + I like science + I want to understand more about mechanical things + I like learning about how things work). The statistical analysis shows a Cronbach $\alpha = 0.691$ for these five items from the 2490 students.

Table 4.5: The Item-Total-Statistics from the iSTEM index at the Pilot-Study.

Items	N	Mean	SD	Item total correlation	Alpha if item deleted
I like using computers.	1747	4.41	0.86	0.354	0.676
I like maths.	1747	3.75	1.32	0.409	0.668
I like science.	1747	3.85	1.18	0.487	0.622
I want to understand more about mechanical things.	1747	3.92	1.13	0.504	0.614
I like learning about how things work.	1747	4.35	0.87	0.522	0.620

The Cronbach's alpha value is questionable and the results from the last row in 4.5 show no possible improvement if an item is deleted. Our recommendation is to modify the last two items because their meaning is similar. The last item is related to activity in the STEM field. The new statement is "I like to research and discover.". The next section checks the information about the difference in interest in STEM by gender.

Analyzing the gender comparison with the iSTEM index

The aim of the comparison is to analyze the results of gender comparison related to the results of studies in this field. Studies have reported that there is a gender gap in the STEM field (see Table 4.6).

The girls' group (N=875) was associated with an iSTEM index of M=19.61 (SD=3.738). By comparison, the boys' group (N=870) was associated with a numerically higher iSTEM index of M=20.94 (SD=3.407). To test the hypothesis that the girls and boys were associated with a statistically significantly different mean iSTEM index, an independent samples t-test was performed. The independent samples t-test was associated with a statistically significant effect, p=0.000. Thus, the boys were associated with a statistically significantly larger mean iSTEM index than the girls before the robotics workshops.

This result confirmed evidence that boys are more interested in the STEM field than girls. The index provides information about the different levels of interest in STEM by gender and the result confirmed the results of studies that boys are more interested in STEM than girls(Wang and Degol, 2017). The next section compares interest in STEM by age groups.

Table 4.6: Gender comparison with the iSTEM index before the robotics workshops in the Pilot study.

	Gender	N	Mean	Std.-Derivation	Standard error of the mean
Personal Interest in STEM	Girls Boys	875 870	19.61 20.94	3.738 3.407	0.126 0.116

Analyzing the comparison with the iSTEM index by age groups

The age groups were divided into three different groups related to school levels. The groups are a primary group (6 to 10 years old), a lower secondary group (11 to 15 years old) and a higher secondary group (15 to 20 years old). The primary group (N=542) was associated with an iSTEM index of M=21.90 (SD=3.078), the lower secondary group (N=1063) was associated with an iSTEM index of M=19.47 (SD=3.633), and the higher secondary group (N=124) was associated with an iSTEM index of M=19.90 (SD=3.603). The comparison shows that the primary group of students have a higher numerical mean than the other groups. To test the hypothesis that the different mean iSTEM index between the school groups was associated statistically significantly, a one-way between subjects ANOVA was performed. There was a significant difference between the school groups (see Table 4.7). [F (3, 1743)=59.587, p=0.000]

Table 4.7: The school level comparison with the iSTEM index by school level with a one-way ANOVA in the Pilot study.

	Sum of squares	df	Mean of the square	F	Significance
Between the groups	2148.250	3	716.083	59.587	0.000
Within the groups	20946.316	1743	12.017		
Total	23094.567	1746			

This result confirmed evidence that students lose interest as they get older.[why do students lose interest in STEM] The next section analyses interest in STEM careers with the subfields “STEM for the job” and “Study STEM”.

Analyzing interest in STEM careers before the robotics workshops

Interest in STEM careers is analyzed with two subfields. The first subfield is "STEM for a job" and is the understanding of the importance of STEM for students' future jobs and their STEM career. It includes two items (see Table 4.8)

Table 4.8: The two relevant items to evaluate the understanding of STEM for students' future jobs before the robotics workshops in the Pilot study.

Kind of items	Items	Token
Likert Scale (1 to 5)	Maths is important for the job I want to do.	PRE-STEM-Imp-1
Likert Scale (1 to 5)	Science is important for the job I want to do.	PRE-STEM-Imp-2

The second subfield is "Study STEM" and is about interest in studying in the STEM field in the future. It includes two questions (see Table 4.9).

Table 4.9: The two relevant items to evaluate the interest to study a subject in the STEM field in the future before the robotics workshops.

Kind of items	Items	Token
Closed question (Yes/No)	Would you like to study maths when you are older?	PRE-STEM-Imp-1
Closed question (Yes/No)	Would you like to study science when you are older?	PRE-STEM-Imp-2

The items in the evaluation of the subfield "STEM for the job" are "Science is important for the job I want to do." and "Maths is important for the job I want to do". The evaluation in detail gave the following results (see Table 4.10). Out of 2291 students who responded to "Science is important for the job I want to do.", 51.1% answered strongly agree and 19.2% answered agree. The result shows that 70.3% of the students responded that science is important for their job in the future. Out of 2323 students who responded to "Maths is important for the job I want to do", 41.4% responded strongly agree and 16.9% responded agree. The result shows that 58.3% of the students responded that science will be important for their job in the future.

The result shows that most of the students think that science and maths are important for their job in the future.

Table 4.10: The understanding of the importance of STEM for students' future jobs before the robotics workshops in [%] in the Pilot study.

Item	Strongly Agree	Agree	Neither	Dis-agree	Strongly Dis-agree
Science is important for the job I want to do	51.1	19.2	18.4	6.9	4.3
Maths is important for the job I want to do	41.4	16.9	21.0	11.6	9.1

The questions in the evaluation of the subfield "Study STEM" are "Would you like to study science when you are older?" and "Would you like to study maths when you are older?". The evaluation in detail had the following results (see Table 4.11). Out of 2048 students who responded to "Would you like to study science when you are older?", 53.7% answered with Yes and 46.3% answered with No. Out of 2055 students who responded to "Would you like to study maths when you are older?", 51.7% answered Yes and 48.3% answered No.

Table 4.11: Interest in studying a subject in the STEM field in [%] before the robotics workshops of the Pilot study.

Question	Yes	No
Would you like to study science when you are older?	53.7	46.3
Would you like to study maths when you are older?	51.7	48.3

The results show that half of the students would like study in the STEM field when they are older. The recommendation is to use one question "Would you like to study science when you are older?" after the educational robotics activities and extend that with the questions in the context of the field of robotics. The further questions are "I am now more interested than before in studying something with computer science." and "I am now more interested than before in studying something with technology.". The items about the importance of the STEM field had to be evaluated after the activities with a modified data type 'Yes' and 'No'. The statements had to be extended with an item which is more in the context of robotics. The new statement is "I now understand better how important technology is.".

Analyzing index for STEM careers; fSTEM, sSTEM

The next STEM index is an index about students' understanding of the importance of the STEM field for their future jobs (fSTEM) before the robotics workshops. The index helps to identify their change of attitudes towards a STEM career. It can select students with an understanding of the importance of STEM in their future job before the workshop and their interest in studying in the STEM field in the future after the workshop. The fSTEM index is calculated with following formula: fSTEM = (Math is important for the job I want to do + Science is important for the job I want to do). The statistical analysis shows a Cronbach's α = 0.628 for these two items from the 2245 students.

Table 4.12: The item Total Statistics from the fSTEM index in the Pilot study.

Items	N	Mean	SD	Item total correlation	Alpha if item deleted
Maths is important for the job I want to do.	2245	4.05	1.167	0.462	N/A
Science is important for the job I want to do.	2245	3.70	1.347	0.462	N/A

The Cronbach's alpha value is questionable and the results from the last row in Table 4.12 show no possible improvement if an item is deleted. The fSTEM index has to be modified in the Phase 1 with an index in the POST-questionnaire. The next step is analyzing the sSTEM index.

The next sSTEM index is an index about students' interest in studying in the STEM field in the future before the robotics workshops. The index helps to identify their change of attitudes towards a STEM career. It can select students with an interest in studying in the STEM field in the future before and after the workshop. The sSTEM index is calculated with following formula: sSTEM=(Would you like to study maths when you are older? + Would you like to study science when you are older?). In the case of two items, the statistical analysis shows a Cronbach's α = 0.545 from the 1879 students.

The Cronbach's alpha value is questionable and the results from the last row in Table 4.13 show no possible improvement if an item is deleted. The sSTEM index has to be cancelled in the PRE-questionnaires and modified in the Phase 1 with an index in the POST-questionnaire. The modified items are "I understand how important mathematics is.", and "I now understand better how important technology is." with a data type 'Yes' and 'No'.

The analysis of the questionnaire before the workshops shows that the first iSTEM index assesses personal interest in STEM in relation to other studies. The

Table 4.13: The item Total Statistics from the sSTEM index in the Pilot study.

Items	N	Mean	SD	Item total correlation	Alpha if item deleted
Maths is important for the job I want to do.	1879	1.49	0.500	0.374	N/A
Science is important for the job I want to do.	1879	1.47	0.499	0.374	N/A

Cronbach's alpha is weak and the index has to be modified. The fSTEM and sSTEM index has a weak Cronbach's alpha and can just be used to evaluate the items in detail. The recommendation is to include these items and questions before the activities into the questionnaire after the activities. This recommendation results in a better validation for the iSTEM and reduces the items in the questionnaire before the robotics workshops by removing the items of the fSTEM and sSTEM indices from the questionnaire before the robotics workshops.

4.3.6 Pilot-Study: Analyzing the questionnaire after the educational robotics workshops

At the beginning of the analysis this section presents the number of valid answers from the students and shows the results in detail with the items from Table 4.3. The next step is a gender comparison with the items after the robotics workshops. The kind of questionnaires used after the robotics workshops are multiple-answer with "Yes". The students respond to questions on their personal interest in STEM, their understanding of the importance of STEM in the future and their interest in studying in the STEM field and in robots in the future with a multiple answer. 1721 students out of 2490 responded with a valid answer to these items (see Table 4.14).

Table 4.14: The number of responses to the POST items in the Pilot study.

	Cases					
	valid		missing		total	
	N	Percent	N	Percent	N	Percent
POST items[a]	1721	69.1%	769	30.9%	2490	100%

a. Dichotomy group tabulated at value 1

Most of the students, 968 (56.2%) out of 1721, said they would like to build robots to solve problems in the future, and 910 (52.9%) said they would like to learn more about programming. More students think that they are good at maths (50.8%) than in science (48.7%), but more students understand how important science is (35.9%) than how important maths is (34.4%). Fewer students (27.8%) state that they are more interested in studying science (see Table 4.15).

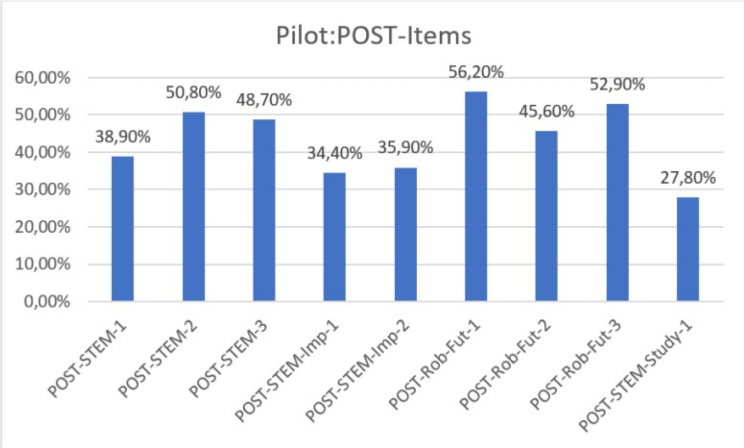


Figure 4.4: Pilot: POST-STEM items

The result in the STEM field maths and science of the POST items is similar to the PRE items result. More students like maths than science in PRE and more students think that they are good at maths rather than in science in POST.

Gender comparison with the POST items

The gender comparison compares all yes statement items from girls and boys (see Figure 4.5). This evaluation is the first step towards identifying the effect of educational robotics activities by gender group. A total of 334 girls and 333 boys responded with yes to the statement "I am now more interested in learning about how things work". This corresponds to 37.8% from the girls' group and 39.8% from the boys' group. This result shows that boys are slightly more interested in learning about how things work than girls. A total of 495 girls and 416 boys responded with yes to the statement "I am good at maths". This corresponds to 52% from the girls' group and 49.8% from the boys' group. This result shows that more girls here think that they are good at maths than boys. A total of 442 girls and 396 boys responded with yes to the statement "I am good at science". This corresponds to 50.1% from the girls' group and 47.4% from the boys' group. This result shows that more girls think that they are good at science than boys. To the statement "I understand how important maths is" 287 girls and 303 boys responded with yes. This corresponds to 32.5% from the girls' group and 36.2%

from the boys' group. This result shows that more boys understand how important maths is than girls. To the statement "I understand how important science is", 320 girls and 296 boys responded with yes. This corresponds to 36.2% from the girls' group and 35.4% from the boys' group. This result shows that more girls understand how important science is than boys. To the statement "I would like to build robots to solve problems in the future", 551 girls and 417 boys responded with yes. This corresponds to 62.4% from the girls' group and 49.9% from the boys' group. This result shows that more girls would like to build robots to solve problems in the future than boys. To the statement "I would like to use robots to learn in the future", 437 girls and 348 boys responded with yes. This corresponds to 49.5% from the girls' group and 41.6% from the boys' group. This result shows that more girls would like to use robots to learn in the future than boys. To the statement "I would like to learn more about programming", 513 girls and 397 boys responded with yes. This corresponds to 58.1% from the girls' group and 47.5% from the boys' group. This result shows that more girls would like to learn more about programming than boys. To the statement "I am now more interested in studying science", 237 girls and 241 boys responded with yes. This corresponds to 26.8% from the girls' group and 28.8% from the boys' group. This result shows that more boys now are interested in studying science than girls.

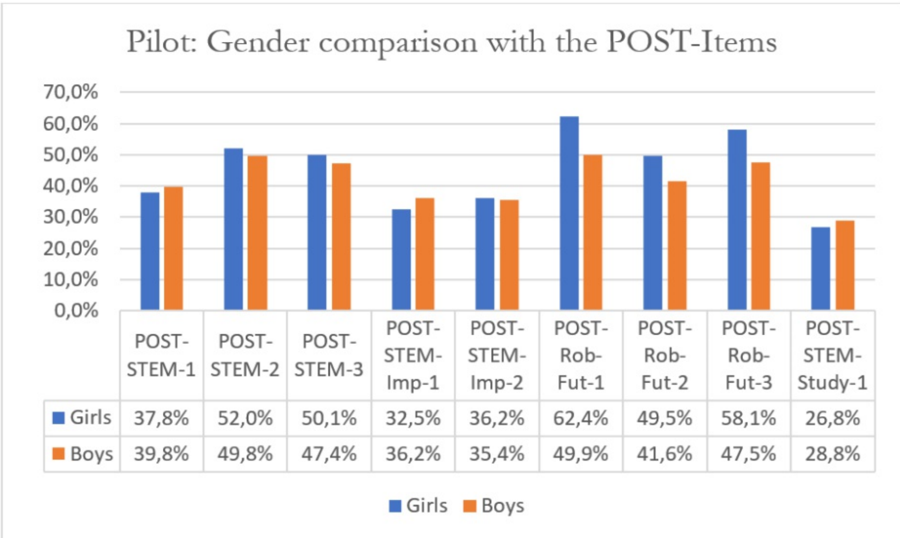


Figure 4.5: Pilot: Gender Comparison with the POST-Items

These results show the effect of all robotics workshops by gender group and the criteria of interest in STEM, understanding the importance of STEM, interest in robots and in studying STEM. The multiple-answer type method is not a useful tool for identifying the impact of educational robotics activities linked with pedagogical interventions. Just one item identifies interest in studying STEM in the future. The recommendation for the Phase 1 is to develop an index for several criteria (interest in STEM, studying STEM and interest in robots) for the POST-questionnaires. The STEM index for the criteria "Interest in STEM" with a 5-point Likert scale has to be included in the PRE- and POST questionnaires. The index for studying STEM has to be extended and checked in the Phase 1. The items for the criterion interest in robots are usable but have to be changed into Yes and No options. The next section shows the evaluation of the impact of educational robotics activities on the interest of students in the STEM field.

4.3.7 Pilot-Study: Analyzing the results of changing the interest in STEM field

This section follows the research question RQb_1: "Which evaluation tool can assess the impact of the 4STEM factors to influence the interest in STEM positively by educational robotics activities?" To this end, the quantitative data from the PRE- and POST questionnaires are compared. The evaluation assesses the students' change in attitude towards STEM. The evaluation verifies the first hypothesis that "Educational robotics activities change students' interest in maths from 'I do not like maths.' to 'I understand how important maths is.' ". The evaluation process begins with the identification of the cases with a low level of interest in STEM in the item PRE-STEM 2 with the responses "strongly disagree, disagree or neither" from the PRE-questionnaires. The selected cases are analysed with the item POST-STEM Imp-1 and the number of cases with the response "Yes" are counted. 804 (32.8%) students responded with "strongly disagree, disagree or neither" to the statement 'I like maths', while 128 (15.9%) of them responded with "Yes" to the statement 'I understand how important maths is.' (see Table 4.15).

Table 4.15: Responses about students' understanding of how important maths is.

		Frequency	Percentage	Valid percentage
Valid	Yes	128	15.9	100
	Absentee	676	84.1	
	Total	804	100	

The first hypothesis is confirmed. Educational robotics activities change levels of interest in maths from "I do not like" to 'I understand how important maths is'. In total, the interest in maths of 15.9% students changed.

The second hypothesis, "Educational robotics activities change students' interest in science from 'I do not like science.' to 'I understand how important science is'."

needs to be verified. The evaluation process begins with the identification of the cases with a low level of interest in STEM in the item PRE-STEM 3 with the response “strongly disagree, disagree or neither” from the PRE-questionnaires. The selected cases are analysed with the item POST-STEM Imp-2 and the number of cases with “Yes” are counted.

726 (29.7%) of students responded with “strongly disagree, disagree or neither” to the item ’I like science’. 121 (16.7%) of them responded with “Yes” to the statement ’I understand how important science is’.

Table 4.16: Responses about students’ understanding of how important science is.

		Frequency	Percentage	Valid percentage
Valid	Yes	121	16.7	100
	Absentee	605	83.3	
	Total	726	100	

The second hypothesis is confirmed. Educational robotics activities change students’ interest in maths from “I do not like maths” to ’I understand how important maths is.’ In total, the interest levels of 16.7% students in maths changed. The final hypothesis, “Educational robotics activities change students’ attitudes from “I will not study science in the future” to “I am now more interested in studying science”, is about STEM careers and therefore this hypothesis is verified. The evaluation process began with the identification of the cases with the response “No” to the item Pre-study-STEM-2. The selected cases are analysed with the item POST-STEM-Imp-2 and the number cases with “Yes” are counted. 726 (29.7%) students responded with “strongly disagree, disagree or neither” to the item ’I like science’, while 121 (16.7%) of them responded with “Yes” to the item ’I understand how important science is.’ The results present the first recommendation for the Phase 1. The selected items can assess the impact of educational robotics activities on interest in STEM. The evaluation package should be provided with a similar STEM index before and after the educational robotics activities for a useful evaluation and subsequent testing of significance. The validation of the index was measured with Cronbach’s alpha. The statistic shows that the iSTEM index of α=0.691 is questionable. The recommendation is to replace the last item with an item in the context of the field of research with the statement “I like to research and discover.”. The results of the gender and age comparison confirms the results from other studies. The evaluation tool is valid in relation to these studies. In addition, it needs items to assess the pedagogical interventions and teaching strategies. The next evaluation shows a case study with quantitative and qualitative data analysis.

4.3.8 Pilot-Study: Analyze the interest in STEM field with a case study

The quantitative evaluation was performed by using the questionnaires which were administered both before and after the workshops. 175 students participated in the workshops. In total, more girls were present in the classes as 91 students were female (52.6%) and 82 were male (47.4%). The workshop series encompassed 83 students from two elementary schools (all around 8 to 9 years old) and 90 from two so-called new middle schools (all around 12 to 14 years old). Many of these students had migration backgrounds from different nations and cultures and a total of 20 different native languages were spoken by the students. Apart from collecting personal information, the questionnaires assessed their interest in STEM, the students' future plans, their experiences with programming and robotics before the workshops, and their attitudes to the subject of STEM afterwards.

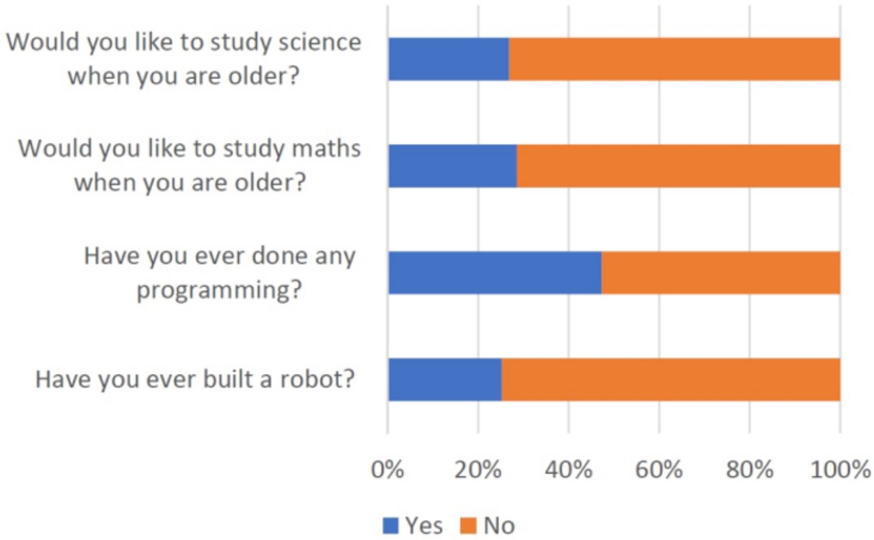


Figure 4.6: Pilot: Results about future plans and prior experience with programming and robotics

Figure 4.6 shows that about 25% of the participants already planned to study maths and science in the future before attending the workshops. About half of the students had already programmed at least once in their lives and about 25% had already built a robot.

The students were also asked about their attitudes to STEM topics (see Figure 4.7). The majority of students had already used a computer and about 70% liked maths and science and viewed science as important; 80% of the students liked to use computers.

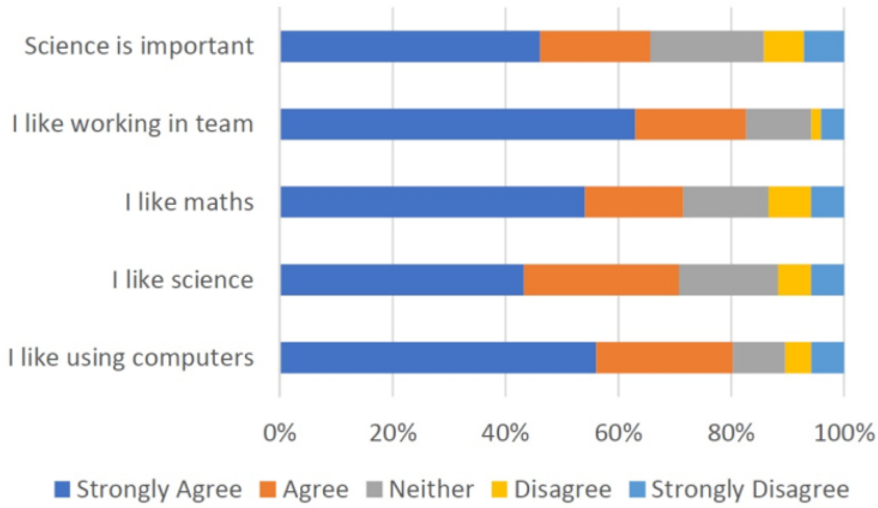


Figure 4.7: Pilot: Results from questionnaires on attitudes to STEM administered before the workshop

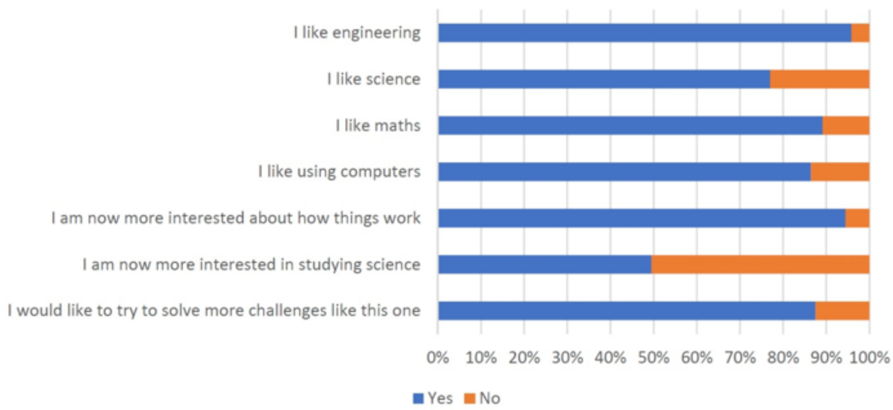


Figure 4.8: Pilot: questionnaires on the students' attitude to STEM topics and future plans

The results of the questionnaire administered at the end of the workshops are shown in Figure 4.8. The number of students who liked maths increased to 89%, and the proportion who liked science to 77%, showing an increase in interest following the workshops. Nearly all of the students had a positive view of the field of engineering after the workshops, and the proportion of students who liked to use computers had increased markedly from before the workshops, to 87%. Almost half of the students were now more interested in studying science and 87% would like to participate again in activities such as those the carried out in the workshops.

Furthermore, of the 21 students who responded to the statement “I like maths” with strongly disagree or disagree before the workshop, 18 responded with “yes” afterwards. Of the 15 students who responded to the statement “I like science” with strongly disagree or disagree before the workshop, 12 responded with “yes” afterwards and six also responded to the statement “I am now more interested in studying science” with “yes”.

The following results of the qualitative method with interviews are based on two educational robotics activities. The workshops A and B provide in-depth results on the experience of the students during the two workshops and on their interest in STEM. Workshop A was attended by 25 elementary school students aged 8 to 10 years and workshop B was attended by 18 elementary school students aged 8 to 11 years. Some s from workshop A stated that the activities with robots generally fostered their interest in engineering, science and maths, and that they found programming cool, as can be seen in the following interview transcription after the workshop:

Interviewer: Ok, do you think the activities with robots today increase the level of interest in engineering, science and maths of other children?
Children 1,2,3: Yes.
Interviewer: And why?
Child 2: ...because it is cool.
Interviewer: Are activities with robots cool?
Child 1: Yes, and if we can do hands-on activities and it functions afterwards, then I like it more if we do more like that.
Interviewer: Ok, if you can do something with your hands.
Child 2: And because children who really like playing with a computer, but their parents stop them, can play with the computer usefully during the workshop.
Interviewer: That is a good point
Child 3: ...and the programming, umm... the robots and the programming.
Interviewer: Programming is cool?
Child 3: Yes

This interview shows that children like hands-on activities combined with robots and that they need their own free learning space to develop their skills during their experience in the workshops. This result confirms the approach of constructionism learning and that it is best if nobody stops the children’s activities, interests and curiosity. In another interview the students from workshop B reported on their positive experience with mathematics during the workshop, and also stated that the workshop would increase the level of interest in mathematics of other children, as can be seen in the following interview transcription:

Interviewer: Ok. And now that you came here and did the workshop, did that somehow change your mind about it?
Child 2: About what?
Interviewer: About technology, science and maths?
Child 2: Yes.
Interviewer: Really?
Child 2: At the beginning I thought it would be boring.
Child 1: Me too.
Child 2: But then I really got to know technology and it's interesting and fun, yes.
Interviewer: Ok, great. Do you think that working with robots would also help other kids become more interested in technology?
Children 1,2: Yes.
Interviewer: ...and science. Ok, why do you believe that?
Child 2: Because many children do not like activities with maths, because it is boring or difficult. But if you become more familiar with maths, you will never forget it, because you just like it.
Interviewer: Mm, so do you have good memories of the workshop?
Child 2: Yes.

This interview shows that the initial expectations regarding the programming workshop were rather low ("boring"), but that then the students were positively surprised and interested in the content. This is a strong indicator that their attitude towards STEM can indeed be positively influenced if content is presented in an attractive way.

This case study presented the results of a case study from two educational robotics activities for primary and middle school students concerned with various activities and technologies of the maker-movement. The constructivist approach to learning in the workshops fosters positive attitudes towards STEM in students and increases their interest in these fields. This was shown by the answers to the questionnaires as well as in the interviews with the students. It can be concluded that the workshop series fosters positive attitudes concerning STEM. Consequently, this is a first step towards a measurement tool for interest in STEM. It can be concluded that the positive experience of the workshops can indeed foster a positive attitude towards STEM. The evaluation package with interviews is an important part of understanding the impact of educational robotics activities in depth.

4.3.9 Pilot-Study:Conclusion and recommendations for Phase 1

The Pilot study analyzes the current activity plan template and reduces the number of items in the current evaluation package to assess interest in STEM. The analyzing process starts with the separate evaluation of the quantitative data with the items from the questionnaires and subsequently with the index which has been created. The results of the index are compared with the gender and age groups. The results of the comparison confirmed the findings of related studies. The case study provides an in-depth assessment of educational robotics for a better understanding of what works to increase interest in STEM.

The recommendations for the Phase 1 are that the activity plan template has to be extended with activity blocks with more details about the pedagogical interventions (see Table 4.3) and a standardized structure (see Table 4.4). The evaluation does not assess the impact of these factors which positively influence interest in STEM. This gap will be bridged in the Phase 1 by assessing the impact of the 4STEM factors related to chapter 2.3. The items for the index about the interest in STEM (iSTEM) must be modified. The number of items stays the same, but the last item should be changed to an activity in the STEM field and reads “I like to research and discover”. The students’ interest in a STEM career is evaluated just after the educational robotics activities. The questions are “I am now more interested than before in studying something related to science”, “I am now more interested than before in studying something related to computer science” and “I am now more interested than before in studying something related to technology.”. The items about students’ understanding of the importance of STEM are “I understand how important mathematics is”, “I understand how important natural sciences (physics, biology, chemistry) are” and “I now understand better how important technology is.” This recommendation leads to a reduction of the items in the questionnaires before the activities. The index for study in STEM, understanding the importance of STEM and interest in building and programming robots in the future has to be extended and checked in the Phase 1. The chapter 5 shows the implementation and checking of these recommendations.

4.4 Conclusion and summary

The research design is divided into three study phases with a mixed-methods approach and offers a data management plan with ethical principles and data protection. The first phase, the pilot study, reduced the items from the current evaluation package to a possible minimum for the assessment of interest in STEM. The analyzing process started with the separate evaluation of quantitative data and subsequently with the created index. At the end a case study was analyzed to assess the effect of educational robotics activities on students' in-depth interest in STEM. The recommendations are to extend the activity plan template with activity blocks which contain more details about the pedagogical interventions and a standardized structure for developing a framework for sharing and comparing educational robotics activities in the STEM field, which is part of objective a. The recommendations for several items and an index will be implemented in Phase 1, which answers the research question RQb_1:"Which evaluation tool can assess the impact of the 4STEM factors to influence the interest in STEM positively by educational robotics activities?" and fosters the development of an evaluation tool to assess the impact of factors which positively influence the level of interest in the STEM field, which is part of objective b (see the next chapter).

5 Research results

This chapter presents the development of an evaluation tool to assess the impact of educational robotics activities on students' interest in STEM in Phase 1 (see section 5.1) and the testing of this evaluation tool with a minimum of costs by using research results in Phase 2 (see section 5.2).

5.1 Phase 1: Development of a conceptual framework with evaluation package

The Phase 1 shows the implementation of a standardized structure in educational robotics activities, the development of an extended activity plan with modified activity blocks in more detail and an evaluation package for assessing interest in STEM, the impact of 4STEM factors (see chapter 2.3) and a STEM career. The activity plan and activity block are extended based on the requirements of the Pilot study, while the analysis of the quantitative data of the evaluation package is carried out with SPSS 26 and the case studies with Maxqua 11. This study provides answers to the research question RQb_1: "Which evaluation tool can assess the impact of these 4STEM factors to influence the interest in STEM positively by educational robotics activities?".

5.1.1 Phase 1: Samplings

The Phase 1 uses the quantitative and qualitative data of the case study from the workshop series from September 2017 to December 2019 in the iBridge project funded by Sparkling Science. The iBridge project is a cross-generational project aimed at increasing the interest of children and students in social and cross-cultural research topics and innovation as well as deepening their relationship with science through the application of robotics in elderly care technologies. For these purposes the children and students will develop innovative "sensitive cuddly animals" as well as other service robots concepts which are already well proven in elderly care. Additionally, the students will support the older generation by providing access to modern technologies through internet courses, learning and paying attention to their needs.[1]

These workshop series took place from September 2017 to December 2019. Sample of data for the Phase 1 PS3:

Time frame: September 2017 to December 2019

Type of study: case study

Setting: Workshop series for students in a university lab

Participants: 356

Environments: Thymio, Pepper

The Phase 1 uses the quantitative and qualitative data of the case study from the workshop series from September 2018 to June 2020 at the outreach program of the automation and control institute at the Technical University of Vienna. Outreach with educational robotics (PS4) has the vision of enlightening all young people about robotic technology and its possibilities. The activities address children from pre-school age to primary school and up to young adults in secondary school and university. Besides content-related knowledge about robotics technology, the focus is on technological literacy, 21st century skills or 4Cs (critical and creative thinking, collaboration and communication), as well as maker, innovator and entrepreneur mindsets. The pedagogical tools are constructionism, project-based learning and design thinking.[2]

Sample of data for the Phase 1 PS4:

Time frame: September 2018 to June 2020

Type of study: Case study

Setting: Workshop series for students in the university lab

Participants: 255

[1] https://www.acin.tuwien.ac.at/en/project/projekt-ibridge/
[2] https://www.acin.tuwien.ac.at/en/vision-for-robotics/outreach-with-educational-robotics/

Environments: Thymio, Pepper

The Phase 1 uses the quantitative and qualitative data of the case study from the workshop series at a Robotic Summer Camp (PS5) in July 2019 at the technical university in Vienna.[3] The slogan of the summer camp was “Robots the way we kids want them to be”. In this summer camp kids slipped into the role of robot researchers. They found out what makes a robot, why a robot is technology, in which areas of application robots can be used, which forms robots can take, and how they work in principle. At the same time, they acquired tools that are needed as robot researchers, e.g. how to check assumptions or how to work out an idea for a solution to a problem. Armed with the new knowledge, children designed robots the way they want them and presented their designs and scientific findings at the end of the camp. It is not only meant to be fun and enjoyable for the kids and teens, but also to teach them technology skills in service robotics and scientific thinking.[4]

Sample of data for the Phase 1 PS5:

Time frame: July 2019

Type of study: Case study

Evaluation instruments: questionnaires, interviews, learning artefacts

Setting: Workshop series for kids and students in a university lab

Participants: 30

Environments: Thymio and Pepper

The Phase 1 uses the quantitative and qualitative data for the case study from the workshop series at the RoboCoop Project (PS6) from February 2019 to January 2020. Educational robotics has proven to be a valuable tool for hands-on learning, not only for robotics itself, but for STEM topics in general. RoboCoop is a unique project aiming to exploit the multidisciplinary potential of robotics and establish cross-border educational activities to stimulate interest in STEM topics. RoboCoop will encourage and engage more than 4,000 students, scholars, and innovative STEM educators on an interregional level to serve as a positive example for broader use on

[3]https://www.m2a-institute.eu/2019/07/12/tu-wien-summer-camp-2019/
[4]https://www.m2a-institute.eu/2019/06/06/tu-wien-summer-camp/

a national level in the two countries. In addition, a comprehensive evaluation of all project activities will lead to policy recommendations to ensure the systematic and long-term implementation of project ideas, leading to early adoption of robotics topics at the secondary level.[5]

Time frame: February 2019 to January 2020

Type of study: Case study

Evaluation instruments: questionnaires, interviews

Setting: Workshop series for students in a university lab

Participants: 352

Environments: Thymio, Hedgehog, BBC Micro Bit

5.1.2 Phase 1: Methodology

The Phase 1 used quantitative and qualitative data with a mixed methods approach. This methodology supports the development of and understanding of the effect of educational robotics activities. The development of the evaluation package is based on design-based research and provides an assessment and comparison of the effect of different educational robotics activities. The quantitative data are analysed with SPSS26 and the case studies are analysed with Maxqua 11. The results of the Phase 1 are the basis for the testing phase in the Phase 2.

5.1.3 Phase 1: Developing a standardized structure for educational robotics activities

This section shows the first case study of educational robotics activities with a standardized workflow related to the AVIVA model. The design of the workshops is based on the didactic AVIVA model, which is a model for classroom management and lesson planning in schools (see Figure 5.1). This model is linked to the real world of the students and combines instruction with the application of knowledge. The last phase enables the evaluation of the different goals of the workshop. This alternation from instruction to construction is a perfect framework for a robotics

[5] https://www.acin.tuwien.ac.at/en/project/robocoop/

workshop, because one of its goals is to pass on information about technical knowledge and robotics and to achieve a better result in terms of acquisition of knowledge. Moreover, the students have a part to play in applying this knowledge. This model includes five different phases, although individual parts can be used in multiple ways, meaning that not all phases have to be performed. The different five phases are called, in the order which they take place: “arrive, activate previous knowledge, instruction, construction or application, and evaluation” [110]

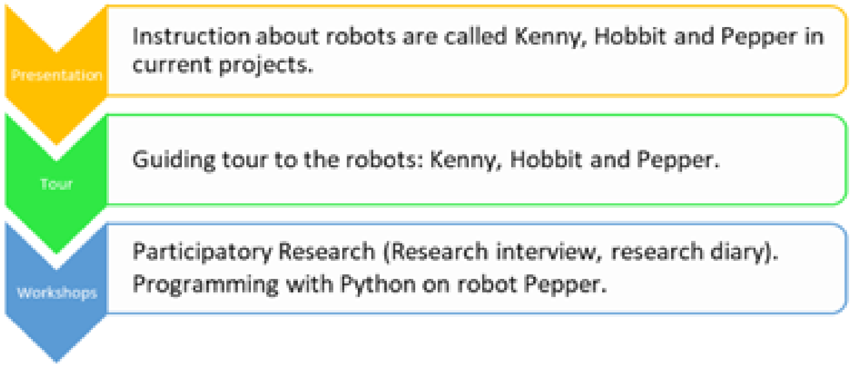


Figure 5.1: Educational robotics activity designed with a standardized structure at the phase 1.

In the phase “Arrive”, the students receive information about the schedule and their role in the workshop. In the phase “Activate previous knowledge”, the students first receive information about robots that is linked to their real world. There is a presentation combined with a discussion about robotics in their daily lives, robotics in industry, and finally a discussion about service robots. In the phase “Instruction” the workshop contains a presentation about the robots at the TU Wien given by a researcher who explains the different components, properties, and demands made on robots based on current projects. Subsequently, the students can see the different robots in reality and hear a detailed explanation of each robot (see Figure 5.2).

In the phase “Construction or application” the students work actively on different topics. One group of students learns about research interviews and research diaries, and subsequently to conduct interviews with their partners to explore their perception and expectations of robotics. During this part, the students gain experience regarding the problems and possibilities associated with research interviews and research diaries. The other group focuses on the robot called Pepper and learns the difference between the software “Choreographe” from Softbank and

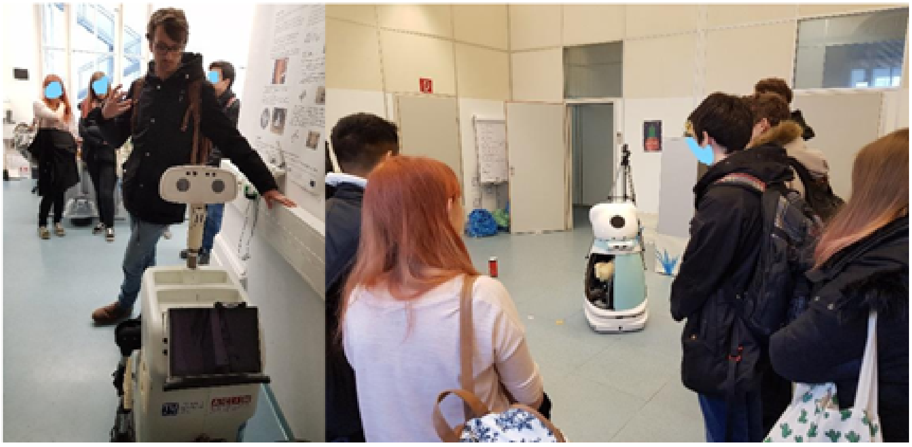


Figure 5.2: In the “Instruction Phase” get the students the relevant information about service robots.

coding with Python (see Figure 5.3).

Figure 5.3: In the “Construction Phase” the students learn with hands-on activities and active programming with choreographe.

The standardized structure offers the possibility to tie in with the students’ previous knowledge and thus to better inspire them for the topic of robotics and STEM. The distinction between the instruction and construction phases creates clear structures for teacher and student activities. The AVIVA model is a useful standard for designing all educational robotics activity with the new C4STEM activity plan in the Phase 2.

5.1.4 Phase 1: Developing an activity plan with structured activity blocks in detail

The current activity plan has no details about pedagogical interventions. (see chapter 2.4.2.) It has therefore been extended with activity blocks which include the 4STEM factors and a standardized structure of the AVIVA model. The schedule of the session contains activity blocks which are divided into seven parameters. The parameters are described in Table 5.1.

The demands made on the activity block are that the educational robotic activities are shareable, easy implementable in repositories, contain a clear description of the tutor and student activities, are easily modifiable and self-descriptive. The modification of the activity blocks in detail provides a link between the 4STEM factors and the evaluation package and can be seen in Table 5.2.

These activity blocks are implemented in the activity plan template and considered in the design of educational robotics activities in the Phase 2. The next section develops an evaluation tool to assess the impact of the 4STEM factors and the effect on a STEM career of educational robotics activities.

5.1.5 Phase 1: Developing of an evaluation tool to assess the impact of 4STEM-factors and STEM Career in educational robotics activities

The phase 1 develops additional measurement instruments based on the recommendations of the Pilot study and which were analyzed with SPSS 26. The additional measurement instruments assess the influence of activities on students' interest in STEM, the effect of role models on students, the effect of active work with robots and the increase in students' self-efficacy on a STEM career.

Interest in STEM

The result of the Pilot study about the iSTEM index shows a Cronbach's α=0.691 from 2249 students. This result questions the recommendation of the Pilot study reports (see section 4.3.9) that the next step is to fit the similar items STEM-4 and STEM-5 into one item with the statement "I want to understand how technical things work.". The iSTEM index is extended by the item STEM-2 "I like to research and discover." related to chapter 2.1. The newly developed index is called the STEM index and can be seen in Table 5.3.

The STEM index is the sum of the five items from Table 19 and compares interest in STEM before and after the workshop activities. The statistical analysis shows a Cronbach's α=0.639 from 352 students in the PRE-test (before the activities) and a Cronbach's α=0.731 in the POST-test (after the activities). The Cronbach's alpha

Table 5.1: The extended activity block with seven parameters.

Parameters	Description
Activity block code	The code consists of two numbers. (E.g.: 0-2, 1-2, 2-3) The first number is the information about the kind of activity. 0 - Periodical activities with all people (e.g. breaks, discussion in the plenum for constructing and co-constructing the students' ideas, etc.) 1 - Instructionism-oriented activity. (e.g.: introduction, lectures, etc.) In this activity, the teachers are more active than the students. 2 - Constructionism-oriented activity (e.g., solving problems, robots in a line, etc.). In this activity the students are more active than the teachers. The second number is the sequence number of different tasks and topics in the different kinds of activities.
Duration	The activity blocks can be designed in intervals of five minutes (e.g., 5, 10, 15, 20)
Name of the AB	Every AB receives a specific name.
Goals	The selected goals should be linked with a quantitative or qualitative evaluation tool (e.g., positive achievement with robots, positive achievement in the STEM field, increasing robotics self-efficacy, a positive relationship with a role model, a positive attitude to robotics, etc.)
Student activity	This parameter describes the activity of the student in this block.
Teacher activity	This parameter describes the activity of the teacher in this block.
Material	The materials are teaching materials (e.g., PPT, Thymio Suite, Thymio, information sheets, worksheets, etc.)

value is better in the newly-developed index (STEM index) than in the iSTEM index before, which was still acceptable [107]. The next factor is the positive relationship with a role model.

The positive relationship with a role model

Table 5.2: The 4STEM-factors are linked with the goals and specific evaluation tool.

No.	Goal	Evaluation tool	Items
1	Positive achievement in the STEM field	STEM index	5
2	Positive relationship	Role model index	3
3	Hands-on activities	Robotic activity index	3
4	Increasing self-efficacy	Robotics self-efficacy index	10

Table 5.3: The items for the STEM index to compare the difference of students' interest in STEM before and after the educational robotics activities.

Items	Statement	Datatype
STEM-1	I like using a computer.	Ordinal (5-point Likert)
STEM-2	I like to research and discover.	Ordinal (5-point Likert)
STEM-3	I like maths.	Ordinal (5-point Likert)
STEM-4	I like science.	Ordinal (5-point Likert)
STEM-5	I want to understand how technical things work.	Ordinal (5-point Likert)

The impact of role models with a STEM background is based on the positive relationship between teachers and learners. As a result, learners identify more with the role model and STEM. This leads to the hypothesis that role models motivate students to take a greater interest in STEM and a STEM career. Therefore, a role model guideline called "Guidelines for introducing the tutors" was developed for all tutors in educational robotics activities. The aim of the guideline is that tutors show students different points of identification and perspectives of a STEM career and interest in STEM. The tutors offer different points of identification for as many students as possible. For this purpose it is important to give the students an impression that there is not just one way into the field of technology and robotics. The guideline includes the following points for the introduction of tutors: name and age, social and cultural background, their way into robotics, technology or STEM in general. The following leading questions can help to consider the points during the introduction: Which languages do I speak?; What is my native language? Has anyone in my family studied/been interested in technology before me?; Why am I interested in technology?; Was there a decisive point?; What about my path so far?; What are the challenges on my personal journey?. This guideline can be individually extended by points in your biography if they are considered relevant to the success of the interview.

The hypothesis is that the tutors are role models for the students and motivate the students to show more interest in technology and technology education. Three items are developed to prove the hypothesis and the impact of tutors in educational robotics activities quantitatively. The items for the role model index can be seen in Table 5.4.

Table 5.4: The items for the role model index to assess the impact of tutors after the activities.

Items	Statement	Datatype
Rol-1	The tutor is a role model for me.	Ordinal (5-point Likert)
Rol-2	The tutor has motivated me towards more interest in technology.	Ordinal (5-point Likert)
Rol-3	The tutor has motivated me to go for a technical education.	Ordinal (5-point Likert)

The role model index is calculated with the sum of the 3 items from Table 20. The statistical analysis shows a Cronbach's α=0.782 from 352 students after the activities. This value is still acceptable [107]. The next factor is positive achievement with hands-on activities.

Positive achievement with hands-on activities

Hands-on activities create higher levels of interest than activities without them. Hands-on in general means learning by experience. Most empirical studies provide evidence for the assumption that conducting hands-on activities leads to positive motivational outcomes [31]. The Robotic Activity index assesses the hands-on activities with three items from [19]. (See Table 5.5.) The items assess how it was for students to work with robots.

The Robotic Activity index is calculated with the sum of the items in table 21. The statistical analysis of the Robotic Activity index shows from 352 students an α=0.450. This Cronbach's alpha value is too weak to use the items for an index, which is why the items have to be evaluated separately. The next evaluation tool is used to assess the factor of students' self-efficacy.

Table 5.5: The items for assessing the work with robots during the activities.

Items	Statement	Datatype
Rob-1	Working with robots during the workshop was interesting.	Ordinal (5-point Likert)
Rob-2	Working with robots during the workshop was difficult.	Ordinal (5-point Likert)
Rob-3	Working with robots during the workshop was fun.	Ordinal (5-point Likert)

Development of a self-efficacy benchmark in the context of robotics

The development of the self-efficacy benchmark took place in three phases. The first phase measured self-efficacy in general with 10 items [111] from 32 students. The result shows that self-efficacy increased during educational robotics activities, but not significantly. The second phase was to develop a self-efficacy test in the context of robotic activities and not in general. This test was developed on the basis of Beierlein (2012) [106]. Beierlein (2012) who extended the self-efficacy test of Jerusalem and Schwarzer (1999) from 4 scales to 5 scales because the re-analysis showed that the four-step answer scale proposed by Jerusalem and Schwarzer (1999) was accompanied by a lack of differentiability of the answers at the upper end of the scale [32]. To address this problem, a five-step response scale was chosen. The robotics self-efficacy (RSE) questionnaire of Riggs and Enochs (1990) [112] was reduced from 25 items to 10 items for an efficient evaluation (see Table 5.6), similar to the standard self-efficacy test of Jerusalem and Schwarzer (1999) with 5 scales.

Table 5.6: The items for the RSE-index to compare the difference in students' robotics-self-efficacy before and after the educational robotics activities.

Items	Item total Correlation	Self-efficacy context	Statement
RSE1	0.142	Positive Feeling (lead robots)	I'm confident that a robot will move the way I want it.
RSE2	0.612	Competence (built robots)	I'm sure I can build a robot.
RSE3	0.669	Achievement (content about robots)	It's easy for me to understand the parts of a robot.
RSE4	0.535	Achievement (difficulties with robots)	It would not cause me any difficulties to make a robot move along a line.
RSE5	0.506	Positive feeling (controlling robots)	If I don't know what to do, I'll find a way to control the robot.
RSE6	0.224	Effort (create robots)	I can create a robot that solves other people's problems if I make an effort.
RSE7	0.673	Achievement (working with robots)	I will work well with robots when I have a chance.
RSE8	0.854	Positive feeling (solving robotics tasks)	I am someone who immediately solves robotic tasks.
RSE9	0.510	Positive feeling (robotics researcher)	I think that I will be able to do everything that a robotics researcher has to do.
RSE10	0.724	Achievement (function of robots)	I'm the one who will explain how robots work.

This robotics self-efficacy test was filled out during the first test phase before and after an educational robotics activity with 30 students. The values below are the sum of the items and were increased during the educational robotics activity (see Table 5.7).

The correlation of the RSE value before and after the activity shows a positive correlation with r=.590 and with p=.000 a significant result. For reliability analysis, Cronbach's alpha was calculated to assess the internal consistency of the subscale for positive effect, which consists of 10 items. The internal consistency of the

Table 5.7: The items for the RSE-index to compare the difference in students' robotics-self-efficacy before and after the educational robotics activities.

Test	Mean	N	Std. deviation	Standard error of the mean
PRE-RSE	37.00	30	4.291	0.783
POST-RSE	41.17	30	6.336	1.157

questionnaire after the activity is a good result with a Cronbach's α= 0.842 [113]. Internal consistency can be increased to .859 by removing Item 1 from the questionnaires.

In the third phase item 1 was modified with a statement in the context of robotics. The new modified item was "I'm confident I can program a robot." The new RSE scale was responded to by 124 students with a Cronbach's α= .905 before the activity and a Cronbach's α= .882 after the activity (see Table 5.8). These Cronbach's alpha results are excellent [107].

The next section shows the development of a measurement tool for interest in a STEM career after the educational robotics activities.

Interest in a STEM career

The development of the measurement tool to assess the impact of educational robotics activities on a STEM career is related to the recommendations of the Pilot study. STEM careers are assessed in three different categories. The first category assesses students' interest to study a subject in the STEM field with the acronym **Study-STEM**. The second category assesses students' understanding of the importance of STEM with the acronym **STEM-Imp**. The third category is to assess the interest of students in building, programming and learning with robots in the future with the acronym **Rob-Fut**.

The evaluation of the first category (**Study-STEM**) is carried out with 3 items which can be seen in Table 5.9. The first item is from the evaluation package from Table 3.4 (from chapter 2). The second and third items were developed in the context of robotics.

The **Study-STEM** index is calculated with the mean of the items in Table 5.9 and assessea the interest to study STEM after the educational robotics activities.

The evaluation of the second category (**STEM-Imp**) is carried out with 3 items which can be seen in Table 5.10. The first and second items are from table 3.4. These items are extended by a third item in the context of robotics.

The **STEM-Imp index** is calculated with the mean of the items in Table 5.10 and assesses students' understanding of the importance of STEM.

Table 5.8: The improved RSE-index to compare the difference in students' robotics-self-efficacy before and after the educational robotics activities.

Items	Item total Correlation	Self-efficacy context	Statement
RSE1	0.693	Positive feeling (lead robots)	I'm confident I can program a robot.
RSE2	0.719	Competence (built robots)	I'm sure I can build a robot.
RSE3	0.629	Achievement (content about robots)	It's easy for me to understand the parts of a robot.
RSE4	0.569	Achievement (difficulties with robots)	It would not give me any difficulties to make a robot move along a line.
RSE5	0.647	Positive feeling (controlling robots)	If I don't know what to do, I'll find a way to control the robot.
RSE6	0.691	Effort (creating robots)	I can create a robot that solves other people's problems if I make an effort.
RSE7	0.524	Achievement (working with robots)	I will work well with robots when I have a chance.
RSE8	0.821	Positive feeling (solving robotics tasks)	I am someone who can immediately solve robotics tasks.
RSE9	0.711	Positive feeling (robotics researcher)	I think that I will be able to do everything that a robotics researcher has to do.
RSE10	0.622	Achievement (function of robots)	I'm the one who will explain how robots work.

The evaluation of the third category (**Rob-Fut**) is carried out with 3 items (see Table 5.11). The third item is from Table 3.4. The other items were developed in the context of robotics. The **Rob-Fut index** assesses working with robots and learning more about programming in general.

The **Rob-Fut index** is calculated with the mean of the 3 items in Table 5.11. The next section is the conclusion of the phase 1.

Table 5.9: The items to assess the interest to study STEM by students after the educational robotics activities.

Items	Statement	Datatype
Study-STEM-1	I am now more interested than before in studying something with science.	Nominal (Yes/No)
Study-STEM-2	I am now more interested than before in studying something with computer science.	Nominal (Yes/No)
Study-STEM-3	I am now more interested than before in studying something with technology.	Nominal (Yes/No)

Table 5.10: The items to assess students' understanding of the STEM field after the educational robotics activities.

Items	Statement	Datatype
STEM-Imp-1	I understand how important mathematics is.	Nominal (Yes/No)
STEM-Imp-2	I understand how important natural sciences (physics, biology, chemistry) are.	Nominal (Yes/No)
STEM-Imp-3	I now understand better how important technology is.	Nominal (Yes/No)

Table 5.11: The items to assess the students' motivation to work with robots in the future.

Items	Statement	Datatype
Rob-Fut-1	I would like to build and program robots in the future.	Nominal (Yes/No)
Rob-Fut-2	I want to use robots to learn new things in the future.	Nominal (Yes/No)
Rob-Fut-3	I would like to learn more about programming.	Nominal (Yes/No)

5.1.6 Phase 1: Conclusion

The phase 1 improved the extended activity plan template and evaluation package. It answers the research question RQb1: "Which evaluation tool can assess the impact of the 4STEM factors to influence the interest in STEM positively by educational robotics activities?". Therefore, the phase 1 starts with a case study designed with a standardized structure related to the AVIVA model. It is a didactic design which is a model of classroom management and is a useful standard to design comparable educational robotics activities in the Phase 2. The activity plan template was extended with structured activity blocks with information about seven parameters including pedagogical interventions. The index for interest in STEM was developed with 5 items, and a statistical analysis shows an improvement in the Cronbach's alpha of about α=0.731. This value is acceptable and assesses the interest before and after the activities. The evaluation tool related to the 4-STEM factors is developed to assess the impact of role models, for hands-on activities and Robotics self-efficacy. The statistical analysis of the role-model index with 3 items shows a Cronbach's α=0.782. This value is acceptable and assesses the effect of role models after the activities. The Robotic-Activity index with 3 items assesses the impact of the hands-on activities. The statistical analysis of this index shows a Cronbach's α=0.450. This value is too weak to be used as an index, therefore the items are evaluated separately after the activities. Self-efficacy is measured with the Robotics self-efficacy scale. The statistical analyses of the 10 items shows a Cronbach's α=0.882. This value is excellent and measures Robotics self-efficacy before and after the activities. The next version of the evaluation tool was developed to assess the impact on a STEM career after the activities. The evaluation tool to assess the impact of the activities on a possible STEM career is divided into three categories. The first category assesses students' interest to study in the STEM field with 3 items and the acronym **Study-STEM**. The second category assesses students' understanding of the importance of STEM with 3 items and the acronym **STEM-Imp**. The third category is to assess the interest of students to build, program and learn with robots in the future with 3 items and the acronym **Rob-Fut**. All categories are calculated with the mean of the items and the data type is nominal with 'Yes' and 'No'. This evaluation package assesses the 4STEM factors and compares different educational robotics activities with a minimum of effort, is user-friendly for students and verifies the significance of students' interest in STEM and Robotics self-efficacy. The developed framework and evaluation package have the acronym **C4STEM** framework with evaluation package. The acronym **(C)** stands for the conceptual framework, and the acronym **(4STEM)** for the field in STEM. The next chapter tests this C4STEM framework and evaluation package by comparing and assessing different educational robotics activities.

5.2 Phase 2: Testing the C4STEM Framework with developed evaluation package

The phase 2 tests the C4STEM framework with an evaluation package to assess interest in STEM, the 4-STEM factors and a STEM career. The study presents two evaluation studies and gives an answer to the research question RQb2: How does a comparison of educational robotics activities look like with this evaluation tool? One study compares different physical educational robotics activities with a gender comparison. The second one evaluates a case study of a virtual educational robotics activity with a gender comparison. The wording physical means that the students interact with robots in groups face to face. The opposite of physical is virtual. The wording virtual means that students interact in a virtual room with robot simulations.

5.2.1 Phase 2: Sampling

For the case studies, the Phase 2 uses the quantitative and qualitative data from the workshops series from February 2019 to June 2020 at the RoboCoop Project (MS1) funded by Interreg V212. Educational robotics has proven to be a valuable tool for hands-on learning, not only for robotics itself, but for STEM topics in general. RoboCoop is a unique project aiming to exploit the multidisciplinary potential of robotics and establish cross-border educational activities to stimulate interest in STEM topics. RoboCoop will encourage and engage more than 4000 students, scholars, and innovative STEM educators on an interregional level to serve as a positive example for broader use on a national level in the two countries. In addition, a comprehensive evaluation of all project activities will lead to policy recommendations to ensure systematic and long-term implementation of project ideas, leading to early adoption of robotics topics at the secondary level.[6]

Time frame: February 2019 to January 2020

Type of study: Case Study

Evaluation instruments: questionnaires, Interviews

Setting: Workshop series students in a university lab

Participants: 352

Environments: Thymio, Hedgehog, BBC Micro Bit

[6]https://www.acin.tuwien.ac.at/en/project/robocoop/

5.2.2 Phase 2: Methodology

The methodology involves a mixed method. Before and after the workshops, the students fill out PRE- and POST-questionnaires and tutors conduct interviews with focus groups. The data analysis is divided into two types: quantitative and qualitative data. The quantitative data from the questionnaires will be analyzed with the software SPSS 25. The questionnaires at the beginning of the workshop provide information about gender, age, the interest in STEM, and prior experience with educational robotics before the workshops. The questionnaires after the workshop provide information about the positive influence on interest in a STEM career, provide role models, and increase the students' self-efficacy and motivation to work with robots during the workshops. All of the data will be analyzed based on the approach of design-based research [104] and mixed-methods [105].

The virtual educational robotics simulation workshop was evaluated using a mixed-methods design [23] with quantitative and qualitative methods. This methodology was chosen in order to triangulate the quantitative and qualitative data for better clarification of the results. All students were anonymized with an ID number; the ID number had, on the end, “f” for female or “m” for male (e.g. 320123f). The quantitative data were analysed using the statistics software SPSS 26. The qualitative data were evaluated through a document analysis method. All students were informed about the evaluation process in writing and gave their consent. The questionnaires measured changes in the students' attitudes towards and their interest in STEM. Thirteen students completed the questionnaire before the workshop and eleven after the workshop. The questionnaire measured interest in STEM with 5 items [114] and robotics self-efficacy with 10 items related to a study by [108]. The first item was re-written in relation to the recommendation for a better Cronbach's alpha. The qualitative data supported the significance of the questionnaires, with a collection of five interviews, two observation sheets, one tutor reflection and 56 learning artefacts in the form of documents, photos, drawings or videos.

5.2.3 Phase 2: Testing the C4STEM framework with a comparison of the impact at different physical educational robotics activities

The Phase 2 tests the C4STEM framework for designing different educational robotics activities and tests the C4STEM evaluation package. It compares three different physical educational robotics activities. All educational robotics activities had the same goal of fostering interest in STEM and were designed with the C4STEM framework. However, all of the workshops were designed differently, varying in activities, program language and robotic kits. Table 5.12 gives an overview of the different workshops, robotics kits, program languages, number of students, the age group and gender mix of the students. The different robotics kits are depicted in Figure 15.4: The different robotic kits (Hedgehog, BBC Micro Bit, Thymio) in educational robotics activities.

Table 5.12: The information about robotics kits, program language, age group and gender is mixed in three different educational robotics activities.

ERAs	Robotics kits	Programm language	students	Age group		Gender mix	
			N	Mean	SD	Mean	SD
A	Hedgehog	Python, Blockly	163	13.09	1.33	1.52	0.5
B	BBC Micro Bit	Python, Blockly	119	14.74	2.08	1.84	0.37
C	Thymio	VPL, Blockly	70	13.31	1.1	1.74	0.44

Figure 5.4: The different robotics kits (Hedgehog, BBC Micro Bit, Thymio) in educational robotics activities.

Educational Robotics Activity A

This educational robotics activity was designed for students who have never encountered robotics and/or programming. The required prior knowledge comprised basic reading skills and understanding of the necessary numeric values; a basic knowledge of working with computers was advantageous. The workshop was suitable for children aged 8-11 years. It was used in schools in a socio-economically disadvantaged area, and despite being carried out in Austria, for a large percentage of the students German was their second language. The aim of the workshop was to familiarize the students with the concepts of design thinking as well as robotics and programming. It consisted of two main sessions held by the workshop tutors in an open space for testing and building the robots, with notebooks or computers, and took place indoors. The first session focused on giving the students an introduction to design thinking and considered what type of robot they could build. The second session explained the basics of programming with the goal of moving the robot. During the activities, the students were expected to observe, communicate, build a robot, program a robot, discuss their ideas with a classmate and present their work in front of their peers. The workshop was divided into two phases. The following slogan for the learning process was used in the first phase: 'I can create something in a small amount of time'. In the second phase, the goal was that the students would try out their code and adapt it to the task. The workshop was intended to develop collaborative skills, as students take on roles within groups and communicate with other groups to exchange ideas and tips as well as advice, and foster presentation and argumentation skills. The students' learning outcomes were either a visual or a python program for the Hedgehog Educational Robotics Controller.

Educational Robotics Activity B

This educational robotics activity was designed with the main goal of developing activities which increase interest in STEM for all students during learning with educational robotics tools like BBC Micro:Bit and :MOVE minirobot. The programming and coding activities took place with Python and Makecode Blockly following a guideline from Makecode. The first part took 45 minutes, during which the students got to know the BBC Micro:Bit as well as the basic commands and trained their skills in creating code. The students were given the exercises step by step according to their individual level and worked in pairs (see Figure 5.5). At the end of the setting, they discussed their results (approx. 5 minutes). The second part also took 45 minutes and involved content about the motion sensor of the BBC Micro:Bit. Again, the students solved the exercises in pairs and at the end discussed their results for 5 minutes. In the third part of a further 45 minutes, the students used the BBC Micro:Bit in motion and the tilt sensor Micro. The students had to solve an everyday problem by developing a useful tool for festivals, events and discos, which was a solution for counting the number of visitors at events. Now, the students worked either individually or in pairs. At the end of the setting, the students discussed their results (approx. 5 minutes). The last setting employed the BBC Micro:Bit MicroPython, which is a version of Python that runs on the BBC micro:bit. This last part required 180 minutes. Python is a very popular and versatile programming language recommended for teaching the basics of programming, and so the aim of this part was to introduce basic commands in this language. The traditional way to start programming in a new programming language is to teach your computer to say “Hello world!”

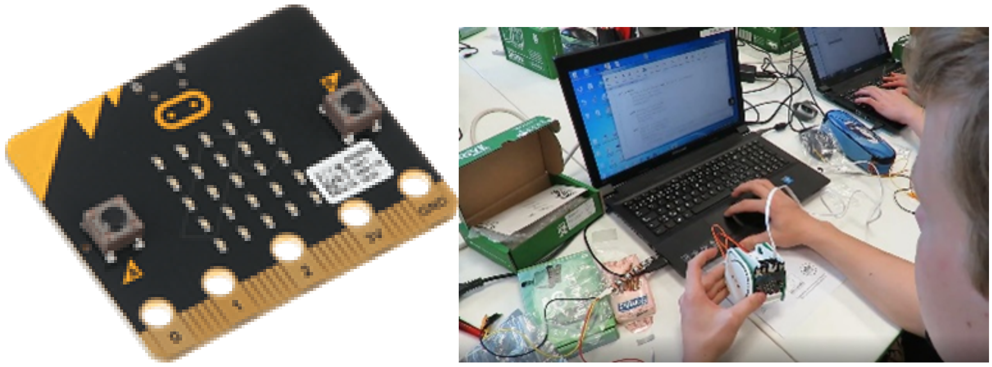


Figure 5.5: The robotics kit and student action in workshop B.

Educational Robotics Activity C

Educational robotics activity C lasted 4 hours and was led by tutors who acted as role models to increase levels of interest in STEM careers. The activity was divided into three parts including two breaks of 15 minutes each. Every part had different activity blocks and at the end of all the parts the students presented and shared their results with the whole class during the activity block “Discussion and presentations”. The first part started with the activity block “Introduction” by the tutors, which was based on a role model introduction guideline. The next activity block was the “Lecture about robots” concerned with a robot definition, the components of a robot, different applications of robots and linking robotic technology with real-life applications. After that, the next activity block, which was called “Explore a robot”, was a hands-on activity for discovering a robot and its different programs. The students used their technology literacy to program and understand robotics and solved the problems in teams (collaboration) applying different individual means (creativity) as researchers. Thus, the students developed their own goals based on their different interests and real-life problems. The next task was to link the different colors of robots with different programs.

During the second part, the students were able to solve problems in their own individual creative way. For example, the robot had to move through a maze or the robot had to draw a bicycle (see Figure 5.6).

The last part was to learn the programming language VPL (Visual Programming Learning) and to control the robot in different settings.

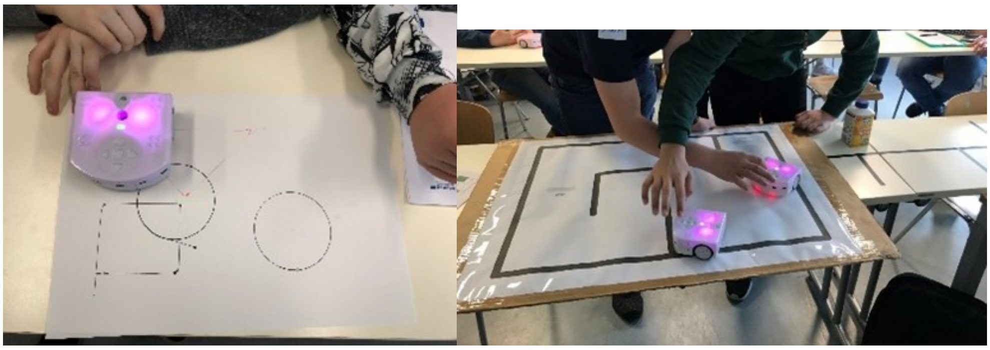


Figure 5.6: Learning artefacts about students' individual creative and problem-solving skills.

Comparison of the results of all students

This section shows the results with the C4STEM evaluation package. The results of the three different activities are compared to identify best practice examples. The first step is to evaluate the metadata and the students' interest in STEM before the activities (see Table 5.13).

Table 5.13: The metadata about the gender mix and experience before the educational robotics activities.

		Workshop A N=163	Workshop B N=119	Workshop C N=70
Gender	Girls	48.2%	16.1%	25.7%
	Boys	51.8%	83.9%	74.3%
Did you build a robot?	School	0.7%	5.9%	2.9%
	Workshop	7.7%	12.6%	1.4%
	At home	10.6%	9.2%	12.9%
	No	74.6%	69.7%	80.0%
Did you program?	School	19.7%	69.7%	28.6%
	Workshop	3.5%	0%	24.3%
	At home	14.8%	20.2%	5.7%
	No	54.2%	9.2%	40.0%

The best gender mix is shown in workshop group A (see Table 5.13). The students of educational robotics activity B had most experience with robots and programming. Most had not built a robot, but most of the students who had programmed before were in activity B.

The next step is to evaluate students' interest in STEM with the STEM index before and after the activities (see Table 5.14) The comparison between students' interest in STEM before the activities (PRE-STEM index) and the change after the workshop (POST-STEM index) provides information about the impact of the activities on interest in STEM.

Table 5.14: The comparison of the STEM index before and after the activities.

index	Group A		Group B		Group C	
	Mean	Std.	Mean	Std.	Mean	Std.
PRE-STEM	18.7	3.1747	19.31	2.946	19.33	3.594
POST-STEM	18.1	4,661	20.35	3.63	19.65	3.382

The mean of the PRE-STEM index in groups B and C is similar and higher than the mean in group A. The interest in group B increased more than in group C, but in group A interest in STEM decreased during the workshops. However, most of the students in group B had experience with programming (seen Table 5.13) and therefore a clearer picture about STEM before the workshop, which could have made them more receptive for the workshop content. By contrast, many of the students in group A had their first experience with robots and programming in these activities. Besides, group A had the best gender mix and therefore significantly more girls in the activity than group B. Due to these different students in the activities a direct comparison is not significant. Nonetheless, the results are important for every individual workshop to identify best practices.

The next step is to evaluate the impact of the hands-on activity during the workshops with 3 Robotic Activity Items from Table 5.5. The evaluation is carried out separately with several items.

Table 5.7 shows the different results about working with robots during the activities. The highest possible score is 5 and the lowest possible score is 1. The best results come from the educational robotics activities in group C. Compared to the other groups, the students in this group had the most fun and showed more interest in working with robots and had less problems working with them.

Table 4.11 shows the different results after the activities. The role model index was evaluated with the sum of 3 items with a five-point Likert scale. The other indexes were evaluated with the mean of 3 items with a response option of yes or no. If the result involves more yes, the mean is close to 1, and if the result involves more no, it is close to 2.

The impact of the role model is greatest in group B. The mean of the Study-STEM index with 1.36 in group B is closer to Yes than the mean of the other groups. This is likewise with the mean of STEM-Importance with 1.13, Rob-Fut with 1.34 and the stars rating with 4.36. However, all groups show a result close

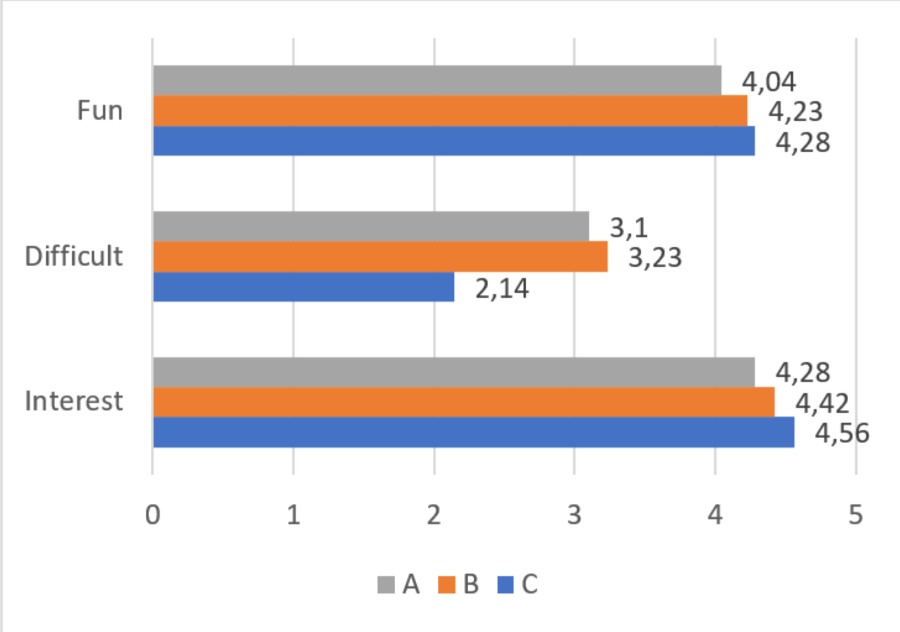


Figure 5.7: The comparison of three educational robotics activities regarding the impact of hands-on activities.

Table 5.15: The comparison of the effects of role models, Study-STEM, STEM-Imp and Rob-Fut after the activities.

index	Group A		Group B		Group C	
	Mean	Std.	Mean	Std.	Mean	Std.
Role model	9.21	3.139	11.51	2.691	9.64	3.014
Study-STEM	1.52	0.302	1.36	0.331	1.51	0.312
STEM-Imp	1.25	0.297	1.13	0.216	1.24	0.302
Rob-Fut	1.6	0.384	1.34	0.340	1.47	0.411

to yes in STEM-Importance. This result is significant for answering the question “How do robotics workshops influence decisions towards STEM careers?”.

Comparison of the results from girls

The comparison is about the results after the educational robotics activities. Figure 5.8 shows how working with robots during the workshop was perceived by girls.

The results show that the highest mean regarding interest was in group C with 4.61 and regarding fun with 4.47, also in workshop C. Besides, the mean of 2.24 in the category difficulty in workshop C was the lowest result. These results show a

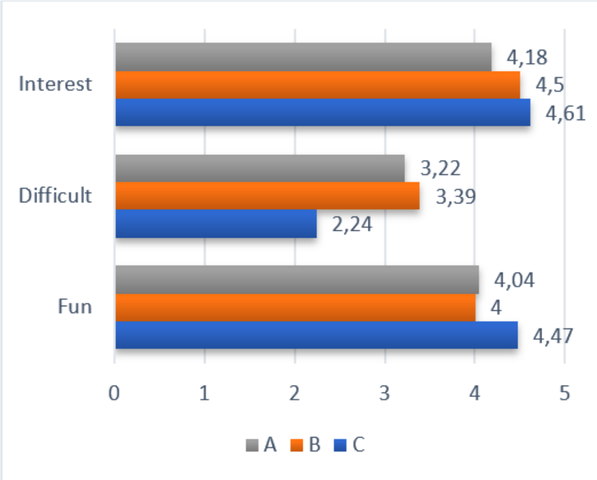


Figure 5.8: The results of working with robots during the activities by girls

clear best practice for increasing the motivation of girls to learn and work with robots.

The evaluation package presents results on the positive influence of essential factors to increase the interest in STEM in different workshops. In this way we can identify best practices in relation to different factors. The evaluation tool focuses on the interest of the students before the workshops and after the workshops, and provides a better understanding concerning the comparison of results between different educational robotics workshop designs. The detailed information about the activities and their different pedagogical interventions and the goals of the workshops provide a better understanding of the different workshop designs. This would allow a better comparison of the results in order to identify best practices. Consequently, C4STEM will support the sharing of educational robotics activities and facilitate the comparison and checking of the quality of educational robotics activities in order to identify best-practice examples for a sustainable increase of interest in STEM among young students. The tried and tested evaluation presented in this work is accurate, but the evaluation needs to reflect the different students to identify suitable activities for the workshops with qualitative data in a case study (see the next section).

5.2.4 Phase 2: Testing the C4STEM Framework with a gender comparison at a virtual educational robotics activity

The Phase 2 evaluates a virtual educational robotics activity with a gender comparison. The results inform about the impact of the educational robotics activity. The educational robotics activity is designed with the C4STEM Framework, which is used to define a standardization for the design and evaluation of all educational robotics activities to assess the learning outcome and to offer a template for sharing the best practices of educational robotics activities with the community. The theoretical background of the C4STEM framework specifies the target to increase interest in STEM and is based on the constructionism approach, the AVIVA model, and problem-based learning. The design includes an Activity Plan Template with Activity Blocks. The Activity Blocks are deployed in the phases of the AVIVA model for a structured teaching process and related effective learning process. The motivation of the students in learning and actively working during the workshop is given by hands-on activities, increasing Robotics self-efficacy and role models. Hands-on activities are one factor to positively influence interest in STEM and self-efficacy. This activities are supported in the constructivist learning approach with 'learning by doing' and 'trial and error' [115]. An important factor in the virtual simulation workshop is that researchers did not find differences between students who worked on virtual or hands-on experiments [116]. According to the basic principles of self-efficacy theory, students are more likely to engage in activities for which they have a high level of self-efficacy, and less likely to do so in those where they do not [82]. This means that students with a high robotics self-efficacy (RSE) score set themselves more challenging goals and work harder and more efficiently to accomplish goals related to robotics than students with a low robotics self-efficacy score. The aim of the workshop is to increase the RSE score through activity blocks using the constructionism approach and the option of positive achievements through active problem solving.

There were thirteen students with eight boys and five girls in grade 13 of a vocational school. Two girls had built a robot before the educational robotics activity. The activity was led by two tutors and two teachers. All of the students worked on their personal computers with their private internet from home.

The educational robotics activity is divided in two sessions: the first session has a duration of four hours and one week later the second session has a duration of two hours. Students learned during the workshop activities to program a robot, acquired knowledge about robot definitions and the components of a robot, different applications in robotics and linked robotic technology with their real-life applications. They solved the problems in teams using different individual methods as co-researchers. The students developed their own goals based on their different interests and real-life problems. The tutor was a role model to provide an example of a person in a STEM career. The students solved different problems which started with easy ones such as multiple entry points and ended with a solution to support the COVID-19 problem with a robot. The learning outcomes were uploaded as screenshots or videos into the LMS system.

The first session consisted of three parts with two breaks. The first part started with the activity block 'Introduction' of the tutors and achieved a positive relationship between the tutors and students. The next activity block was a 'Lecture about Robots' about a definition of technology and man-made and useful artefacts as opposed to natural ones. The students learned the definition of a robot as an autonomous self-driven technology with a physical embodiment that senses its environment. The lecture continued with different application areas and the appearance of different robots. Finally, it finished with a demonstration of robotic parts, sensors, and microcontrollers. After the two instructionism-oriented activity blocks, the first constructionism-oriented activity block was conducted with 'Install Thymio Suite' followed by a break (see Table 5.16). The activity block code is related to table 3.3.

The second part started with the activity block 'Explore the Thymio Simulation with VPL'. In this activity block the students learned during their research the function of the Thymio Suite and concluded the activity block with a discussion in the plenum. During this discussion the students talked about their first experience and challenges with the program. The students learned to solve their first problem in a robotics context with the activity block with the name 'Push the button'. It contained an exercise on programming the buttons and the wheels of the robot. After this activity block, the students presented their results as learning outcomes and discussed the challenges they had experienced during the exercise. Part two finished with a break (see Table 5.17 and Table 5.18).

The third part started with the activity block 'Robots in line'; this is the second exercise and the students programmed the robots to move in a line. The results are discussed in the activity block 'Discussion in plenum'. The third exercise was to move a robot through a maze described in the activity block of 'Robot in a Maze'. The last exercise was to define a problem involving COVID-19 in a real-life context. The students had to find a solution with robots for their individual problem. The students recorded their solution in a simulation and made comments. This last exercise was in the activity block 'Solve a COVID-19 problem with a robot' (see Table 5.19).

Session 2 (see Table 5.20 and Table 5.21) started one week later with a 'Short Introduction' to recall the last session and give them an overview of session 2. After this activity block, the students received an introduction about the process of Design Thinking for developing a robot to provide solutions to their COVID-19 problem. The students developed their robot in relation to their problem and related to the Design Thinking process. For an optimal presentation, the students received input about the structure of a pitch. After this instruction, the students prepared their robot pitch. The activity block 'Pitch your robot' gave the students the chance to present their results of the individual COVID-19 problem in the plenum. The last activity block is 'Conclusion of the entire workshop'.

Results of the case study

This section shows the results from the case study about thirteen students who participated in the virtual robotic workshop, all of whom provided informed consent to participate in the research. Data collection took place at the beginning of the educational robotics activity with an online survey, during the workshop with observation and screenshots of the learning artefacts, and after the educational robotics activity with an online survey and semi-structured interviews. The semi-structured interviews with five of the thirteen students began with the students describing what they had created and learnt during the educational robotics activity. The results provide an example what works to increase interest in STEM among students.

The **observations demonstrate** that the girls were more participative than boys during part two of session one in the activity block 'Discussion in the plenum' (Code: 0-3). The girls solved problems and shared their results with others during the break at the end of part two of session one. Figure 5.9 displays a result from student with the ID number 320123f about solving the problem from activity block 2-5. The result is the programming of two floor sensors. The student with the ID number 320123f explained her result and the generated text code (see Figure 5.9).

```
Text Code:
when prox.ground.delta[0]
<= 400 and
prox.ground.delta[1] <=
400 do
        motor.left.target
= 500
        motor.right.target
= 500
        emit pair_run 5
         emit debug_log
[0x5, 0x2, 0x83, 0xa,
0x190, 0x1c2, 0x1414]
end
```

Figure 5.9: The text code from student with the ID number 320123f at a virtual educational robotics activitiy.

Several students (320123f; 320120f; 320116m) worked in a team and shared their solutions online. They shared their computer screens with one another and explained their solution process. They each had individual creative results on VPL. The student with the ID number 320116m recorded his solution and explained it to the others with his shared computer screen so they can make a video on their own. Several students shared their computer screens, which led to a discussion and a productive setting for problem-solving. The student with the ID Number 320123f stated that starting programming is very easy, easier than she had anticipated.

In session two, the students put forward proposals with robots which solve COVID-19 problems in the real lives of the students. One example is seen from the student with the ID number 320122m in a PowerPoint presentation (see Figure 5.10).

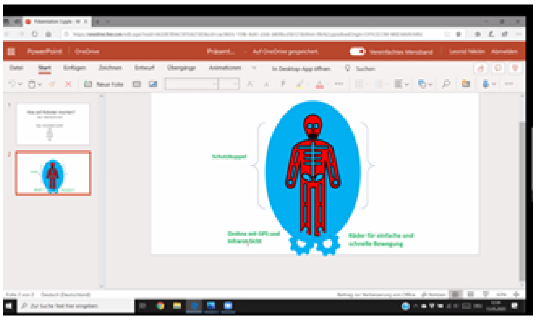


Figure 5.10: The text code from student with the ID number 320123f at a virtual educational robotics activitiy.

Results from interviews

Five interviews with one boy and four girls were collected. The objective of the document analyses was to find results related to the C4STEM evaluation package for qualitative data (see section 3.2.2) with the parameters 'Activities during the workshop', 'Learnings strategies' and 'Interest in STEM'.

The results of the parameter 'Activities during the workshop.' shows that the students learnt more about programming with robots and problem-solving. The exercises involving the definition of a robot and participation in a webinar were new for the students. The biggest challenge was to program a robot so that it moves along a line. The interesting things were to see how the robot moves after programming, to solve an individual COVID-19 problem by programming a robot, to move a a robot along a line and program the sensors. The students obtained more impressions about different applications of robots in real life, saw that robotics is definitely interesting and that programming with VPL is a simple way to learn the programming of a robot. The interviews for this parameter are in Table 5.22.

The results of the parameter 'Learning strategies.' show that the students need logical thinking, more content-related knowledge of technology (e.g. sensors) and more content-related knowledge of informatics. The workshop enhanced the skills of the students in solving problems in the field of technology and robotics. The students learnt through sharing their ideas and found solutions for problems in a team. They learnt through 'trial and error' and by playing with the program.

The results of the parameter 'Interest in STEM' show that the students in the workshops were more interested in technology and robotics after the workshop and want to learn more about programming.

Results from questionnaires with a gender comparison

The results from the online survey about the RSE-index score, assessed with 10 items, and the STEM index with 5 items are displayed in Table 5.25. The participants responded to the online survey before and after the workshop with a 5-point Likert scale; 5 corresponded to strongly agree and value 1 to strongly disagree. The RSE-index score increased following the workshop. The largest increase is shown by the girls, and their RSE-POST index score is higher than that of the boys. The STEM index score did not change following the workshop. The STEM index score reveals that the girls were more interested in the STEM field than boys. Table 5.25 displays a comparison of the RSE index and STEM index by gender.

The girls had a higher RSE index score (M=35.5, SD =7.33) than the boys (M=32.43, SD=5.91) after the online workshop. This difference is not significant ($t(9) = 0.76$, $p=0.465$). The girls had a higher STEM index score (M=22.75, SD =1.26) than the boys (M=20.67, SD=2.50) after the online workshop. This difference is not significant ($t(8) = 1.52$, $p=0.167$).

The hands-on activities with robots were similarly interesting for girls and boys, but they were also on average more difficult and more fun for boys; See Table 5.26.

The interest in studying STEM after the workshop was measured by answering the statements with Yes (1), Neither (2) or No (3); these results are displayed in Table 5.27. The interest in studying technology after workshops was higher among girls than boys.

Results from learning artefacts

Below are some learning artefacts for visualising the learning outcomes during the workshop. Figure 5.11 depicts a program to solve the problem in which by pushing the buttons the light displays different colors. Figure 5.12 displays a learning artefact about the solution for moving robots along a line.

Figure 5.13 displays a screenshot from the beginning of video exercise 4-320125 from student 320125f in AB 2-6.

Video exercise 4-320125: 'I would use my robot in the COVID-19 situation in hospitality for serving food in a restaurant, but you can also use it as a waiter at home. All the different directions of movement have different colors; for example, if the robot stops, the light is green, that means you can take your food. The front sensor was programmed to make a sound if somebody was too close or the robot moves too close to an object. It is possible to display the information about the different colors of a robot in a restaurant'

The questionnaires about interest in STEM showed no significant differences before and after the workshop. The questionnaires about interest in STEM in the

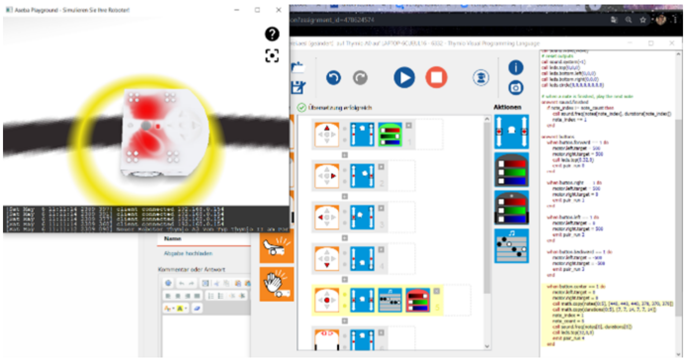


Figure 5.11: Learning artefact from 320123f in AB 2-3

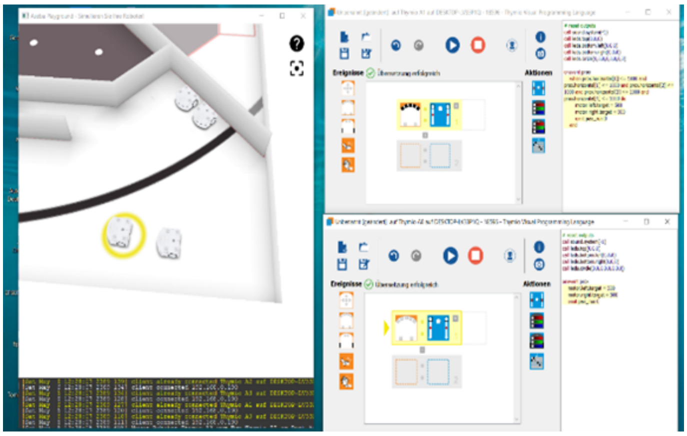


Figure 5.12: Learning artefact from 320118m in AB 2-4

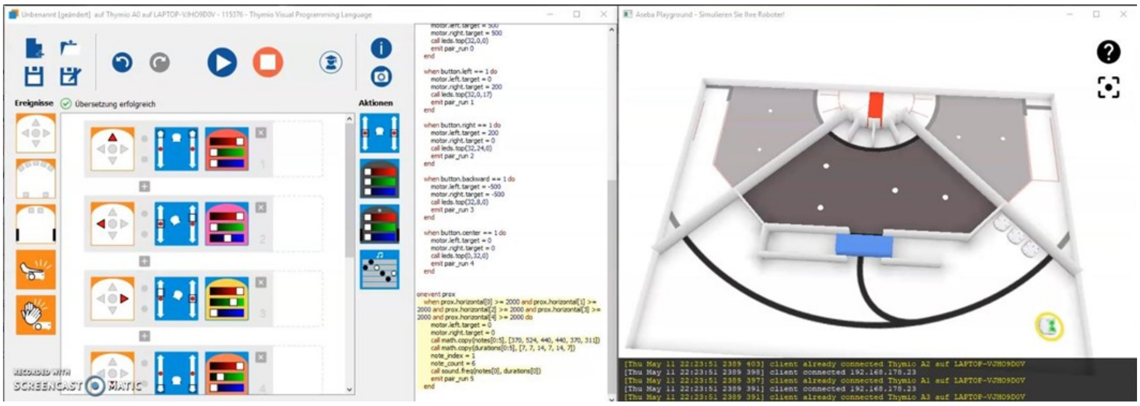


Figure 5.13: Screenshot from the beginning of the video from 320125f

future showed that the boys were more interested in understanding how technical things function than the girls were, but the girls were more interested in studying something related to technology and wanted to learn more about programming. All the girls reported that they wanted more workshops like this one. Triangulation of the quantitative and qualitative data showed that the students were more interested in technology and robotics after the workshop. The questionnaire results showed that the influence of the virtual educational robotics simulation workshop was positive. The analysis shows, by triangulation of the quantitative data with the qualitative data, that the qualitative data confirms the results of an interview with 320115f, who reported that for her the field of robotics was a very complicated field, but that the workshop was an easy entry point and that now she was able to control a robot. Before the workshop she had a lot of respect for informatics, but now it seemed easier to her. The students reported that it was a good idea to start programming with a VPL, and that the most interesting thing was to solve a COVID-19 problem in an individual way with robots. The biggest challenge was moving the robot along a line in the simulation. The students reported in the interviews that they had learnt about programming and to solve problems by controlling a robot. The learning artefacts show the simulation room with robots and the VPL code used to control the robots. Figure 7 shows the perspective of one student of a robot solving the COVID-19 problem.

Educational robotics activities in a virtual workshop is a new field in the educational robotics community, and the results demonstrate that girls were more engaged and interested in robotics and coding during and after the workshop than boys. The observation shows that girls shared their ideas more actively than boys. During the breaks, the girls discussed different strategies and shared their screens online. Also the fact that all of the girls and just one boy had a solution for the COVID-19 shows the engagement of the girls. The interviews reported that the field of robotics was, in the view of the girls, a complex field before the activity, but that the virtual workshop gave the students a higher level of self-efficacy in the field of robotics field by solving real life problems related to COVID-19 with robots after the activity. The gender comparison shows that girls increased their RSE-index score more than boys. This means that girls have more belief more in their problem-solving skills in a robotics context than boys. This is an important finding which is relevant to increasing interest in technology, programming, and the filed of robotics. The results fit in with the research about online activities which reported that girls have been described as being attracted towards communicating online. According to Dyer (2004), online settings promote gender equitable participation. The RSE-index score was initially lower among girls than among boys, but after the educational robotics activity the RSE-index score was higher among girls than boys. One interview reported that the activity block 2-4 'Robots in a line' was the biggest challenge. Maybe the activity block should be replaced with another exercise. Students reported that the programming and following the movement of the robot was exciting. The learning artefacts demonstrate the creative results of the students and connect with the interview results that the students liked to develop their own individual robotic solutions to problems. The interviews reported that the learning strategies of the students were 'learning by doing' and 'trial and error'. These components are related to the constructivist approach and hands-on activities. The validity of VPL as an easy entry point was confirmed by students in interviews. They commented about this being an easy way to enter into programming, the virtual world and coding a robot. The combination of programming and educational robotics is a learning setting that motivates students to learn more about computational thinking and the field of robotics.

Educational robotics activities in a virtual workshop also foster the promotion of women in technology, robotics, and the programming field, encourage computational thinking, and increases the RSE-index, particularly in girls. In this learning setting, girls in particular are empowered to cope with coding and creating robots. This result confirmed those of previous studies reporting that the effect of increasing student self-efficacy is linked with an increased interest in STEM (Kramer-Bottiglio, 2018). The virtual educational robotics workshop empowered the computational identity of students and increased belief in their skills to solve problems with the coding of robots. It suggested one means of giving students the belief that they can put their computational identity into practice in an authentic and meaningful way. This study is a contribution towards understanding how we can attract more students to the STEM field to satisfy the demand for engineers in robotics jobs around the world.

5.2.5 Phase 2: Conclusion

The Phase 2 answers the research question RQb2 with two studies. One study compares different educational robotics activities with a gender comparison. The second study evaluates a case study with a gender comparison. All educational robotics activities in these studies are designed with the C4STEM Framework and evaluated with the C4STEM evaluation package. Assessing different educational robotics activities enables the identification of best practice examples for different gender and age groups. The evaluation tool compares the different gender and age groups and provides a better understanding of the effects of different educational robotics activities. Consequently, C4STEM will support the sharing of educational robotics activities and facilitate the comparison and verification of the quality of these activities for identifying best-practice examples for a sustainable increase of interest in STEM among young students. The case study about educational robotics activity in a virtual workshop is a new field in the educational robotics community and assesses the different students to identify suitable activities. The results demonstrate that girls were more engaged and interested than boys in robotics and coding during and after the workshop. During the break in the digital space, the girls discussed different strategies and shared their screens online. They were more active and solved more problems than boys during the activity. The interviews reported that the field of robotics was - in the girls' estimation - a complex field before the activity, but that the virtual workshop gave the students a higher level of self-efficacy for solving real life problems with COVID-19 with robots after the activity. The comparison by gender shows that girls increased their RSE index score more than boys. This means that girls believe more in their problem-solving skills in a robotics context than boys. This is an important finding which is relevant to increasing interest in technology, programming, and the field of robotics.

The qualitative data of the interviews identify improvements for the activity. For example, one interviewee reported that the activity block 2-4 'Robots in a line' was the greatest challenge. Maybe the activity block should be replaced with another exercise. The educational robotics activity in a virtual workshop also fosters the promotion of women in technology, robotics and the programming field, fosters computational thinking, and increases the RSE-index, particularly in girls. In this learning setting, girls in particular are empowered to handle coding and create robots. The Phase 2 tests the C4STEM framework with evaluation package. This is a beginning in the assessment of educational robotics activities using a benchmark and enables the identification of best practice for with the goal of increase the interest in STEM. This identification helps to find suitable activities for gender or age groups. The reduced evaluation package is user-friendly for the students so that they are more concentrated to fill out these items before and after the educational robotics activities. The interviews do not need more than 10 to 15 minutes. The Phase 2 shows the necessity of quantitative and qualitative data. The case study presents how interviews help to get recommendations regarding the activities from students. The activity blocks help to identify the exercises which need to be change and the those which work. The next chapter presents the conclusion and summary of the whole study.

5.3 Conclusion and summary

The aim of the research was to develop a conceptual framework with an evaluation package to assess and compare students' interest in STEM with a minimum of effort by using different educational robotics activities. Therefore, all phases follow a data management plan with the ethical principles and data protection from chapter 4. The entire study analyzed data from six data samplings from 3417 students. The data were analyzed with SPSS 26 and Maxqda software. The Pilot study identified recommendations for Phase 1 including the development of an improved framework with an evaluation package. Phase 1 was developed on the basis of recommendations from the Pilot study with an extended framework including a standardized workflow and activity blocks with more details about the pedagogical interventions related to 4STEM factors, and has been implemented in educational robotics activities. The improved framework with an evaluation package is called C4STEM and was tested in Phase 2.

The standardized structure was developed in relation to the AVIVA model. A didactical design with a model of classroom management and a user-friendly standardised framework for designing and comparing educational robotics activities. The activity blocks have seven parameters including the pedagogical interventions related to the 4-STEM factors. The improved evaluation package was extended with a measurement tool to assess the 4-STEM factors like role models, hands-on activities and Robotics self-efficacy. The results prove that the index developed for interest in STEM, role models and Robotics self-efficacy are useable and valid. The three items used to assess the hands-on activities are not valid and have to be evaluated separately. The evaluation package was improved with an index for assessing the effect on STEM careers in three categories after the educational robotics activities. The first category assesses students' interest in studying in the STEM field after the activities, while the second category assesses students' understanding of the importance of STEM and the last category assesses students' interest to build, program or learn with robots in the future after the activities. The framework with evaluation package was called the C4STEM framework.

The final analysis of the Phase 2 with two evaluation studies tests the application of the C4STEM framework to designing educational robotics activities and answers the research question RQb2: "How does a comparison of educational robotics activities look like with this evaluation tool?". One evaluation study compares different physical educational robotics activities and one evaluates a virtual educational robotics activity as a case study. The comparison of the different educational robotics activities informs us about the impact of increasing students' interest in STEM, and how the effect of the 4STEM factors are linked with pedagogical interventions and the students' interest in a STEM career. These assessments identify best practice examples for specific gender or age groups. For example, the results of the first study, by comparing three different groups, shows that the best-of with the greatest increase in the interest in STEM was the third group. The comparison shows that the best results were in the hands-on activities in this group, too. The second evaluation study informs about the impact of the educational robotics activities in depth. The evaluation tool can help to develop recommendations for the next designs or informs us how the design works for whom. Students informed us about major challenges during the activities. This information helps us to modify and improve the activities in the future. The results show that the activities have a greater impact among girls than boys. The evaluation package offers the option to assess the impacts of different educational robotics activities on the interest in STEM, see 4STEM factors and STEM career. It is user-friendly for students and stakeholders such as teachers, educators or researchers. The next chapter presents a discussion of the thesis with an outlook.

Table 5.16: The activity block design with all information for the first part of session 1.

AB Code	Duration [min]	Name of the activity block	Goal	Student Activity	Teacher Activity	Materials
1-1	30	Introduction	Positive relationship with a role model	Identifying with the tutors.	Introduction of the tutors and the workshop activities.	Slides
1-2	30	Lecture about robots	Positive attitude to robotics	Students activate their previous knowledge and learn about definitions of technology and robotics.	Tutors present a definition of technology, nature, and robotics and link the topic with the lives of the students.	Slides
2-1	15	Install Thymio Suite	Positive achievement in the STEM field	Students download and install the Thymio Simulation with the Introduction sheet about the Thymio Suite.	Tutors give the students an introduction to the Learning management ystem.	Thymio Suite Information sheet
0-1	15	BREAK				

Table 5.17: The activity block design with all information for the second part of session 1-1.

AB Code	Duration [min]	Name of the activity block	Goal	Student Activity	Teacher Activity	Materials
2-2	20	Explore Thymio Simulation with VPL	Positive achievement in robotics.	Students open Thymio Suite and choose VPL (Visual Program Language). They research the function of Thymio Simulation.	Tutors give the students an introduction to the Learning Management System.	Thymio Simulation
0-3	10	Discussion in plenum	Positive achievement in robotics	Students talk about their challenges and first experience.	Tutors manage the presentations and provide the students with positive feedback.	Webinar
2-3	20	Push the button	Positive achievement in robotics	Students program the button of the robot on VPL and simulate the individual solutions.	Tutors are available for support or questions.	Thymio Simulation, Exercise 1

Table 5.18: The activity block design with all information for the second part of session 1-2.

0-3	5	Discussion in plenum	Positive achievement in robotics	Students present their results and talk about their handling of challenges.	Tutors manage the presentations and give them positive feedback.	Webinar
0-1	15	BREAK				

Table 5.19: The activity block design with all information for the third part of session 1.

AB Code	Duration [min]	Name of the activity block	Goal	Student Activity	Teacher Activity	Materials
2-4	15	Robots in a line	Positive achievement in robotics	Students program the sensors of robots on VPL and simulate the individual solutions.	Tutors are available for support or questions.	Thymio Simulation, Exercise 2
0-3	5	Discussion in plenum	Positive achievement in robotics	Students present their results and talk about handling the challenges.	Tutors manage the presentations and give them positive feedback.	Webinar
2-5	15	Robot in a maze	Positive achievement in robotics	Students program the sensors of robots on VPL and simulate the individual solutions.	Tutors are available for support or questions.	Thymio Simulation, Exercise 3
2-6	30	Solve a COVID-19 problem with a robot	Positive achievement in robotics	Students describe a problem, solve it with a VPL program on a robot, record the simulation and comment on the video.	Tutors are available for support or questions.	Thymio Suite, Exercise 4, Screencas-o-matic
0-3	15	Discussion in plenum	Positive achievement in robotics	Students present their results and talk about their handling of the challenges.	Tutors manage the presentations and give positive feedback.	Webinar 114
0-1	15	BREAK				

Table 5.20: The activity block design with all information for the session 2-1.

AB Code	Duration [min]	Name of the activity block	Goal	Student Activity	Teacher Activity	Materials
1-4	10	Short Introduction	Remember	Students remember their tasks and topics from session 1.	Tutor presents a short overview of Session 1 and the tasks of session 2	Webinar
0-4	10	Define a problem	Learn to develop a problem	Students define a problem linked to their real life and COVID-19.	Tutors manage the finding process and visualize the problems of all students.	Webinar
1-5	10	Design thinking (DT) process of a robot	Knowledge about DT processes for designing a robot.	Students can ask questions.	Tutors present the DT process with the worksheet	DT Worksheet
2-7	20	Develop a robot based on DT	Design a robot with the DT process.	Students develop a robot based on their individual COVID-19 problem.	Tutors are ready for support or questions.	DT Worksheet

Table 5.21: The activity block design with all information for the session 2-2.

AB Code	Duration [min]	Name of the activity block	Goal	Student Activity	Teacher Activity	Materials
1-6	10	Pitch a robot	Knowledge about a pitch for their robot.	Students can ask questions.	Tutors present the structure of a pitch.	Pitch slide
2-8	10	Prepare a pitch for your robot	Develop a pitch for their robot.	Students develop a pitch for their COVID-19 robot.	Tutors are available for support or questions.	Pitch slide
2-9	40	Pitch your robot	Positive achievement	Students pitch their COVID-19 robot.	Tutors give them positive and constructive feedback.	Webinar
0-5	10	Reflect on the workshop	Remember the teaching and positive achievement	Students reflect on their challenges, learning and experiences.	Tutors manage the process of reflection.	Webinar

Table 5.22: Interview results about the activities during the virtual workshop.

Interviewer	What did you do during the workshop?
320125f	I learnt more about programming a robot. Not just straight ahead or backwards, but also to program sensors so that the robot can move in different ways and so that the robots do not move too fast.
320123f	I solved problems during the workshop.
Interviewer	What was new in the workshop?
320123f	For me the definition of a robot was new.
320125f	The exercises were new for me.
320125f	It was the first time I participated in a webinar.
Interviewer	What was interesting and what was a challenge during the workshop?
320123f	It was interesting to program a robot and to see how the robot moved.
320125f	The biggest challenge was to program the robot so that it moves along a line. The most interesting thing was to find an individual COVID-19 problem and to solve it by programming a robot.
320119m	The most interesting thing was to move Thymio along a line and to program the sensors.
320116m	The most interesting thing was the topic about robotics, controlling a robot with programming and the exercise to program a robot to follow a line.
320115f	The most interesting exercise was to solve the COVID-19 problem and the development of the problem in the plenum. I got a lot of new ideas about problems and the different applications of robots in real life.
320115f	It was a good idea to start programming with VPL. I did not have any idea how I would start with programming, but this was a simple way to do so. In my opinion the field of robotics is a very complicated field, but this is an easy entry point. Robotics is definitely interesting.

Table 5.23: Interview results about learning strategies during the virtual workshop.

Interviewer	What did you need to solve the problems?
320123f	I needed logical thinking to solve the problems.
320125f	I needed more content-related knowledge of technology to solve the problems. I needed knowledge about sensors.
320115f	I needed logical thinking and technical knowledge for solving the problems.
320116m	I needed spatial imagination and knowledge about informatics. I did not need special knowledge. I need logical thinking.
320119m	I needed knowledge about technology and informatics.
Interviewer	How did you solve the problems?
320123f	My first experience was that I wanted to program the robot so that it moves right, but the robot moved in a circle. I tried different programs and in this way I learned to program a robot.
320115f	I learned from the lecture about the sensors and components of robots. The workshop reduced my inhibitions about doing something in technology and robotics, because before the workshop robotics seemed complicated and not so easy to find a point of entry to this topic.
320116m	I learned that I can say something to robots with the controller and that I can put a robot into an automatic mode by programming the sensors.
320115f	The most interesting exercise was to solve the COVID-19 problem and the development of the problem in the plenum. I got a lot of new ideas about problems and the different applications of robots in real life.
320115f	It was a good idea to start programming with VPL. I did not have any idea how I would start with programming, but this was a simple way. In my opinion the field of robotics is a very complicated field, but this is an easy entry point. Robotics is definitely interesting.
Interviewer	How did you learn?
320123f	The first step of my learning strategy is to try some samplings and after some time I got help from colleagues. I learnt through sharing our ideas and problems and finding a solution together.
320125f	I learned through trial and error and by talking with other colleagues and observing the solutions of others.
320116m	I found a solution by playing with the program and trial and error. I learnt thanks to the easily understandable instructions, but mostly during learning by doing. At the beginning I had an idea about a solution which did not work, but through trial and error I found another solution.
320115f	I learned through playing and by trial and error.
320119m	I learned through learning by doing.

Table 5.24: Interview results about interest in STEM.

Interviewer	How much are you interested in technology and robotic after the workshop?
320125f	I am now more interested in technology after the workshop. I want to do more with programming. It is interesting to see the different programming languages in action.
320115f	Yes, I am now more interested in technology and robotics. In robotics, definitely. Because I had never programmed a robot before and the technical background is interesting. I think I can control Thymio now. I didnâ€™t know anything about Thymio before the workshop. I had a lot of respect for informatics, because I did not have a lot of experience with it. It now looks easier for me.
320116m	I am now more interested in robotics.
320119m	Th field of robotics was really new for me and it was exciting. Yes, I can say that I am more interested in robotics than I was before.

Table 5.25: The gender comparison of robotics self-efficacy and interest in STEM before and after the workshop.

	Girls (n=4)				Boys (n=7)			
index	Pre-test		Post-test		Pre-test		Post-test	
	M	(SD)	M	(SD)	M	(SD)	M	(SD)
RSE index score	23.25	(6.94)	35.5	(7.33)	30.43	(10.52)	32.43	(5.91)
STEM index score	23.00	(2.16)	22.75	(1.26)	20.67	(2.73)	20.67	(2.50)

Table 5.26: The results of the hands-on activities with a gender comparison.

	Girls (n=4)	Boys (n=7)
Working with robots was interesting (5-point Likert scale)	4.7	4.7
Working with robots was difficult (5-point Likert scale)	1.7	3.0
Working with robots was fun (5-point Likert scale)	4.0	4.4

Table 5.27: The results on interest in studying STEM with a gender comparison.

	Girls (n=4)	Boys (n=7)
I am now more interested in studying something with technology.	1.75	1.86

6 Discussion and outlook

Educational robotics has proven to be a valuable tool for practical learning, not only about robotics but also about STEM topics in general. There are several educational robotics activities designed to promote young people in the field of STEM and to increase their interest in STEM, but they are not comparable, provable and but there is a need for a concept with practical guidelines and a validation mechanism to ensure the effective use of educational robotics in STEM. This problem is able to be divided in two different parts: it needs a framework for sharing and comparing educational robotics activities in the STEM field and an evaluation tool to assess the impact of factors which positively influence interest in the STEM field. Both are necessary parts to identify what works how and for whom, and what are the best examples.

The design-based research offers recommendations for a re-design of educational robotics activities. Therefore data about the effect of educational robotics activities are should be collected. This collection needs a standardized framework and evaluation methodology. This thesis developed a standardized framework and evaluation package is based on a mixed-methods approach. The mixed method was chosen because it can take advantage of both quantitative methods (large sample size, trends, generalization) and qualitative methods (case study, details, in depth). Both methods are different in the way of perceiving the reality, but none of them achieves the reality more objectively. Quantitative method offers what and to what extent but often fails to answer more on why and how. It is difficult to understand context of a phenomenon. The quantitative data helps to get a overview and to compare different groups or activities. The qualitative data helps to understand the context of a phenomena and the effect in depth. It provides more detailed information to explain complex issues and offers improvements for a better re-design of educational robotics activities. The data collection by the qualitative method is usually time consuming. Every method have a strength and a weakness, so it needs both in a triangulation and for qualitative data it needs time and resources to collect and analyze them. The thesis offers an approach to solve these problems with a C4STEM framework including a standardized structure and activity blocks with details about pedagogical interventions and a C4STEM evaluation package with user-friendly evaluation tools for students and stakeholders based on the mixed-methods approach.

The thesis figure out during the development of the C4STEM framework that the educational robotics community responds to the requirements of a pedagogical trend. The self-efficacy plays a huge role in increasing the interest in STEM and is a part to influence the imagination of students in their personal probabilities to solve problems. Furthermore educational robotics activities needs more space for students to make mistakes and to learn from trial and error. Students need time and place to discuss their solving ideas, results and progress work with hands-on activities. The activities will take place out of the school and students need positive relationship with tutors as role-models. The educational robotics community can add these results in educational robotics activities with the C4STEM framework and assess them with the C4STEM evaluation package.

6.1 Summary

This thesis aims to minimize the gap between recruitment needs in the STEM sector and the declining number of STEM graduates by using educational robotics activities. To this end, a framework for sharing and comparing educational robotics activities in the STEM field and an evaluation tool to assess the impact of factors which positively influence students' interest in the STEM field during these activities are necessary. The following research questions (RQ) were derived from these requirements and are answered by the thesis. There are four research questions:

RQa_1: "What does a framework need to be able to compare and share educational robotics activities in the STEM field?"

The analysis of the relevant literature and the state of the art of educational robotics activities in the STEM field (Chapter 2) led to the following results. The framework needs to be based on a theoretical background with a constructionism approach, and a teaching strategy with a problem-based learning approach and a standardized structure with the AVIVA model. The constructionism approach offers a window into what students are interested in, and able to achieve, at the different stages of their development and support learning by the exploration of what they most care about. It offers opportunities for students to engage in hands-on explorations that fuel the constructive process to get a personal experience. The problem-based learning leads to positive learning outcomes and is a pedagogical approach that enables students to learn while engaging actively with problems. The learning process is self-directed through practice and reflection. The typical problem-based learning setting is based on the belief that effective learning takes place when students both construct and co-construct ideas through social interactions. The AVIVA-Model is a didactic design contains both constructionism-oriented and instructionism-oriented approaches to foster problem solving and the constructivist learning approach with a step-by-step process leading. The AVIVA model helps to integrate the activities into a standardized structure and to implement activity blocks with the teaching strategy of problem-based learning.

All educational robotics activities in this thesis were designed against this background. The framework provides a structure with a standard template. This template is an activity plan template with an activity block template. The activity plan template offers a standardized structure for the comparison of different educational robotics activities and the activity block template provides a framework for comprehensible pedagogical interventions. It also offers the possibility of implementation in a repository for sharing these activities.

RQa_2: "Which factors positively influence the interest in STEM by educational robotics activities?"

Several factors positively influence students' interest in STEM (Chapter 2). Increasing the students' self-efficacy through more practical, hands-on lessons and establishing a good relationship between teachers and students will foster learning and will give students a feeling of success. It is necessary to coordinate in- and out-of-school activities with shared spaces for the different disciplines of STEM, and it is also advisable to implement constructionist activities in those shared spaces to allow the students to express their results and ideas in and outside of classrooms. The relevant factors, which influence the interest in STEM by educational robotics activities are 4-STEM factors with out-of-school activities, positive identification with role-models, hands-on activities and increasing Robotics self-efficacy. The impact of these factors were evaluated with the design-based research follows a three step process.

RQb_1: "Which evaluation tool can assess the impact of these factors to influence the interest in STEM positively by educational robotics activities?"

The conceptual framework developed with the name C4STEM includes an activity plan, activity blocks and a valid evaluation package with a minimum level of effort (chapter 3). This evaluation package assesses the effect of interest in STEM, role models, hands-on activities, Robotics self-efficacy and on the STEM careers of students. The evaluation employs a mixed methods approach which allows the activities to be analysed in depth. The quantitative data are collected with questionnaires before and after the educational robotics activities. The qualitative data are collected with semi-structured interviews for focus groups. The questionnaires at the beginning of the workshop provide information about gender, age, personal experience with robotics and programming, interest in STEM and the

Robotics Self-Efficacy (RSE) score. The questionnaires after the workshop provide information about how the workshops increase the interest in STEM and robotics self-efficacy, how the role model fosters students' interest in a STEM career and the effect of hands-on activities on their interest in a STEM career. The interview gives in-depth information about what works during the educational robotics activities, how and why. This makes it possible to identify best practice examples which can be used for activities in robotics workshops in the future to increase the interest in STEM.

RQb_2: "How does a comparison of educational robotics activities look like with this evaluation tool?".

The development of the conceptual framework and evaluation tool for educational robotics activities in the STEM field was guided by research question RQb_2 and carried out in three phases (Chapter 4). The first phase (Pilot study) checks the current Activity Plan Template and Evaluation Package in the STEM field and gives recommendations for the second phase. The second phase (Phase 1) develops and verifies evaluation tools related to the recommendations of the Pilot study. The third phase (Phase 2) provides the research question RQb_2 with two examples for assessing and comparing the effect of educational robotics activities on students' interest in STEM with the C4STEM Framework and evaluation package. This framework supports a better understanding and optimizing of educational robotics activities for the educational robotics community. The C4STEM Evaluation Package provides information on the results compared to another gender, age group or previous knowledge of students. It offers necessary information for redesigning and optimizing the different educational robotics activities in order to increase the number of STEM graduates and engineers in the field of robotics.

6.2 Outlook

Concluding, there is an outlook on how to use the findings of this thesis for further research steps and strategies. One research step is to use this design in more settings, with more children, in different countries and with new challenges and exercises and to identify the 'best of' within the C4STEM framework. The collected data should be made available in open access to identify the best examples for all stakeholders such as teachers, instructional designers, educational technology developers or researchers.

A further research and development step would be to analyze the correlation between the different factors and to analyze the long-term effect for a better understanding and strategy for increasing the interest in STEM among students.

One enabling strategy is linked with the understanding that the STEM field, which stands for Science, Technology, Engineering and Mathematics, is extended by the field of robotics as a part of this field. Therefore the evaluation package should provide a tool to assess the interest in robots to provide useful information about the effect of educational robotics activities.

The strategy is that educational robotics activities should not just be offered to students, but also to adults. Adults could have a further impact to bring children and young students into the field of robotics in the long term. A comprehensive database would help to conduct long-term studies and to explore different effects with best examples. These best examples would be used for the most suitable group and would conclude an effective activity to attract more young people to choose a STEM career.

Bibliography

[1] C. Kearney, „Efforts to increase students' interest in pursuing mathematics, science and technology studies and careers," *National measures taken by*, vol. 30, 2016.

[2] M Caprile, R Palmén, P Sanz, and G Dente, „Encouraging STEM studies for the labour market," *Directorate General for Internal Policies, European Union*, 2015.

[3] I. Andreitz, F. H. Müller, D. Kramer, and K. Krainer, *Wer studiert Technik? Eine Befragung österreichischer SchülerInnen und Studierender*, 2013.

[4] A. Joyce, „Stimulating interest in STEM careers among students in Europe: Supporting career choice and giving a more realistic view of STEM at work. European Schoolnet, Brussels," in *3rd Education and Employers Taskforce Research Conference: Exploring School-to-Work Transitions in International Perspectives. London, England*, 2014.

[5] *ZAHLEN, DATEN FAKTEN Arbeitsmarkt und Karrierechancen in Mathematik, Informatik, Naturwissenschaften und Technik*, (Date last accessed 15-July-2014), 2013. [Online]. Available: `http://thznetwork.net/index.php/thz-images`.

[6] B. Siciliano and O. Khatib, *Springer handbook of robotics*. Springer, 2016, ISBN: 3-319-32552-3.

[7] T. Lauwers, „Aligning capabilities of interactive educational tools to learner goals," 2010.

[8] A. Eguchi, „RoboCupJunior for promoting STEM education, 21st century skills, and technological advancement through robotics competition," *Robotics and Autonomous Systems*, vol. 75, pp. 692–699, 2016.

[9] D. Alimisis, „Educational robotics: Open questions and new challenges," *Themes in Science and Technology Education*, vol. 6, no. 1, pp. 63–71, 2013, ISSN: 1792-8788.

[10] A. Eguchi, „What is educational robotics? Theories behind it and practical implementation," in *Society for information technology & teacher education international conference*, Association for the Advancement of Computing in Education (AACE), 2010, pp. 4006–4014.

[11] Y. He and L. Liang, „Application of Robotics in Higher Education in Industry 4.0 Era,“ *Uni. J. of Edu. Research*, vol. 7, pp. 1612–1622, 2019.

[12] E. Kolberg and N. Orlev, „Robotics learning as a tool for integrating science technology curriculum in K-12 schools,“ in *31st Annual Frontiers in Education Conference. Impact on Engineering and Science Education. Conference Proceedings (Cat. No.01CH37193)*, ISSN: 0190-5848, vol. 1, Oct. 2001, T2E–12.

[13] D. Oppliger, „Using FIRST LEGO League to enhance engineering education and to increase the pool of future engineering students (work in progress),“ in *32nd Annual Frontiers in Education*, ISSN: 0190-5848, vol. 3, Nov. 2002, S4D–S4D.

[14] E. Sklar and A. Eguchi, „RoboCupJunior Four Years Later,“ en, in *RoboCup 2004: Robot Soccer World Cup VIII*, D. Nardi, M. Riedmiller, C. Sammut, and J. Santos-Victor, Eds., ser. Lecture Notes in Computer Science, Berlin, Heidelberg: Springer, 2005, pp. 172–183, ISBN: 978-3-540-32256-6.

[15] A. Bredenfeld and T. Leimbach, „The roberta initiative,“ 2010, pp. 558–567.

[16] J. Ortiz, R. Bustos, and A. Rios, „System of indicators and methodology of evaluation for the robotics in classroom,“ in *Proceedings of the 2nd International Conference on Robotics in Education (RiE 2011)*, 2011, pp. 63–70.

[17] D. Miller and I. Nourbakhsh, „Robotics for education,“ in *Springer handbook of robotics*, Springer, 2016, pp. 2115–2134.

[18] A. Ioannou and E. Makridou, „Exploring the potentials of educational robotics in the development of computational thinking: A summary of current research and practical proposal for future work,“ *Education and Information Technologies*, vol. 23, no. 6, pp. 2531–2544, 2018.

[19] Girvan Carina and C. Todorova, *Evaluation Tool Kit*, 2018. [Online]. Available: `https://zenodo.org/record/1473714#.YHgcTegzY2x`.

[20] L. Lammer, W. Lepuschitz, C. Kynigos, A. Giuliano, and C. Girvan, „ER4STEM Educational Robotics for Science, Technology, Engineering and Mathematics,“ en, in *Robotics in Education*, M. Merdan, W. Lepuschitz, G. Koppensteiner, and R. Balogh, Eds., ser. Advances in Intelligent Systems and Computing, Cham: Springer International Publishing, 2017, pp. 95–101, ISBN: 978-3-319-42975-5.

[21] N. Yiannoutsou, S. Nikitopoulou, C. Kynigos, I. Gueorguiev, and J. A. Fernandez, „Activity Plan Template: A Mediating Tool for Supporting Learning Design with Robotics," en, in *Robotics in Education*, M. Merdan, W. Lepuschitz, G. Koppensteiner, and R. Balogh, Eds., ser. Advances in Intelligent Systems and Computing, Cham: Springer International Publishing, 2017, pp. 3–13, ISBN: 978-3-319-42975-5.

[22] J. Creswell, V. Clark, M. Gutmann, and W. Hanson, „Advance Mixed methods Research Designs," in *Handbook of mixed methods in social and behavioral research*, Journal Abbreviation: Handbook of mixed methods in social and behavioral research, Jan. 2003, pp. 209–240, ISBN: 978-0-7619-2073-1.

[23] J. W. Creswell and V. L. P. Clark, *Designing and conducting mixed methods research*. Sage publications, 2017, ISBN: 1-4833-4701-X.

[24] R. A. Mead, S. L. Thomas, and J. B. Weinberg, „From grade school to grad school: An integrated STEM pipeline model through robotics," in *Robots in K-12 Education: A New Technology for Learning*, IGI Global, 2012, pp. 302–325.

[25] P. C. Honebein, T. M. Duffy, and B. J. Fishman, „Constructivism and the design of learning environments: Context and authentic activities for learning," in *Designing environments for constructive learning*, Springer, 1993, pp. 87–108.

[26] R. Kramer-Bottiglio, „Intersecting Self-Efficacy and Interest: Exploring the Impact of Soft Robot Design Experiences on Engineering Perceptions," *American Society for Engineering Education*, 2018.

[27] S. Britner, „Sources of Science Self-Efi¬$cacyBeliefsofMiddleSchoolStudents$," *Journal of research in science teaching*, vol. 43, no. 5, pp. 485–499, 2006.

[28] A. Ornstein, „The frequency of hands-on experimentation and student attitudes toward science: A statistically significant relation (2005-51-Ornstein)," *Journal of Science Education and Technology*, vol. 15, no. 3-4, pp. 285–297, 2006, ISSN: 1059-0145.

[29] B. J. Foley and C. McPhee, „Students' attitudes towards science in classes using hands-on or textbook based curriculum," *American Educational Research Association*, 2008.

[30] K. P. Dabney, R. H. Tai, J. T. Almarode, J. L. Miller-Friedmann, G. Sonnert, P. M. Sadler, and Z. Hazari, „Out-of-School Time Science Activities and Their Association with Career Interest in STEM," *International Journal of Science Education, Part B*, vol. 2, no. 1, pp. 63–79, Mar. 2012, ISSN:

2154-8455. [Online]. Available: https://doi.org/10.1080/21548455.2011.629455 (visited on 01/23/2019).

[31] N. Holstermann, D. Grube, and S. Bögeholz, „Hands-on Activities and Their Influence on Students' Interest,“ en, *Research in Science Education*, vol. 40, no. 5, pp. 743–757, Nov. 2010, ISSN: 1573-1898. [Online]. Available: https://doi.org/10.1007/s11165-009-9142-0 (visited on 05/18/2020).

[32] A. Bandura, *Self-efficacy: The exercise of control*. Macmillan, 1997, ISBN: 0-7167-2850-8.

[33] C. Hill, C. Corbett, and A. St Rose, *Why so few? Women in science, technology, engineering, and mathematics*. ERIC, 2010.

[34] K. Schwab and X. Sala-i Martin, *The Global Competitiveness Report*, en. Switzerland: World Economic Forum, 2012, OCLC: 775784625, ISBN: 978-92-95044-35-7.

[35] *Rising STEMs*, en, Library Catalog: www.cedefop.europa.eu, 2014. [Online]. Available: https://www.cedefop.europa.eu/en/publications-and-resources/statistics-and-indicators/statistics-and-graphs/rising-stems (visited on 07/31/2020).

[36] I. Kudenko and À. Gras-Velázquez, „The future of European STEM workforce: What secondary school pupils of Europe think about STEM industry and careers,“ in *Insights from Research in Science Teaching and Learning*, Springer, 2016, pp. 223–236.

[37] H Schiefele, A. Krapp, M. Prenzel, A Heiland, and H Kasten, *Principles of an Educational Theory of Interest*. Aug. 1983.

[38] A. Krapp, „An educational-psychological theory of interest and its relation to SDT,“ *The handbook of self-determination research*, pp. 405–427, Jan. 2002.

[39] A. Krapp, „An educational-psychological conceptualisation of interest,“ *International journal for educational and vocational guidance*, vol. 7, no. 1, pp. 5–21, 2007, Publisher: Springer, ISSN: 0251-2513.

[40] M. Thomas and M. Weigend, *Informatik und Natur: 6. Münsteraner Workshop zur Schulinformatik*, Deutsch, 1st ed. Books on Demand, Apr. 2014, ISBN: 978-3-7357-2042-9.

[41] M. Kandlhofer and G. Steinbauer, „Evaluating the impact of educational robotics on pupils' technical-and social-skills and science related attitudes,“ *Robotics and Autonomous Systems*, vol. 75, pp. 679–685, 2016, ISSN: 0921-8890.

[42] G. Jäggle, M. Merdan, G. Koppensteiner, W. Lepuschitz, A. Posekany, and M. Vincze, „A Study on Pupils' Motivation to Pursue a STEM Career," en, in *The Impact of the 4th Industrial Revolution on Engineering Education*, M. E. Auer, H. Hortsch, and P. Sethakul, Eds., ser. Advances in Intelligent Systems and Computing, Cham: Springer International Publishing, 2020, pp. 696–706, ISBN: 978-3-030-40274-7.

[43] R. Balogh, „I am a Robot - Competitor: A Survey of Robotic Competitions," en, *International Journal of Advanced Robotic Systems*, vol. 2, no. 2, p. 17, Jun. 2005, Publisher: SAGE Publications, ISSN: 1729-8814. [Online]. Available: `https://doi.org/10.5772/5791` (visited on 05/04/2020).

[44] R. Balogh and P. Petrovič, „Robot League - A Unique On-Line Robotics Competition," en, in *Robotics in Education*, M. Merdan, W. Lepuschitz, G. Koppensteiner, R. Balogh, and D. Obdržálek, Eds., ser. Advances in Intelligent Systems and Computing, Cham: Springer International Publishing, 2020, pp. 344–355, ISBN: 978-3-030-26945-6.

[45] A. Eguchi, „Computational thinking with educational robotics," in *Society for Information Technology & Teacher Education International Conference*, Association for the Advancement of Computing in Education (AACE), 2016, pp. 79–84.

[46] P. Petrović and R. Balogh, „Summer League: Supporting FLL Competition," 2016.

[47] F. B. V. Benitti, „Exploring the educational potential of robotics in schools: A systematic review," en, *Computers & Education*, vol. 58, no. 3, pp. 978–988, Apr. 2012, ISSN: 0360-1315. [Online]. Available: `http://www.sciencedirect.com/science/article/pii/S0360131511002508` (visited on 07/20/2020).

[48] A. Cruz-Martín, J.-A. Fernández-Madrigal, C. Galindo, J. González-Jiménez, C. Stockmans-Daou, and J.-L. Blanco-Claraco, „A LEGO Mindstorms NXT approach for teaching at data acquisition, control systems engineering and real-time systems undergraduate courses," *Computers & Education*, vol. 59, no. 3, pp. 974–988, 2012.

[49] M. J. Mataric, „Robotics education for all ages," in *Proc. AAAI Spring Symposium on Accessible, Hands-on AI and Robotics Education*, 2004.

[50] K. Davcev, N. Koceska, and S. Koceski, „A Review of Robotic Kits Used for Education Purposes," Zrenjanin, Serbia, Jun. 2019, pp. 152–155, ISBN: 978-86-7672-322-5. [Online]. Available: `http://eprints.ugd.edu.mk/22322/` (visited on 07/20/2020).

[51] M. Kiss, *Matching skills and jobs in the European Union - Think Tank*, en, Library Catalog: www.europarl.europa.eu, 2016. [Online]. Available: `https://www.europarl.europa.eu/thinktank/en/document.html?reference=EPRS_BRI%282016%29573893` (visited on 07/20/2020).

[52] D. Alimisis and C. Kynigos, „Constructionism and robotics in education," *Teacher education on robotic-enhanced constructivist pedagogical methods*, pp. 11–26, 2009, Publisher: ASPETE.

[53] K. P. King and M. Gura, *Classroom robotics: Case stories of 21st century instruction for millennial students*. IAP, 2007.

[54] I. R. Nourbakhsh, K. Crowley, A. Bhave, E. Hamner, T. Hsiu, A. Perez-Bergquist, S. Richards, and K. Wilkinson, „The robotic autonomy mobile robotics course: Robot design, curriculum design and educational assessment," *Autonomous Robots*, vol. 18, no. 1, pp. 103–127, 2005.

[55] B. Fagin and L. Merkle, „Measuring the effectiveness of robots in teaching computer science," *Acm sigcse bulletin*, vol. 35, no. 1, pp. 307–311, 2003.

[56] M. Robinson, „Robotics-driven activities: Can they improve middle school science learning?" *Bulletin of Science, Technology & Society*, vol. 25, no. 1, pp. 73–84, 2005.

[57] A. Eguchi and L. Uribe, „Robotics to promote STEM learning: Educational robotics unit for 4th grade science," in *2017 IEEE Integrated STEM Education Conference (ISEC)*, Mar. 2017, pp. 186–194.

[58] N. Arís and L. Orcos, „Educational robotics in the stage of secondary education: Empirical study on motivation and STEM skills," *Education Sciences*, vol. 9, no. 2, p. 73, 2019, Publisher: Multidisciplinary Digital Publishing Institute.

[59] S. Murphy, A. MacDonald, and L. Danaia, „Sustaining STEM: A Framework for Effective STEM Education Across the Learning Continuum," en, in *STEM Education Across the Learning Continuum: Early Childhood to Senior Secondary*, A. MacDonald, L. Danaia, and S. Murphy, Eds., Singapore: Springer, 2020, pp. 9–28, ISBN: 9789811528217. [Online]. Available: `https://doi.org/10.1007/978-981-15-2821-7_2` (visited on 07/20/2020).

[60] G. Chiazzese, M. Arrigo, A. Chifari, V. Lonati, and C. Tosto, „Educational Robotics in Primary School: Measuring the Development of Computational Thinking Skills with the Bebras Tasks," en, *Informatics*, vol. 6, no. 4, p. 43, Dec. 2019, Number: 4 Publisher: Multidisciplinary Digital Publishing Institute. [Online]. Available: `https://www.mdpi.com/2227-9709/6/4/43` (visited on 07/20/2020).

[61] S. Kubilinskiene, I. Zilinskiene, V. Dagiene, and V. Sinkevićius, „Applying Robotics in School Education: a Systematic Review," *Balt. J. Mod. Comput.*, 2017.

[62] L. Lammer, A. Weiss, and M. Vincze, *The 5-Step Plan: A Holistic Approach to Investigate Children's Ideas on Future Robotic Products.* Bamberg, 2015, vol. International Conference on Human-Robot Interaction Extended Abstracts.

[63] F. Riedo, P. Rétornaz, L. Bergeron, N. Nyffeler, and F. Mondada, „A Two Years Informal Learning Experience Using the Thymio Robot," en, in *Advances in Autonomous Mini Robots*, U. Rückert, S. Joaquin, and W. Felix, Eds., Berlin, Heidelberg: Springer, 2012, pp. 37–48, ISBN: 978-3-642-27482-4.

[64] S. Holmquist, „A multi-case study of student interactions with educational robots and impact on Science, Technology, Engineering, and Math (STEM) learning and attitudes," *Graduate Theses and Dissertations*, Apr. 2014. [Online]. Available: `https://scholarcommons.usf.edu/etd/5043`.

[65] M. Brzozowy, K. Holownicka, J. Bzdak, P. Tornese, F. Lupiañez-Villanueva, N. Vovk, J. S. de la Torre, J. Perello, I. Bonhoure, and E. Panou, „Making STEM education attractive for young people by presenting key scientific challenges and their impact on our life and career perspectives," in *Proceedings of the 11st International Technology, Education and Development Conference (INTED2017)*, 2017, pp. 9948–9957.

[66] G. Nugent, B. Barker, G. Welch, N. Grandgenett, C. Wu, and C. Nelson, „A model of factors contributing to STEM learning and career orientation," *International Journal of Science Education*, vol. 37, no. 7, pp. 1067–1088, 2015, ISBN: 0950-0693 Publisher: Taylor & Francis.

[67] E. Baran, S. C. Bilici, C. Mesutoglu, and C. Ocak, „Moving STEM beyond schools: Students' perceptions about an out-of-school STEM education program," *International Journal of Education in Mathematics, Science and Technology*, vol. 4, no. 1, pp. 9–19, 2016, ISBN: 2147-611X.

[68] J. Shin, S. R. Levy, and B. London, „Effects of role model exposure on STEM and non-STEM student engagement," *Journal of Applied Social Psychology*, vol. 46, no. 7, pp. 410–427, 2016.

[69] A. Sithole, E. T. Chiyaka, P. McCarthy, D. M. Mupinga, B. K. Bucklein, and J. Kibirige, „Student Attraction, Persistence and Retention in STEM Programs: Successes and Continuing Challenges.," *Higher Education Studies*, vol. 7, no. 1, pp. 46–59, 2017, ISBN: 1925-4741 Publisher: ERIC.

[70] T. G. Brasier, „The effects of parental involvement on students' eighth and tenth grade college aspirations: A comparative analysis," 2008.

[71] IET, „Studying Stem: What are the Barriers? A Literature Review of the Choices Students make. Stevenage:The institution of Engineering and Technology,“ en, p. 18, 2008.

[72] L. Flick, „The meanings of hands-on science,“ *Journal of Science Teacher Education*, vol. 4, no. 1, pp. 1–8, Mar. 1993, Publisher: Routledge _eprint: https://doi.org/10.1007/BF02628851, ISSN: 1046-560X. [Online]. Available: `https://doi.org/10.1007/BF02628851` (visited on 05/18/2020).

[73] J. Young, N. Ortiz, and J. Young, „STEMulating Interest: A Meta-Analysis of the Effects of Out-of-School Time on Student STEM Interest.,“ *International Journal of Education in Mathematics, Science and Technology*, vol. 5, no. 1, pp. 62–74, 2017, Publisher: ERIC.

[74] K. A. Blotnicky, T. Franz-Odendaal, F. French, and P. Joy, „A study of the correlation between STEM career knowledge, mathematics self-efficacy, career interests, and career activities on the likelihood of pursuing a STEM career among middle school students,“ *International journal of STEM education*, vol. 5, no. 1, p. 22, 2018, ISBN: 2196-7822 Publisher: Springer.

[75] M. C. Ayar and B. Yalvac, „Lessons learned: authenticity, interdisciplinarity, and mentoring for STEM learning environments,“ *International Journal of Education in Mathematics, Science and Technology*, vol. 4, no. 1, pp. 30–43, 2016.

[76] S. Compeau, *The calling of an engineer: High school students' perceptions of engineering*, en, 2016. [Online]. Available: `https://cutt.ly/Bxl2Jqj` (visited on 03/22/2021).

[77] R. Christensen, G. Knezek, and T. Tyler-Wood, „Alignment of Hands-on STEM Engagement Activities with Positive STEM Dispositions in Secondary School Students,“ en, *Journal of Science Education and Technology*, vol. 24, no. 6, pp. 898–909, Dec. 2015, ISSN: 1573-1839. [Online]. Available: `https://doi.org/10.1007/s10956-015-9572-6` (visited on 05/19/2020).

[78] S. S. Guzey, M. Harwell, and T. Moore, „Development of an Instrument to Assess Attitudes Toward Science, Technology, Engineering, and Mathematics (STEM),“ en, *School Science and Mathematics*, vol. 114, no. 6, pp. 271–279, 2014, _eprint: https://onlinelibrary.wiley.com/doi/pdf/10.1111/ssm.12077, ISSN: 1949-8594. [Online]. Available: `https://onlinelibrary.wiley.com/doi/abs/10.1111/ssm.12077` (visited on 05/19/2020).

[79] M. W. Kier, M. R. Blanchard, J. W. Osborne, and J. L. Albert, „The development of the STEM career interest survey (STEM-CIS),“ *Research in Science Education*, vol. 44, no. 3, pp. 461–481, 2014, ISSN: 0157-244X.

[80] A. Bandura, „Self-efficacy: toward a unifying theory of behavioral change.,“ *Psychological review*, vol. 84, no. 2, p. 191, 1977, Publisher: American Psychological Association, ISSN: 1939-1471.

[81] A. Bandura, „Exercise of personal and collective efficacy in changing societies,“ *Self-efficacy in changing societies*, vol. 15, p. 334, 1995.

[82] J. J. van der Bijl and L. M. Shortridge-Baggett, „The theory and measurement of the self-efficacy construct,“ eng, *Scholarly Inquiry for Nursing Practice*, vol. 15, no. 3, pp. 189–207, 2001, ISSN: 0889-7182.

[83] E. A. Locke and G. P. Latham, „Building a practically useful theory of goal setting and task motivation: A 35-year odyssey.,“ *American psychologist*, vol. 57, no. 9, p. 705, 2002, Publisher: American Psychological Association, ISSN: 1935-990X.

[84] A. D. Rittmayer and M. E. Beier, „Overview: Self-efficacy in STEM,“ *SWE-AWE CASEE Overviews*, pp. 1–12, 2008.

[85] D. Scaradozzi, L. Screpanti, and L. Cesaretti, „Towards a definition of educational robotics: a classification of tools, experiences and assessments,“ in *Smart Learning with Educational Robotics*, Springer, 2019, pp. 63–92.

[86] A. E. Kelly, R. A. Lesh, and J. Y. Baek, *Handbook of Design Research Methods in Education*, Englisch. New York : London: Routledge, Aug. 2008, ISBN: 978-0-8058-6059-7.

[87] D. Euler and P. F. E. Sloane, Eds., *Design-based research*, de, ser. Zeitschrift für Berufs- und Wirtschaftspdagogik Beiheft 27. Stuttgart: Franz Steiner Verlag, 2014, OCLC: 881822014, ISBN: 978-3-515-10838-6 978-3-515-10841-6.

[88] J. M. Angel-Fernandez and M. Vincze, „Towards a definition of educational robotics,“ 2018, p. 37.

[89] J. M. Angel-Fernandez, L. Lammer, C. Kynigos, I. Gueorguiev, P. Varbanov, W. Lepuschitz, A. Duca, J. Pullicino, M. Grizioti, N. Yiannoutsou, S. Nikitopoulou, C. Girvan, and P. Vrba, „Best Practices and Requirements,“ eng, Oct. 2018, Publisher: Zenodo. [Online]. Available: `https://zenodo.org/record/1471328#.X9tDP9hKg2w` (visited on 12/17/2020).

[90] E. Castro, F. Cecchi, M. Valente, E. Buselli, P. Salvini, and P. Dario, „Can educational robotics introduce young children to robotics and how can we measure it?“ *Journal of Computer Assisted Learning*, vol. 34, no. 6, pp. 970–977, 2018.

[91] C. Socratous and A. Ioannou, „A Study of Collaborative Knowledge Construction in STEM via Educational Robotics,“ en, Jul. 2018, Publisher: International Society of the Learning Sciences, Inc. [ISLS]. [Online]. Available: `https://repository.isls.org//handle/1/895` (visited on 09/16/2020).

[92] A Bandura, „Self-efficacy,“ 4th ser., pp. 71–81, 1994.

[93] C. Sharp, K. Pocklington, and D. Weindling, „Study support and the development of the self-regulated learner,“ *Educational Research*, vol. 44, no. 1, pp. 29–41, 2002, Publisher: Routledge, ISSN: 0013-1881. [Online]. Available: `https://doi.org/10.1080/00131880110107333` (visited on 06/03/2020).

[94] L. Üredi and S. Akbasli, „Classroom teachers' self-efficacy beliefs on constructivist approach,“ *Anthropologist*, vol. 20, no. 1, p. 2, 2015.

[95] E. Ackermann, „Piaget's constructivism, Papert's constructionism: What's the difference,“ *Future of learning group publication*, vol. 5, no. 3, p. 438, 2001.

[96] Y. B. Kafai and M. Resnick, *Constructionism in practice: Designing, thinking, and learning in a digital world*. Routledge, 2012, ISBN: 1-136-49142-2.

[97] C. Städeli, A. Grassi, K. Rhiner, and W. Obrist, *Kompetenzorientiert unterrichten: das AVIVA-Modell*. hep, der Bildungsverl., 2010, ISBN: 3-03905-459-7.

[98] G. Jäggle, L. Lammer, H. Hieber, and M. Vincze, „Technological Literacy Through Outreach with Educational Robotics,“ en, in *Robotics in Education*, M. Merdan, W. Lepuschitz, G. Koppensteiner, R. Balogh, and D. Obdrzalek, Eds., ser. Advances in Intelligent Systems and Computing, Springer International Publishing, 2020, pp. 114–125, ISBN: 978-3-030-26945-6.

[99] E. H. J. Yew and K. Goh, „Problem-Based Learning: An Overview of its Process and Impact on Learning,“ en, *Health Professions Education*, vol. 2, no. 2, pp. 75–79, Dec. 2016, ISSN: 2452-3011. [Online]. Available: `http://www.sciencedirect.com/science/article/pii/S2452301116300062` (visited on 06/05/2020).

[100] C. Kynigos, „Constructionism: Theory of learning or theory of design?“ In *Selected regular lectures from the 12th International Congress on Mathematical Education*, Springer, 2015, pp. 417–438.

[101] N. Yiannoutsou, C. Kynigos, J. Pullicino, D. Annalise, I. Gueorguiev, C. Todorovar, J. M. Angel-Fernandez, D. Diamantidis, G. Baras, C. Girvan, L. Schuster, C. Hackenberger, A. Giuliano, M. Nikolaos, M. Xenos, S. Nikitopoulou, A. Pachouli, and V. Spahos, „Final Release of Activity Plans,“ eng, Oct. 2018, Publisher: Zenodo. [Online]. Available: `https://zenodo.org/record/1473662#.X9tB1dhKg2w` (visited on 12/17/2020).

[102] G. Nugent, B. Barker, and M. Toland, *(11) Measuring the Impact of Robotics and Geospatial Technologies on Youth Science, Technology, Engineering and Mathematics Attitudes | Request PDF*, en, 2009. [Online]. Available: `https://www.researchgate.net/publication/277745061_Measuring_the_Impact_of_Robotics_and_Geospatial_Technologies_on_Youth_Science_Technology_Engineering_and_Mathematics_Attitudes` (visited on 01/16/2020).

[103] C. Girvan, S. Hopkins-Weaver, L. Saidlova, L. Schuster, C. Greka, S. Nikitopoulou, G. Jäggle, J. M. Angel-Fernandez, C. Todorova, W. Lepuschitz, and C. Kynigos, „Year 3 Evaluation,“ eng, Oct. 2018, Publisher: Zenodo. [Online]. Available: `https://zenodo.org/record/1473726#.X_7TDehKhaQ` (visited on 01/13/2021).

[104] P. Baxter, S. Jack, *et al.*, „Qualitative case study methodology: Study design and implementation for novice researchers,“ *The qualitative report*, vol. 13, no. 4, pp. 544–559, 2008.

[105] N. L. Leech and A. J. Onwuegbuzie, „A typology of mixed methods research designs,“ en, *Quality & Quantity*, vol. 43, no. 2, pp. 265–275, Mar. 2009, ISSN: 0033-5177, 1573-7845. [Online]. Available: `http://link.springer.com/10.1007/s11135-007-9105-3` (visited on 03/08/2019).

[106] C. Beierlein, A. Kovaleva, C. J. Kemper, and B. Rammstedt, „Ein Messinstrument zur Erfassung subjektiver Kompetenzerwartungen: Allgemeine Selbstwirksamkeit Kurzskala (ASKU),“ 2012.

[107] M. Blanz, „Forschungsmethoden und Statistik für die Soziale Arbeit,“ *Grundlagen und Anwendungen. Stuttgart: Kohlhammer*, 2015.

[108] G. Jäggle, L. Lammer, W. Jan-Ove, and V. Markus, „Towards a Robotics Self-Efficacy Test in Educational Robotics,“ en, in *Proceedings of the 2020 Constructionism Conference*, Dublin: Open Access, 2020, pp. 537–550, ISBN: 978-1-911566-09-0.

[109] M. B. Miles and A. M. Huberman, *Qualitative data analysis: An expanded sourcebook*. sage, 1994.

[110] C. Städeli, A. Grassi, K. Rhiner, and W. Obrist, *Kompetenzorientiert unterrichten - Das AVIVAÂ©-Modell*, Deutsch, 2nd ed. Bern: hep verlag, Jan. 2013, ISBN: 978-3-03905-900-3.

[111] R. Schwarzer and M. Jerusalem, „Skalen zur erfassung von Lehrer-und Schülermerkmalen," *Dokumentation der psychometrischen Verfahren im Rahmen der Wissenschaftlichen Begleitung des Modellversuchs Selbstwirksame Schulen. Berlin*, 1999.

[112] I. M. Riggs and L. G. Enochs, „Toward the development of an elementary teacher's science teaching efficacy belief instrument," en, *Science Education*, vol. 74, no. 6, pp. 625–637, 1990, ISSN: 1098-237X. [Online]. Available: `https://onlinelibrary.wiley.com/doi/abs/10.1002/sce.3730740605` (visited on 10/28/2019).

[113] D. L. Streiner, „Starting at the beginning: an introduction to coefficient alpha and internal consistency," *Journal of personality assessment*, vol. 80, no. 1, pp. 99–103, 2003, ISSN: 0022-3891.

[114] G. Jäggle, W. Lepuschitz, T. Tomitsch, P. Wachter, and M. Vincze, „Towards a conceptual and methodological framework for the evaluation of educational robotics activities," in *Advances in Intelligent Systems and Computing*, in press: Springer, 2020.

[115] G. Jäggle and M. Vincze, „A Conceptual Framework for Educational Robotics Activities C4STEM: A Virtual Educational Robotics Workshop," in *Handbook of Research on Using Educational Robotics to Facilitate Student Learning*, IGI Global, 2021, pp. 274–298.

[116] M. Schwichow, C. Zimmerman, S. Croker, and H. Hürtig, „What students learn from hands-on activities," en, *Journal of Research in Science Teaching*, vol. 53, no. 7, pp. 980–1002, 2016, ISSN: 1098-2736. [Online]. Available: `https://onlinelibrary.wiley.com/doi/abs/10.1002/tea.21320` (visited on 05/18/2020).