TECHNISCHE UNIVERSITÄT WIEN

DISSERTATION

Introducing Young People to Real-Life Problem-Solving in Multi-Disciplinary Teams with Robotic Product Development

ausgeführt zum Zwecke der Erlangung des akademischen Grades eines Doktors der technischen Wissenschaften unter der Leitung von

Ao.Univ.Prof. Dipl.-Ing. Dr.techn. Markus Vincze
Institut für Automatisierungs- und Regelungstechnik (E376)

eingereicht an der Technischen Universität Wien
Fakultät für Elektrotechnik und Informationstechnik

von

Dipl.-Ing. Lara Lammer
Matr. Nr.: 9230189

Wien, im Juli 2016

Lara Lammer

Abstract

Following the evidence on the positive connection between technological innovation and steady economic performance, many countries worldwide including the European Union are encouraging young people to engage in STEM (Science, Technology, Engineering, Mathematics) fields. Robots and robotics are excellent for teaching STEM. They are powerful constructionist tools that involve young learners in authentic problem-solving activities. Children easily connect robots to their personal interests and share their ideas through these tangible artefacts. Robots seem to have the ability to attract and inspire the imagination of students who are often unmotivated by conventional classroom curricula. Consequently, the field of educational robotics has gained increased importance and attention worldwide as an excellent teaching tool. However, the focus of most approaches being on teaching STEM and robotics, catching the enthusiasm of young learners who are not already interested in STEM proves to be difficult.

In this work, we introduce the Crazy Robots concept that follows constructionist and design-based learning theories as well as interaction design methods that empower young people. The concept is based on product development with the use case robotics to introduce young people to real-life problem solving in multi-disciplinary teams. In this holistic top-down approach, children are encouraged to address problems from their lives as product developers by imagining solutions that incorporate an interactive technology like robots. They start with the needs of a target group that they know very well: themselves, other children at their age or their family. Then, step-by-step, they translate their imagined solutions into sketches, descriptions, models, and finally adapt them into working prototypes. Instead of specializing on engineering or science early on, curious learners are introduced to the holistic concept of product development focusing on finding solutions to people's everyday problems in a creative way by imagining robotic solutions. At the same time, the importance of each individual talent and the immanent need for collaboration is lived by being responsible for a certain most compelling aspect of the product in a team with the common goal to "help someone with a problem". Consequently, some children are attracted to technological fields, and some prefer social or humanistic fields.

With a multiple-case study, we show that this concept addresses all young learners and introduces them to real-life problem solving and multi-disciplinary teamwork. The concept is a valuable tool for researchers, teachers, and workshop instructors to empower children, plant the seeds for conscious or critical technology users, and inspire interested children to pursue STEM careers or become innovators who tackle societal challenges of the 21st century.

Kurzfassung

Viele Länder der Welt, auch die Europäische Union, folgen den Beweisen, die eine positive Verbindung zwischen technologischer Innovation und stetiger wirtschaftlicher Leistung darlegen, und versuchen deshalb junge Menschen für MINT (Mathematik, Informatik, Naturwissenschaften, Technik) Felder zu begeistern. Roboter und Robotik sind für den MINT-Unterricht hervorragend geeignet. Sie sind leistungsstarke "konstruktionistische" Werkzeuge, die junge Lernende in authentische Problemlösungsaktivitäten einbeziehen. Kinder können Roboter leicht mit ihren persönlichen Interessen verbinden und ihre Ideen über diese Artefakte zum Anfassen kommunizieren. Roboter scheinen die Fähigkeit zu haben, die Phantasie jener Schülerinnen und Schüler zu inspirieren, die durch herkömmliche Lehrpläne oft unmotiviert sind. Folglich hat der Bereich der Bildungsrobotik weltweit als ausgezeichnetes Lehrmittel an erhöhter Bedeutung und Aufmerksamkeit gewonnen. Mit dem Fokus der meisten Ansätze auf den MINT-Unterricht und der Robotik, erweist es sich dennoch als schwierig die Begeisterung jener jungen Menschen zu erwecken, die nicht bereits an MINT interessiert sind.

In dieser Arbeit stellen wir das Konzept Schräge Roboter vor, das auf konstruktionistische und design-basierte Lerntheorien baut, so wie Methoden des Interaktionsdesigns, die junge Menschen bemächtigen, einsetzt. Es geht um Produktentwicklung mit dem Anwendungsfall Robotik, um junge Menschen an reale Problemlösung in multidisziplinären Teams heranzuführen. In diesem ganzheitlichen Top-down Ansatz werden Kinder ermutigt, Probleme aus ihrem Leben als Produktentwicklerinnen und Produktentwickler zu adressieren, in dem sie sich Lösungen vorstellen, die interaktive Technologien wie Roboter enthalten. Sie beginnen mit den Bedürfnissen einer Zielgruppe, die sie sehr gut kennen: sich selbst, andere Kinder in ihrem Alter oder ihre Familie. Dann verwandeln sie Schritt für Schritt ihre erdachten Lösungen in Skizzen, Beschreibungen, Modelle, und passen diese schließlich in funktionierende Prototypen an. Anstatt sich früh auf Technik oder Wissenschaft zu spezialisieren, werden neugierige Lernende mit dem holistischen Konzept der Produktentwicklung bekannt gemacht und fokussieren sich auf Lösungen für alltägliche Probleme von Menschen in einer kreativen Art, mit Lösungsideen aus der Robotik. Gleichzeitig durchleben sie die Wichtigkeit jedes einzelnen individuellen Talents und die immanente Notwendigkeit zur Kollaboration, in dem sie im Team für einen Teilaspekt des Produktes verantwortlich sind, mit dem gemeinsamen Ziel „jemandem mit einem Problem zu helfen". Folglich werden einige Kinder von technologischen Gebieten angezogen, und einige bevorzugen soziale oder humanistische Felder.

Mit einer Multiple-Case Studie zeigen wir, dass dieses Konzept alle jungen Lernenden berücksichtigt und sie an reale Problemlösung und multidisziplinäre Teamarbeit heranführt. Das Konzept ist ein wertvolles Werkzeug für Forscherinnen und Forscher, Lehrerinnen und Lehrer, und Leiterinnen und Leiter von Workshops, um Kinder zu ermächtigen, die Samen für bewusste oder kritische Technologie Anwender zu streuen und interessierte Kinder zu inspirieren, STEM Karrieren zu verfolgen oder Innovatoren zu werden, die gesellschaftliche Herausforderungen des 21. Jahrhunderts bewältigen.

Acknowledgments

This work would have never been accomplished without the support of many people. I am very grateful for having met each one of them.

I would like to thank my supervisor Markus Vincze for his sharp eye in trending topics, and providing me with an inspiring work environment. I would also like to thank my external reviewer, Chronis Kynigos, for believing in my ideas, encouraging me to stay in research, and being part of an amazing EU proposal turned project in education.

Special thanks go to Astrid Weiss for her encouragement and support, especially for sending me to the IDC2014 doctoral consortium, and to Andreas Huber for our inspiring discussions and work together.

Without Bernhard Weingartner and Florian Aigner pushing me into the right direction with the FWF proposal, and the teachers who participated in the FWF project with their classes, Sonja Wenig, Katharina Kanzian, Michael Adensamer, Franz Bauer, Herbert Wieninger, Holger Moser, and Michaela Götsch, these lines would not have been written. Many thanks to all of you and all your students!

I am also grateful for having met Matthias Hirschmanner who worked as my student assistant in the project. He proved to be a reliable, quick-learning, and self-sufficient colleague with inspiring ideas. Many thanks also to Dimitrios Prodromou and Christian Haas-Frangi for the Romeo robot demos, which certainly were a highlight of the student visits at the TU Wien.

The research leading to this thesis has received funding from the FWF Science Communication Projects WKP12 and WKP42, “Schräge Roboter” (“Crazy Robots”).

Last but not least, I want to thank my family for their incredible support and sacrifices to clear the path towards my goals. I love you.

Contents

Chapter 1

Introduction

Lisa is devastated by the image of a dead sea bird with its stomach torn open and full of plastics (Figure 1.1, left). This is how the nine-year-old primary school student who lives near the sea learns about the plastic pollution of the oceans. Her first reaction to the problem is having plastics forbidden altogether. She urges her parents to replace everything in their home made of plastic with other materials like glass or stainless steel. She then starts campaigning in her neighbourhood to convince her neighbours to join these efforts. She even creates a petition to change laws regarding plastic use because she sees plastics technology as the problem. Besides these long-term solutions, she organizes cleaning trips to the beach in her community. In these activities, volunteers clean the beaches and filter the immediate beach area water from plastics with colanders. Even though, in a broader sense, colanders are technology, Lisa's solutions to the ocean pollution are social, not technological.

Boyan, an 18-year-old student, is also disturbed by the million tons of plastic that enter the oceans every year and by their devastating effects on the sea life. Yet, he has another angle on the same problem: he creates technologies to tackle global issues of sustainability. Thus, he designs a machine to clean the oceans from plastic waste (Figure 1.1, right). He then founds a company, The Ocean CleanUp, which is now working on the deployment of this technological solution. Although Boyan and his team also use social components, like addressing the effects on human health and economy as well as preventing plastic waste as long-term solutions, their primary solution is based on **technological innovation**.

Figure 1.1 (left) Bird with stomach full of plastic. Photo credit: Sparkle Motion/Flickr; (right) Pilot of the coastal array. Photo credit: The OceanCleanUp

While Boyan feels comfortable with using technology as a solution for an environmental issue, Lisa rather prefers a social or humanist approach to solve a problem seemingly caused by technology. Thus, Boyan and Lisa have very different perspectives to the solution. They are two of many young people who have different talents and interests depending on their personality and environment (e.g. (Bloom, 1985), (Renzulli, 1997)). Yet, despite their differences, what do Lisa and Boyan have in common? Besides their interest in the habitat, both work on solving a "real-life" or "real-world" problem, a complex societal problem that actually exists and concerns them both.

Addressing a real-life problem in the attempt to solve it requires many different skills. Lisa and Boyan learn not only about a subject or domain through questioning, they also acquire skills like critical thinking, collaboration, or communication (e.g. (Krajcik and Shin, 2014)) which are often referenced to as deep learning or 21st century skills (Pellegrino and Hilton, 2012). Despite their differences or exactly for that reason, both are encouraged to develop collaboration and communication skills, because complex societal problems require knowledge from different domains, often too much to be overseen by one person alone, and consequently, need many experts working in multi-disciplinary teams (DeTombe, 2015). By leveraging on the combination of people with diverse characteristics, skills, knowledge, and capabilities such teams arrive at better and more creative problem solutions (Leiffer, et al., 2005). This can be observed in patient care (Plsek and Wilson, 2001) or engineering project teams (Thamhain and Wilemon, 1987). Lisa and Boyan bring in different, nearly opposed perspectives to the same problem which makes them ideal candidates in a multi-disciplinary team. What would their solution together in a team look like? Does it have to be either a technological or a social solution?

1.1 Motivation and Problem Statement

Following the evidence on the positive connection between technological innovation and steady economic performance (e.g. (Steil et al., 2002), many countries worldwide including the European Union are encouraging young people to engage in STEM (Science, Technology, Engineering, Mathematics) fields[1] (Kearney, 2016). As an excellent tool to teach STEM (Mataric, 2004) backed by humans' fascination with robots, **educational robotics** has gained increased importance and attention worldwide (IEEE Transactions, 2013). Consequently, current approaches mostly focus on teaching STEM (Baretto and Benitti, 2012) with hands-on, technical problem solving, and teamwork (Feil-Seifer and Mataric, 2009).

How many young people like Lisa would these educational robotics approaches attract? As we see with her example, not all are interested in STEM (e.g. (Rusk et al., 2008)), even further, probably influenced by their near environment, they may also be opposed to technological determinism. In the end, we may not need all young people to become robot experts, engineers or scientists. We may rather need curious learners who recognize problems in their environments and are equipped with the necessary skillsets to solve these (Wagner, 2014) or innovators who have learned to understand societal issues, solve real problems and work in multi-disciplinary teams (Gerber, et al., 2012). Educational robotics could help young people learn these skills if activities consider their different talents and interests by addressing all, not only the ones already talented and interested in STEM (e.g. (Alimisis, 2013) (Hamner et al., 2008).

[1] https://ec.europa.eu/programmes/horizon2020/en/h2020-section/science-education

1. Introduction

The motivation for this thesis is to bring educational robotics **out of the technology corner** into real-case robotic product development where the human is in the centre and the technology is the tool. Such an approach, consequently, will address all children, not only the ones interested in STEM fields, and more young people will take advantage from the benefits of educational robotics.

1.2 Contributions

Some approaches have taken up the issue, trying to address all young learners with different entry-points or project-based learning, however, the main core in educational robotics approaches remains in the fields of mechanical, electrical (or mechatronics) and computational engineering with activities around solving low-level tasks. A concept that addresses all children will enhance the impact of educational robotics in society, and thus contribute to the fields of (1) educational robotics and (2) robotics in general. First, an approach complementing existing approaches so that more children are addressed will broaden the educational robotics landscape. The concept and its instruments will introduce young people to real-life problem solving and multi-disciplinary teamwork, two important skills for success in the 21st century. Second, more people will be touched by robotics and technical product development (young people, their peers, teachers, parents, etc.), and thus will be introduced to the advantages of robotic products as well as their shortcomings. Consequently, some of the young people will get attracted to robotics fields (including STEM), and some will become more conscious or critical technology users.

1.3 Thesis Overview

This PhD thesis describes a concept called Crazy Robots that follows constructionist and design-based learning theories as well as interaction design with children methods to empower young people slipping into the role of robotic product developers. We claim that this approach:

- **addresses all young learners (C1)**, and
- **introduces young people to real-life problem solving and multi-disciplinary teamwork (C2).**

In order to support these claims, the research work based on qualitative analysis methods involves an extensive research of related work in educational robotics and related theoretical learning frameworks. These are elaborated on in **Chapter 2**. Cases where robots themselves are used as tools for teaching are excluded since it would go beyond the scope of this work.

In **Chapter 3**, first, theoretical work on product development and product design is elaborated on in order to elucidate the theories, practical work and considerations the concept is based on. Second, the two main instruments of the concept, the 5-step plan and Mattie robot designed for multi-disciplinary teamwork, are introduced in detail. Finally, the Crazy Robots concept that was developed for school classes and emulates three important phases of product development (ideation, prototyping, and evaluation) is described with the help of a pedagogical design tool, the educational robotics activity plan (Yiannoutsou et al., 2016).

1. Introduction

Chapter 4 deals with the research design which is based on qualitative data analysis methodology (e.g. (Miles et al 2013)) and structured through a **conceptual framework** that is linked to following **research questions** supporting the claims C1 and C2:

- Does an approach combining robotics and product development cover a sufficient range of fields so that young people can find their interests in the activities? **(RQ1)**
- What kind of influences on young people need to be considered during analysis? **(RQ2)**
- Does the approach offer an introduction to real-life problem solving in multi-disciplinary teams with robotic product development? **(RQ3)**

During the research, the Crazy Robots concept or its elements were applied in different settings with different groups of young people between ages 7 to 16. These groups are summarized in a multiple case study. Following cases are described in Chapter 4.

- Pilot Studies
  - One exploratory study (PS1) and one participatory observation (PS2) in 2013
  - Two exploratory studies (PS4 and PS5) and two participatory observations (PS3 and PS6) in 2014
  - Crazy Robots Project Day (PS7) in 2015
- Main Study (school year 2014/15):
  - Crazy Robots Workshops – first run (MS1)
  - Crazy Robots Workshops – second run (MS2)

Furthermore, a full variety of evidence was collected via documents, artefacts, interviews, questionnaires, and observations. Sampling, instrumentation, and qualitative data analysis with analytic memoing in four sequential cycles as well as mixed methods in certain cases to emphasise qualitative findings are also described in this chapter.

In **Chapter 5**, first, the findings of the qualitative data analysis are presented case by case from the first to the forth sequential data analysis cycle. Then, these findings are discussed from the view points of the three research questions to make the case for robotic product development in school classes to empower students by acknowledging their individual talents and interests and allowing them to work on real-life problems in teams.

In the final **Chapter 6**, the conclusions are presented and an outline for future work given. The outcome of the work contributes to the areas of Educational Robotics, Interaction Design and Children, and Human-Robot Interaction. The concept can be a valuable tool for researchers, teachers, and workshop instructors to empower children, plant the seeds for conscious or critical technology users, and inspire interested children to pursue STEM careers or become innovators who tackle societal challenges of the 21st century.

1.4 List of Publications

Parts of the content presented in this thesis have been previously published in the following manuscripts:

Lammer, L. 2014. The 5-Step Plan: Guidelines for Teaching Children Robotics as Experience Design Partners. *International Conference of Interaction Design and Children IDC'14*, Doctoral Consortium, Aarhus, Denmark

Lammer, L., Weiss, A., and Vincze, M. 2015. The 5-Step Plan: A Holistic Approach to Investigate Children's Ideas on Future Robotic Products. *International Conference of Human-Robot Interaction HRI'15*, Extended Abstracts, Portland, OR, USA

Lammer, L., Hirschmanner, M., Weiss, A., and Vincze, M. 2015. Crazy Robots – An Introduction to Robotics from the Product Developer's Perspective with the 5-Step Plan and the Mattie Robot Project Assignment. In *Proceedings of International Conference of Robotics in Education RIE'15*, Yverdon-les-Bains, Switzerland

Lammer, L. and Vincze, M. 2015. Crazy Robots – Introducing Children with Different Interests and Backgrounds to Robotics. *International Conference of Robotics in Education RIE'15*, "Which approaches do actually work when introducing children to robotics?" Workshop Position Paper, Yverdon-les-Bains, Switzerland

Hirschmanner, M., Lammer, L., and Vincze, M. 2015. Mattie Robot – a White-Box Approach for Introducing Children with Different Interests to Robotics. *International Conference of Robotics in Education RIE'15*, Short Paper and Poster, Yverdon-les-Bains, Switzerland

Hirschmanner, M., Lammer, L., and Vincze, M. 2015. Mattie - a simple robotic platform for children to realize their first robotic product ideas. *International Conference of Interaction Design and Children IDC'15*, Short Paper and Poster, Boston, USA

Lammer, L., Weiss, A., and Vincze M. 2015. The 5-Step Plan – Empowered Children's Robotic Product Ideas. *International Conference on Human-Computer Interaction INTERACT 2015*, Short Paper, Bamberg, Germany.

Lammer, L., Vincze, M., Kandlhofer, M., and Steinbauer, G. 2016. The Educational Robotics Landscape: Exploring Common Ground and Contact Points. *International Conference of Robotics in Education RIE'16*, Short Paper and Poster, Vienna, Austria

Lammer, L., Lepuschitz, W., Kynigos, Ch., Giuliano, A., and Girvan, C. 2016. ER4STEM – Educational Robotics for Science, Technology, Engineering and Mathematics. *International Conference of Robotics in Education RIE'16*, Short Paper and Poster, Vienna, Austria

1. Introduction

Furthermore, following works in robotic product development and human-robot interaction have served as basis of this work:

Lammer, L., Huber, A., Zagler, W., and Vincze, M. 2011. Mutual Care: Users will love their imperfect social assistive robots. *International Conference on Social Robotics ICSR2011*, Short paper, Amsterdam, Netherlands

Körtner, T., Schmid, A., Batko-Klein, D., Gisinger, Ch., Huber, A., Lammer, L., and Vincze, M. 2012. How Social Robots Make Older Users Really Feel Well− A Method to Assess Users‘ Concepts of a Social Robotic Assistant". *Lecture Notes in Computer Science*, Volume 7621, 2012, pp 138-147

Vincze, M., Zagler, W., Lammer, L., Weiss, A., Huber, A., Fischinger, D., Körtner, T., Schmid, A., and Gisinger, Ch. 2014. Towards a Robot for Supporting Older People to Stay Longer Independent at Home, *International Symposium on Robotics ISR2014*, Munich, Germany

Huber, A., Lammer, L., Weiss, A., and Vincze, M. 2014. Designing Adaptive Roles for Socially Assistive Robots: A New Method to Reduce Technological Determinism and Role Stereotypes. *Journal of HRI*, 3(2), 100-115.

Lammer, L., Huber, A., Weiss, A., and Vincze, M. 2014. Mutual care: How older adults react when they should help their care robot. In *AISB2014: Proceedings of the 3rd international symposium on new frontiers in human–robot interaction*. London, UK

Chapter 2

Related Work in Educational Robotics

Robotics is a widely used technology to introduce young people to science, technology, engineering and mathematics (STEM) in formal and informal learning spaces. It is an important teaching instrument for the pedagogical approach of constructionism (Alimisis, 2009) and also popular in the Maker Community. Consequently, various stakeholders are involved in educational robotics; e.g. organizations offering fun and play for different occasions like summer camps or birthday animations, technology developers commercializing different educational robots or kits, teachers looking for more engaging ways to teach their subjects, or educational researchers studying how certain activities foster certain skills (Lammer et al 2016).

Through the involvement of many different stakeholders, the educational robotics landscape is scattered and sparsely documented. For a structured approach, the categorisation suggested by Yiannoutsou and colleagues (2016) is partly used as a base to guide the reader through the educational robotics landscape. In section 2.1 Context, educational robotics activities are highlighted from the perspectives **place**, **participant**, and **theoretical framework**. In the section 2.2 Educational Activity, the activities are illuminated from the perspectives **connected with a curriculum** and **motivation for the activity**. Section 2.3 Tools describes **technology** that is used in activities and the **artefacts** produced by the young learners. Finally, in section 2.4 Evaluation, different **evaluation** goals and methods used in educational robotics are highlighted.

2.1 Context

2.1.1 Place

Information about the space where the activity takes place is important in order to understand aspects of the learning activity outcome that are influenced by the environment. There are activities in classrooms (e.g. (Barker, 2012)) orchestrated by the teacher (e.g. (Cacco and Moro, 2015)) or by other experts (e.g. (Veselovská and Mayerová, 2014)), activities in educational scientific organizations or science institutions, or activities in clubs or other places outside of schools (e.g. (Demo et al., 2014) (Nugent et al., 2016) (Nourbakhsh et al., 2005)). Students behave differently in school settings compared to outside school, as well as in mixed gender groups compared to gender based (e.g. (Milto et al., 2002) (Melchior et al., 2004)).

2.1.2 Participants

Information about the participants (age, background, culture or prior knowledge) is important so that the activity is better aligned to their needs. There are educational robotics activities classified by age considering cognitive and kinetic capabilities of the children: pre-school (e.g. (Eck et al., 2013) (Bers et al., 2002) (Rogers, 2012)), elementary school (e.g. (Sung et al., 2013) (Romero et al., 2012)), junior or senior high school (e.g. (Langley and Zadok, 2009)) or cross-generational where, for example, Kandlhofer and colleagues (2013) brought kindergarten children together with their grandparents. In some cases, activities are designed for children with special needs (e.g. for autistic children (Ismail et al., 2012)).

Children's perception of robots and their interaction with robots are influenced by culture (e.g. (Shahid et al., 2014)) and prior knowledge. Since in most cases the interaction with a robot is a novel experience, prior knowledge and expectations come from other sources than past experiences, like popular culture or science fiction (e.g. (Feil-Seifer and Mataric, 2009) (Kriz et al., 2010)). There are also already established notions in society concerning robotic technology, e.g. robustness, intelligence, autonomy, and anthropomorphism (Jacobssen et al., 2013) which play into these expectations.

In recent years, through the popularity of educational robotics, another phenomenon has emerged: the prior knowledge of robots and robotics, and thus the expectations from an educational robotics activity can be formed by previous activities. Furthermore, according to Kandlhofer and Steinbauer's (2016) study, young people who sign up for educational robotics activities are already interested in STEM. The influence of educational robotics activities and environmental factors on participants is discussed in Chapter 5 section 5.5.2 under the second research question (RQ2).

2.1.3 Theoretical Framework

There are different pedagogical approaches underlying educational robotics activities. For example, constructionism (e.g. (Alimisis, 2009) (Stager, 2010)), project-based learning (e.g. (Frangou et al., 2008) (Martin et al., 2000) (Langley and Zadok, 2009) (Val and Pastor, 2012)), design-based learning (e.g. (Flannery and Bers, 2013) (Urrea, 2001)), problem-based learning (e.g. (Hamner et al., 2010) (Weirich et al., 2010) (Hernandez-Barrera, 2014)), collaborative learning (e.g. (Denis and Hubert, 2001) (Kabátová and Pekárová, 2010) (Weirich et al., 2011)), learning by doing (e.g. (Romero et al., 2012) (Veselovská and Mayerová, 2014)) or inquiry-based learning (e.g. (Eck et al., 2013) (Demo et al., 2014)). Many of these approaches are not mutually exclusive, thus can be combined with each other for informed learning experiences during educational robotics activities. In many documented cases, the theoretical framework of the activity is not explicitly referred to, sometimes guessable from the way the activity is orchestrated. Before moving on to the next section, we will have a short discourse to two main theoretical frameworks that are widely used in educational robotics: constructionism and project-based learning.

Motivation and emotions play an important role in learning. Children are driven to grow and assert themselves, as well as to love and be loved. Considering these drivers, adapting learning activities to **children's lives and interests** (Piaget, 1969) and empowering children to learn through play (Montessori, 1964) will motivate them. These ideas build the base of the theoretical framework of constructivism. Furthermore, according to Bruner's (2009) constructivist learning theories, the act of learning involves three almost synchronous processes: acquisition (gaining new information), transformation (changing old information into new information), and evaluation (judging if the information change makes sense). Bruner sees the learning experience in a spiral where something new can be learned with refined repetitions. A growing child is provided with problems that tempt him or her into the next stages of development while the teaching is built on earlier reactions to create more explicit and mature understanding (Bruner, 2009). Social support enhances the learning experience; knowledge and strategies are shared and developed through social interaction with other people. Language, tools and artefacts are important media to externalize ideas, which in turn is key for **communication** with others (Vygotsky, 1978).

Tangible artefacts build the base for an important theory of learning and education strategy, **constructionism**, a term coined by Seymour Papert based on the constructivist theoretical framework of Piaget and others. The main idea is that "*learners actively construct and reconstruct knowledge out of their experiences in the world […] by building personally meaningful artefacts*" (Kafai and Resnick, 1996). Based on the principles of constructionism, Resnick (2014) suggests that children need four things to flourish: project, passion, peers, and play. These are the 4 P's of creative learning. People learn best when they actively work on projects that are meaningful to them by generating new ideas, designing prototypes and refining them iteratively. Working on a project that is related to their life or is important to them motivates people to work harder and longer, enhances their persistence in case of drawbacks, and may even evolve into a passion. When people share ideas and **collaborate** on projects with peers the learning flourishes as a social activity. Learning also involves playful experimentation like trying new things, testing boundaries or taking risks (Resnick, 2014).

At the same time, **playing** can diverse from the pursuit of rationality (e.g., the building of useful artefacts), into humor and whimsy that are also meaningful as "*oblique ways of looking at the world that brings about new insights*" (e.g., pretense or phantasy play) (Ackerman, 2014). New insights or ideas can be externalized or given form in different ways, e.g. as a poem or song (auditory), a prototype or drawing (tactile), or a scheme or description (visual), and thus become tangible and shareable, which in turn helps the ideas to be formed and transformed (Papert and Harel, 1991). As sharing ideas and building new ideas on experiences with others are crucial parts of the constructionist learning process, collaboration and **communication** become important constructionist elements (Kafai and Resnick, 1996).

Project-based learning (PBL) also has its roots in constructivist learning theories (Condliffe, 2016) and many intersections with constructionism. It is an approach that supports deeper learning and 21st century skills (Pellegrino and Hilton, 2012) by involving students in the construction of knowledge and in-depth inquiry through active exploration of **real-life problems** and challenges. These activities can "*mirror the complex social situation of expert problem solving*" and thus introduce students to **problem-solving** and critical thinking skills. Furthermore, **collaboration** skills "*should lead students to confront and resolve conflicting ideas*".

Condliffe (2016) summarizes the design principles of PBL activities in her literature review as following:

1. Curriculum design principles (what is taught?)
    a. Driving questions to motivate learning
    b. Targeting significant learning goals
    c. Using projects to promote learning
    d. Dedicating sufficient time
2. Instructional approaches (how do students develop new skills and knowledge?)
    a. Promoting the construction of knowledge
    b. Cultivating student engagement
    c. Using scaffolds to guide student learning
    d. Encouraging student choice
    e. Supporting collaborative learning
3. Assessment design principles (how do students demonstrate learning?)
    a. Creating a product that answers the driving question
    b. Providing opportunities for student reflection and teacher feedback
    c. Presenting products to authentic public audiences

Design-based learning is a special case of PBL. It can introduce young people to the holistic view of product design as well as the notion and practices of design thinking (Grammenos, 2015). While engineering design education with robotics has been followed at university level (e.g. (Kokosy, 2014) (Gerber et al., 2012)), there are only a few researchers combining the advantages of educational robotics and design-based learning for younger students, mostly focusing on very young children (e.g. (Flannery and Bers, 2013) (Bers and Urrea, 2000) (Urrea, 2001)).

The Crazy Robots concept is based on the theoretical frameworks of constructionism, project-based and design-based learning. The reasons why the Crazy Robots educational activities evolve around robotic product development and how it is implemented in the concept are elaborated on in Chapter 3.

2.2 Educational Activity

2.2.1 Connected with a Curriculum

In some cases, activities are connected to a curriculum (e.g. (Sullivan and Bers, 2015) (Kohlberg and Orley, 2001) (Mataric, 2004) (Mead et al., 2012), (Nourbakhsh, Crowley, et al., 2005) (Hirsch et al., 2009)). In other cases, activities are built around a framework with a community (e.g. (Alimisis, 2009)[1] (Lammer et al., 2016)[2]).

2.2.2 Motivation for the Activity

A comprehension of the different motivations of stakeholders helps to understand the design, orchestration and outcome of activities. Many activities evolve around the motivation to evoke interest in STEM fields (e.g. (Mead et al., 2012) (Bredenfeld and Leimbach, 2010)). In

[1] Terecop Project at terecop.eu
[2] ER4STEM Project at er4stem.com

some cases, there are more specific motivations, like teaching robotics (Yudin, 2016), mathematics (Norton, 2004), physics (Williams et al., 2007), computational thinking (Caitlin and Woollard, 2014), engineering (Rogers, 2012), programming design and project management (Wolz, 2000) or mechanics (Chambers et al., 2008). Consequently, the focus of most approaches is on teaching STEM and robotics (Baretto and Benitti, 2012) as well as hands-on problem solving, teamwork, and innovation (Feil-Seifer and Matarić, 2009).

However, activities being short-term, high-intensity, competition driven (e.g. First League (Melchior et al., 2004), RoboCup Junior (Sklar et al., 2000), Botball (Koppensteiner et al., 2015)), and technology focused may limit participant diversity (Hamner, 2008). Alimisis (2013) similarly argues that the way robotics is currently introduced in educational settings is narrow. Furthermore, he reasons that educational robotics could provide constructionist learning experiences for all learners in order to promote technological and computational fluency (or literacy). If young people with a wider range of interests are to be addressed, broader perspective projects and new and innovative ways to increase the attractiveness and learning profits of robotics are needed. Kandlhofer and Steinbauer (2016) confirm this by arguing that the results of their study suggests that the "*concept of educational robotics should not only focus on separate, isolated topics but [..] also be applied as an integrated approach, fostering a holistic understanding and acceptance of different areas and fields*".

In this sense, Rusk and colleagues (2008) suggest following strategies as new pathways into robotics: focusing on themes, not just challenges; combining art and engineering; encouraging storytelling; and encouraging exhibitions rather than competitions. For example, Artbotics (Yanco et al., 2006) is one such approach that combines art and technology in order to broaden participation. Another example is the Roberta Initiative that offers a course concept using robot construction kits with gender-balanced didactic material to address young people with other interests, especially girls (Bredenfeld and Leimbach, 2010).

There are a few approaches that have taken educational robotics from teaching STEM or robotics to teaching any concept as Stager (2010) suggests. For example, in *teutolab* young people learn human-robot interaction in a playful way with the same robots used by researchers (Weirich, 2010). Holistic learning experiences can be used to support the development of technological fluency, e.g. with personally meaningful robotic projects that engage young children in learning complex abstract ideas in combination with storytelling (Bers, 2008) or with design projects that incorporate storytelling (Martin et al., 2000) (Sung et al., 2013). Storytelling has been used to facilitate collaboration in different contexts including design or children (e.g. (Benford et al., 2000) (Lutters, 2002) (Kahan, 2006)). It is the oldest method of knowledge transfer and popular through all ages (Katuscáková, 2015). Other activities are motivated to teach math, science, reading and writing through design (McNamara et al., 1999), technological fluency along with design skills (Hamner, 2008), natural science with a real-life scenario (Cacco and Moro, 2015) or **real-life problem solving** in **multi-disciplinary** settings (Zubricky and Granosik, 2015).

Real-life problem solving deeply connects with personal interests. Young people thrive when they solve real-life problems through projects (Resnick, 2014). Further elaborations on activities engaging young people in real-life problem solving and multi-disciplinary teamwork, and especially how it is implemented in the Crazy Robots concept can be found in

Chapter 3. The resulting findings from the case study are discussed in Chapter 5 section 5.5.3 under the third research question (RQ3).

2.3 Tools

2.3.1 Technology

The specific technology used for the implementation of an activity should facilitate the learning objectives and motivation. Hendler (2000) separates robots for children into the categories toys, pets, interactive displays, educational robotics, and service robotics. Bertel and colleagues (2013) further distinguish between educational robotics (or hands-on robotics) and educational service robots. Mubin and colleagues (2013) describe a robot's role in the learning activity as a tutor, tool or peer. In this related work analysis, the focus will be on educational robots as a learning tool that young people construct, re-construct or control. This includes commercially available "black-box" robots (e.g. Thymio (Magnenat et al., 2014)) as well as maker electronics for building robots from scratch (e.g. MakeyMakey[3] or Arduino[4]).

Robots and robotics are powerful constructionist tools that involve young learners in authentic **problem-solving** activities (Alimisis, 2009). Children can easily connect robots to their personal interests and share their ideas through these tangible artefacts (Rusk et al., 2008). Also, people find robots fascinating (e.g. (Oh and Park, 2014)), and students have a great sense of accomplishment even after building or programming the simplest systems and watching them work (Welty et al, 1998). Robots seem to have the ability to attract and inspire the imagination of students who are often unmotivated by conventional classroom curricula (Hendler, 2000). Robotics is excellent to teach any concept (Stager, 2010) because it involves more subject areas than other motivating contexts (Johnson, 2003). Educational robotics can be used across broad educational themes that extend beyond STEM as well as in teaching skills like problem solving, **collaboration** and **communication** (Nourbakhsh, 2005). In fact, educational robotics proves to be an excellent learning tool to teach so-called 21st century skills like collaboration and team work, critical thinking and problem-solving, communication, and creative thinking skills (4Cs) (Eguchi, 2014a). At the same time, it is "*a transformational tool for learning, computational thinking, coding, and engineering*" (Eguchi 2014b). In Chapter 5 section 5.5.1 under the first research question (RQ1), the findings on why robots and robotics make such a nice tool for learning are discussed from the perspective of the multiple case study.

There are many educational robotics technologies with some of them very successfully deployed (Karim and Mondada (2015) offer an overview). The teaching medium is important, its particular properties limit or enhance what young people can build, create, and learn (Resnick et al., 2000). Thus, in designing a teaching medium, developers should also consider learning goals. E.g. should young people understand the inner workings of a technology or should they learn other content through the technology? Depending on the goal, technology developers can hide the inner workings completely by using "black boxes" (e.g. LEGO mindstorms (Melchior et al., 2004) or Cubelets (Correll et al., 2012)), "selectively expose"

[3] makeymakey.com
[4] arduino.cc

them (Blikstein, 2013), use "black-and-white" approaches (Kynigos, 2008), or let users start from scratch with "white-box designs" (e.g. Arduino (Buechley et al., 2010)). The findings on the influence of the technology used are discussed in Chapter 5 section 5.5.2 under the second research question (RQ2).

The domain of robotics represents a multi-disciplinary and highly innovative field encompassing engineering, design as well as social sciences. However, the available technologies in educational robotics do not support activities for learning social sciences and humanities, despite voices suggesting the importance of those two in engineering education (e.g. (Hynes and Swenson, 2013) (Sanders, 2008)). Very often, the activities focus on working prototypes, an outcome from the engineering perspective. Yet, when solving a real-world problem, a working prototype is only one part of the solution. The holistic view that sees the robotic solution as a product with other concerns like production, procurement, sales, marketing, R&D (research and development) or customer service is missing. In Chapter 3 Crazy Robots Concept, the necessity of product development processes in robotics activities and how they are implemented in the Crazy Robots concept are elaborated on. The findings regarding the use of product development and design are offered in Chapter 5 section 5.5.1 under the first research question (RQ1).

2.3.2 Types of Artefacts Produced

The outcome of the activity usually influences the satisfaction of participants. This can be a piece of programming code for a robot accomplishing a certain task (e.g. (Cacco and Moro, 2015)), a robot prototype built from scratch (e.g. (Sklar et al., 2000)), a blog or diary (e.g. (Hamner et al., 2008)) or an artefact to present (e.g. (Zubricky and Granosik, 2015)). In Figure 2.1 some examples of student artefacts from various activities involving robots are shown. Rewards or quick-wins along the way are important as is failure and learning from things going different than expected. The artefacts also give evaluators the opportunity to analyse the activity.

Figure 2.1. Student artefacts in educational robotics activities (clockwise): Rooster robots (source www.titech.ac.jp), Code to move Sphero robot (source qz.com), Audrey's "Happy robot" (source josettebrouwer.edublogs.org), robots following a line (source ocio.grc.nasa.gov), and robots unloading a spacecraft at ESA challenge (source www.esa.int)

2.4 Evaluation of the Activity

A methodological evaluation of the activity is important in order to understand if the educational or other objectives are achieved, and thus have an informed understanding about what needs to be improved. Studies that focus on investigating the impact of educational robotics on students' skills or science related attitudes and interests in an empirical way are rare (Baretto and Benitti, 2012) (Kandlhofer and Steinbauer, 2016). Most often pre- and post-tests and self-assessment surveys or questionnaires are used as instruments to have quantitative results about certain skills or attitudes (e.g. (Nugent et al., 2016) (Chambers et al., 2008) (Weirich et al., 2010) (Flannery and Bers, 2013)). Sometimes electronic activity logs are also used to display findings with quantitative analysis (e.g. (Hamner et al., 2008)).

Quantitative results may well answer the "what" and "how many" research questions, however, they do not give insights into the "how" and "why" questions (Borrego et al., 2009). Thus, for a better understanding of the activity design and the influence on students, many educational robotics evaluations are based on qualitative data analysis and use the instruments observation, interview or inquiry (e.g. (Dennis and Hubert, 2001) (Milto et al., 2002) (Hamner et al., 2010)), or the analysis of artefacts, blogs or reflective essays (e.g. (Eguchi, 2014a) (Cacco and Moro, 2015) (Veselovská and Mayerová, 2014)) or combinations. In some cases, mixed-methods combine quantitative with qualitative data analysis (e.g. (Eguchi 2014a)).

2.5 Summary

In this chapter, the reader was taken to a brief excursion through the educational robotics landscape. Different educational activities following various goals and concepts were listed to show the broadness of the landscape. In order to have a structured presentation, the landscape was divided into the context of the activity, its description, the tools used and produced, and evaluation. Educational robotics has big potential to help young people learn how to recognize problems in their environments and solve these, especially if activities consider their different talents and interests by not only addressing the ones already talented and interested in STEM. Current approaches seem rather to be focused on either STEM, robotics, and technical problem solving, or on holistic approaches with tinkering or storytelling for very young children. An approach for older children that takes the holistic concept of robotics into consideration to address more young learners is missing.

What kinds of innovative solutions for everyday problems would Boran and Lisa create together in collaboration? Probably, we will never know because Lisa would not join an educational robotics activity voluntarily, and if she participated, she would have her beliefs about technology and engineering like "boring" or "nerd stuff" confirmed or would not make the connection between the fun activity that she just had and the polluted oceans. In the next chapter, the Crazy Robots concept will be introduced, designed with the aim to address all young people and introduce them to real-life problem solving in multi-disciplinary teams.

"Design is the practice of intentional creation to enhance the world. It is a field of doing and making, creating great products and services that fit human needs that delight and inform. Design is exciting because it calls upon the arts and humanities, the social, physical, and biological sciences, engineering and business. Design thinking comprises strategies for finding and solving problems by bringing an understanding of people and society to technology design, focusing upon finding the correct problem before rushing to a solution. We believe that design thinking skills will be a key success factor for a new generation of creative leaders in technology, business, and education." – Don Norman

Chapter 3

Crazy Robots (Schräge Roboter) Concept

Crazy Robots (Lammer et al., 2015a) is a concept based on product development with the use case robotics to introduce young people to real-life problem solving in multi-disciplinary teams. In this holistic **top-down** approach, children are encouraged to address problems from their lives as product developers by imagining solutions that incorporate an interactive technology like robots. They start with the needs of a target group that they know very well: themselves, other children at their age or their family. Then, step-by-step, they translate their imagined solutions into sketches, descriptions, models, and finally adapt them into working prototypes. The focus is on **finding creative solutions to real needs and presenting these to others with tangible artefacts**. At the same time, the importance of each individual talent and the immanent need for **collaboration** is lived by being responsible for a certain most compelling aspect of the product in a team with the common goal to "**help someone with a problem"**.

This educational robotics concept is designed for school settings in order to address all children regardless of their interests and talents, and builds on the theoretical frameworks of constructionism, project-based and design-based learning. It distinguishes itself from most of the educational robotics approaches that focus on teaching STEM (science, technology, engineering, mathematics), robotics or other curricular subjects by offering a holistic learning experience to young people and showing them the immense possibilities and application areas in robotics. Thus, young people learn about robotics and product development from the perspective of their own talents and interests and discover how they can contribute in making the world a better place or only improving their own lives, for that matter.

The educational goal of the approach is to give young people an experience in **solving a problem** that can be applied in **real life** together with their peers who have different personalities, talents and interests, and thus to create an awareness about the importance of collaboration and **communication** when problems become as complex as robotics technology is. Young people are encouraged to engage in defining problems that they see in the world or in their near environments, and then come up with **creative ideas** to solve them.

However, before entering the details of the Crazy Robots concept, theoretical frameworks and practical applications from industrial product development (section 3.1) and product design (3.2) need to be described because they build the structure of the concept. Based on this structure, three instruments were developed: the 5-step plan (Lammer et al., 2015b), multi-disciplinary teamwork with Mattie robot (Hirschmanner et al., 2015), and the workshop series structure. Those are described in section 3.3. Finally, after giving a rationale on why and how elements from product development and product design were incorporated as well as the introduction of the three main instruments of the concept, the Crazy Robots concept itself is described in detail with the help of a pedagogical tool, the activity plan (Yiannoutsou et al., 2016), in section 3.4.

3.1 Product Development

Krishnan and Ulrich (2001) define product development as "*the transformation of a market opportunity and a set of assumptions about product technology into a product available for sale*". In their survey, they have identified four different perspectives to product development: marketing (product positioning and pricing, customer needs), organizations (organizational alignment), engineering design (creative product concept), and operations management (production, suppliers, project management). Thus, many experts and managers are involved in the development of a product, especially when it has the complexity of an automobile (e.g. (Gülke et al., 2012)).

In complexity, service robots are not different than automobiles. Their development requires the integration of highly dependent single robotic components like navigation, manipulation or human-robot interaction which are in turn complex and involve multiple disciplines. However, a clear service robot product development process has not been defined yet. This seems to be the reason why many robot research projects focus on developing single components (Prassler, 2012). Interestingly, educational robotics approaches that teach robotics also follow this pattern. The most common tasks young people solve in these kind of activities are navigation and manipulation, followed by human-robot interaction. There is no process that describes robotic product development for children. The 5-step plan (section 3.3.1) emerged from this need, and consequently prepared the grounds for the product development approach of the Crazy Robots concept with its workshop series structure based on design phases and multi-disciplinary teamwork with the Mattie robot platform.

Offering product development to young people will address them from three perspectives:

1. Global thinkers who like situations in which they are not concerned with details and like to see how the task fits into the general picture (Sternberg, 1999), and thus are not interested in bottom-up task solving during educational activities become interested with a top-down approach.

2. By getting involved in multi-disciplinary teamwork that goes beyond engineering and design (as is the case in most educational robotics activities), more young people have the chance to contribute their talents in subject areas that interest them, e.g. by adding sales, marketing or project management.
3. Giving young people the opportunity and tools to create something “on their own” that is related to a **real-life** problem will engage them. Thus, in a classroom context with a certain heterogeneity in talents and interests of young people, a wider audience will be addressed.

Using robotics and its application areas as the final product will address even more young people. Besides the fascination and motivation robots invoke (section 2.3.1), robotics covers a broad range of fields:

- research & development (engineering **science**)
- **technology**
- **engineering** (mechanical, electrical, and computer science)
- design (**arts**)
- **mathematics** (formal science)
- project management
- human-robot interaction
- law and business administration (social sciences)
- ethics (humanities)
- any other domain where the robotic product is applied to, like medicine, geriatrics, chemistry, agriculture or environmental sciences.

With guidance and encouragement young people can connect the problem that they want to address as well as their interests and talents to one of these fields. They discover fields that they can specialize in or areas where they can work as global thinkers. In this sense, experimentation is important, thus young people should also be encouraged to try areas that they do not feel comfortable with to understand their talents and personalities, e.g. become a project manager in one workshop, then a user evaluation specialist in another.

Robotic product development is complex. A real robot is not built in two hours by one person. There is a reason why robots are not seen walking around the streets or throwing households. We deem this connection to reality important. However, from an educational perspective, it is also important to give young people a sense of achievement along with the knowledge about possible career paths in robotics when the workshops are finished. For this reason, the Mattie robot platform is used (section 3.3.2) and the class visits the TU Wien Vision for Robotics (V4R) lab, so that young people can see “real” experts at work, watch demonstrations of “real” robots, and ask questions. Research question one (RQ1) asks why robots, robotics and product development can address all young people. In Chapter 5 section 5.5.1, findings are discussed taking into account if the theoretical considerations above find ground in the practical implementation of the Crazy Robots concept.

3.2 Product Design

The product development process determines whether a company is innovative and successful (e.g. (Kahn, 2013) (Schrage, 2000)). Product design (or engineering design), traditionally viewed as one perspective of the product development process or even merely a "nice wrapping" of the product, has become an important key for successful innovation (Brown, 2009). The British Design Council conducted a study to analyse the design process in eleven successful companies (BDC). Although, the companies and their products were very different, the researchers found striking similarities and shared approaches in the design processes, so they mapped those into the Double Diamond Design Process Model that divides the design process into four distinctive phases: discover, define, design, and deliver (Figure 3.1). The process encourages divergent and convergent thinking alternatingly. First, from the identified problem many ideas and options are brainstormed to create choices (divergent thinking). Then, the existing alternatives are analysed in a practical way to decide among them (convergent thinking). After the problem is defined, both these steps are repeated again to reach a final solution.

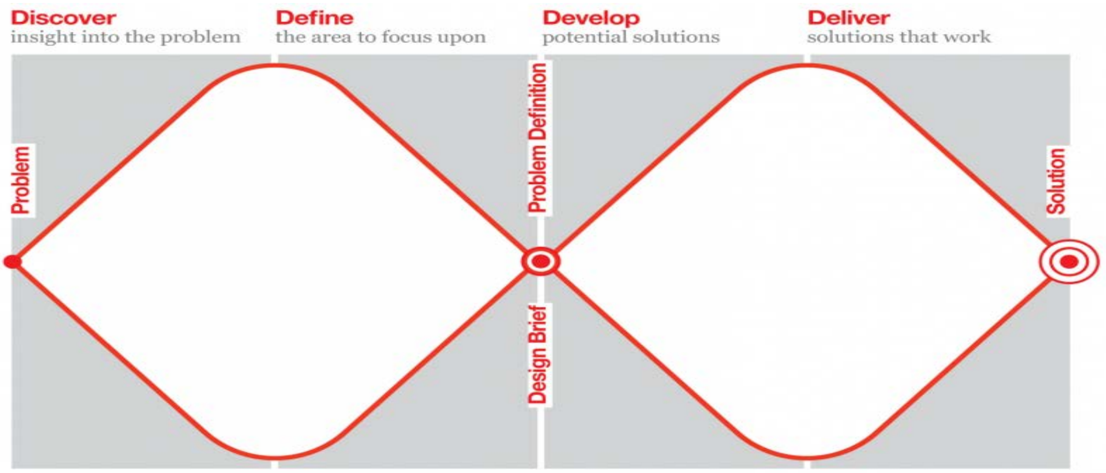


Figure 3.1 The Double Diamond Design Process Model.
Photo Source: rachelraynard.com

Looking at the phases in more detail, the discover phase is dedicated to the **identification of user needs** (divergent thinking); in the define phase the needs are **aligned with the business objectives** (convergent thinking); the develop phase signifies the time where design-led solutions are developed, iterated and tested within the company (divergent thinking); and finally in the deliver phase the product or service is finalised and launched in the relevant market (convergent thinking).

Brown (2009) describes the design process as chaotic and divergent for creativity to flow and the best idea to take on. This kind of thinking underlies the methodology of **design thinking** that "*imbues the full spectrum of innovation activities with a human-centred design ethos*". The process has rather "*a system of spaces*" than linear milestone-based steps which a design project must pass. The design team works in-between three distinctive spaces which Brown names inspiration, **ideation**, and implementation. The outcome, an innovative product or service, is the result of "*hard work augmented by a creative human-centred discovery process and followed by iterative cycles of prototyping, testing, and refinement*" (Brown, 2009)

Actually, design thinking is more than design, it is a "*mind set, the confidence that everyone can be part of creating a more desirable future*", as IDEO[1], a successful business consulting company and expert in design thinking, describes it. Recently, the company offers a tool kit for educators to implement design thinking in their classrooms[2], where they have adapted the same processes, methods, and tools that they use at the company in tackling complex challenges. In this toolkit, they describe the design process in five phases: discovery, interpretation, **ideation**, experimentation, and evolution. Every phase has its questions and instruments to provide a simple structure and guidance for the creative process. Figure 3.2 shows the five phases in an overview.

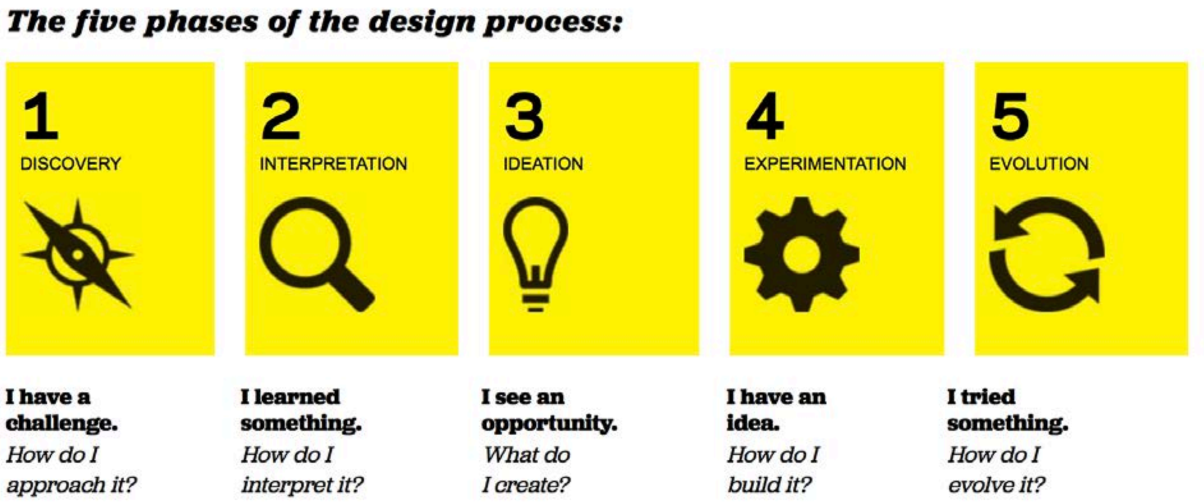


Figure 3.2 The design process.
Source: http://www.designthinkingforeducators.com

The structure of the Crazy Robots concept supports the creative process and shares the same values as the design thinking toolkit describes: human-centred, collaborative, optimistic, and experimental (=learning from mistakes). It follows a simplified product design process **from ideation to prototyping to evaluation** (section 3.3.3). It also borrows methods and instruments from various participatory design approaches that consider growth (learning by doing), diversity (not everyone will arrive with the same set of skills) and motivation.

For example, **learner-centred design** promotes participants' understanding, creating and sustaining their motivation, offers a diversity of learning techniques, and encourages the individual's growth through an adaptable product (Soloway, 1994). Another design method is **bonded design**, where children participate for a short but intensive time in activities with adult designers. The techniques include brainstorming to generate new ideas, paper-prototyping design ideas both individually and in small groups, and building a consensus on a final low-tech prototype (Large, 2008). Finally, in **cooperative inquiry** children and adults

[1] https://www.ideo.com
[2] http://www.designthinkingforeducators.com

work together as partners throughout the design process in a collaborative and elaborative manner (Druin, 2002); this leads to **empowered children** as well as a wide range of **creative and innovative ideas** (Fails, 2012).

Design-based learning (DBL) approaches (briefly mentioned in Chapter 2 section 2.1.3) build on industrial product design processes and participatory design with children methods. As Doppelt (2008) describes, DBL provides students the possibility to design and engage in inventive and creative projects to initiate the learning process **fitted to their preferences, learning styles and skills**. Consequently, students develop a rich understanding of design and technology, are motivated to learn because of the application of their knowledge to **real-life** situations, construct knowledge in an active learning process that recognizes their different learning styles, and **collaborate** in a team that helps them to develop **interpersonal communication skills, presentation and problem solving skills**.

Doppelt (2008) also argues that DBL may motivate students in a classroom, but the open-ended nature of the activity may leave low-achievers behind, and DBL can be too difficult to learn for teachers and students (see also (Kolodner, 1998)). Mishra (2006) confirms this by arguing that adapting open-ended problem solving situations into the structure and organization of the conventional classroom is difficult. However, learning the exact design process is not the focus, rather it is essential that students document their process and learn to reflect on their creations properly (Doppelt, 2008). Furthermore, in a holistic learning experience, children's curiosity should be respected and nurtured (Bers, 2000). Resnick and Silverman (2005) suggest that the **best learning experiences occur, when people are actively engaged in designing and creating things**. Inducing the right mind set and confidence that enables young people to create a robotic solution for a real-life problem is a useful addition to the different kind of educational robotics activity goals that already exist.

Designing and creating things, thus **prototyping** is an important part of the design process. However, building a robot prototype for a real application takes time and the effort of many experts in the field, e.g. the first prototype of the HOBBIT robot was built in a year and could only be used in a wizard-of-oz setting (=controlled by a technician), the second prototype two years after that[3]. On the other hand, building a LEGO Mindstorms robot to follow a line does not really connect to the interests of all young people, e.g. Lisa would probably not see the connection to the solution of environmental problems with robots. But then, how do "real" experts deal with the difficulties?

Schrage (2000) argues that in industry, rapid iteration of prototypes, models or simulations make the essence of innovation. For example, the design studio is a process for software design and a project-based approach where software architects work on complex and open ended problems. They focus on user needs and practices keeping the whole in mind (top-down), consider the heterogeneity of the issues, and **use constraints creatively to rapidly iterate solutions** (Kuhn, 1998). Yet, prototyping does not have to be complex and expensive. Brown (2009) makes the case to invest in prototypes only as much as is needed to generate useful feedback, learn about the strengths and weaknesses of the idea, and identify future directions. Thus, the closeness of the prototype to the final product is not as important as conveying the idea to potential users.

[3] http://hobbit.acin.tuwien.ac.at

Finally, the outcome of a design activity can be a material artefact as well as a non-material artefact, such as a poem, a theory or a scientific experiment (Mishra, 2006). The most important factor in conveying the idea is that the artefacts are **tangible** – tangible not only in the sense of *capable of being perceived especially by the sense of touch*, but also *capable of being precisely identified or realized by the mind*[4], like a picture, a piece of program code, a sound file or a robot concept as in the Crazy Robots approach.

3.3 Robotic Product Development for Young People

Following the overview on theoretical frameworks and practical applications from industrial product development (section 3.1) and product design (3.2) that serve as a base for the Crazy Robots concept, this section describes the three instruments of robotic product development for young people that were constructed as part of this work: the 5-step plan (section 3.3.1), multi-disciplinary teamwork with Mattie robot (section 3.3.2), and the workshop series structure based on design phases (section 3.3.3).

3.3.1 The 5-Step Plan

The use of complex or expensive technology is not the key to empowering young people and introducing them to technology. Hamidi and colleagues (2014) show that this can be achieved with simple tools – paper and LEDs – combined with elements of powerful methods like cooperative inquiry, learner-centred and bonded design, and constructionism. They empowered children from a disadvantaged rural area in Mexico to create digital artworks that were linked to cultural subjects (thus connected to the children's lives).

The **5-step plan** (Lammer, 2015b) is the first instrument of the Crazy Robots concept and uses design methods that empower young people to **address problems that influence their lives** by helping them assume the role of **robotic product developers**. It builds on previously described theoretical frameworks and related work, as well as on the experience in "real" robotic product development. It offers young people a child-appropriate structure to conceptualize a robot from scratch, and share their ideas through low-tech prototyping with art materials. This simple tool encourages holistic or top-down thinking, starting with the big picture, then focusing on details (e.g. (Faste, 1994) (Garzotto, 2008)). Although designed for primary and secondary school students, the plan can be integrated into different teaching or research contexts; it can be adapted to different age groups or even to adults who are not familiar with robotics.

The 5-step plan goes through three phases (Figure 3.3). Before the **main phase** (section 3.3.1.2) in which five steps to conceptualize a robot from scratch are introduced, there is a **preparation phase** (section 3.3.1.1) where the definitions of technology and robot are elaborated on. After the main phase, there is a **reflection phase** (section 3.3.1.3) in which ideas are shared and discussed, and eventually the process iterated. In the next sections, these three phases will be explained in detail.

[4] Definitions of "tangible" from the Merriam-Webster Dictionary

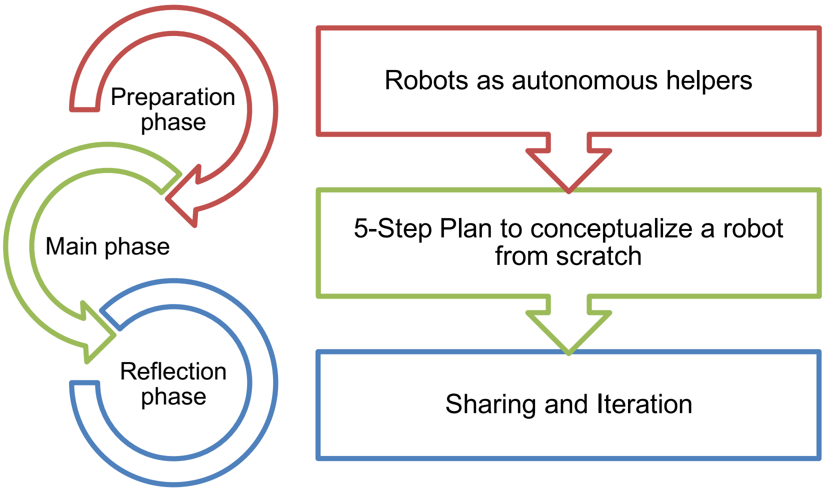


Figure 3.3 The 5-step plan – three phases

3.3.1.1 Preparation Phase

The 5-step plan starts with a preparation phase where young people are instructed to become (or assume the role of) robotic product developers. As a starting point, technology is introduced as "**human-made** objects, tools, artefacts, or processes that **help** us or make our lives easier". This definition is along the lines of Hamidi and colleagues' (2014) use of technology as the extension of a human's arm and based on the VDI guidelines (2000). By this definition, for example pencils, chairs or clothing are also technology. The group of young people is encouraged to reflect and think about more examples.

The definition of robots draws on the definition of technology: "*True robots act autonomously. They may be able to take input and advice from humans, but are not completely controlled by them*" (Matarić, 2007). Autonomy distinguishes robots from other machines and results recurrently in unexpected or "strange" behaviour. The group can discuss different robotic applications, the main difference between a machine and a robot and the meaning of autonomy or semi-autonomy (e.g. (Beer et al., 2011)).

Examples of robotic applications are also important and they should incorporate different areas from industrial to service robotics, including personal robots, exoskeletons and prostheses to demonstrate application areas that go beyond public knowledge and link to subjects that young people care about. Figure 3.4 shows examples from the Crazy Robots workshops. One of these pictures is a dishwasher that is crossed out because it is not a robot. Actually, this is a point of discussion because modern dishwashers have sensors and react to the amount of dishes loaded into them, thus have some degree of autonomy. Another picture is from the MIT professor Hugh Herr with his prostatic legs which is accompanied by the short story that he lost his legs in a young age during a climbing accident, but did not give up until he built himself new ones. However, as this manuscript goes into printing, in the fast changing field of robotic products, there are already many new and exciting applications to replace these.

Figure 3.4 (Left to right, top down) Robotics application areas: a dishwasher (crossed out because not a robot), an industrial robot welding a car, the Mars rover, the cleaning robot Roomba, the robot seal Paro, a car parking robot, a shopping robot (prototype), an agricultural robot (picking strawberries), an oil catastrophe robot, an exoskeleton for a disabled person, a hospital robot for handling patients, a prostatic hand, MIT professor Hugh Herr with his prostatic legs (and the short story that he did not give up until he had new legs), the prototype PR2 as a robot for older people at home.

By teaching these definitions and enforcing the "human-made" and "helpful" aspects of technology, young people are primed to the notion that robots are "something that we build to make our lives easier". In the main phase, as they go through the steps one by one, they are encouraged to think critically of what that means, e.g. when a robot does the homework of a student or helps harming other people.

3.3.1.2 Main Phase

In the main phase, young people are made acquainted with robotic product development with following introduction:

Real robots are complex and built by a team of experts from different disciplines (designers, human-robot interaction experts, programmers, engineers, etc.) after months (even years) of work. These robot experts consider a few things before they start building prototypes. They ask other people, make sketches, build models, discuss their ideas, and share them with others. This is what we are going to do. Each of you will think of a robot idea and then build a model to share it with others. This phase is named ***ideation*** *in the product design process and having a first model of the idea is the first step in many to finally have a product sold in shops or elsewhere. And there are other considerations that go beyond product design besides having a working prototype, such as market situation, production, procurement or quality.*

Giving a real-life example helps young people in trying to grasp the complexity and also understand that robot experts work the same way, e.g. in workshops with the 5-step plan, the development of HOBBIT robot in three phases is presented and briefly explained (Figure 3.5). First, users design models from art materials to better explain the robot experts what they need. Second, based on the models and other findings from interviews with experts and users a first prototype is built. This first prototype is tested in user trials to understand what is working well and what can be done better. Finally, based on the findings of the user trials, a second prototype is built. And although the second prototype already looks like a product and has some considerations regarding marketing and production, it is still a prototype with new technologies in it that need to be tested and further refined.

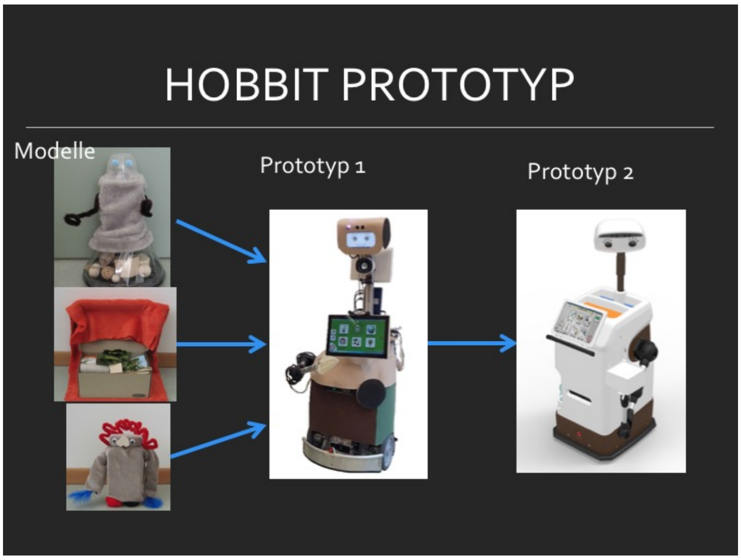


Figure 3.5 The development of HOBBIT robot by TU Wien: first models made by users, then first prototype tested in lab trials, then second prototype tested in homes of older people

After this introduction, the 5-step plan (Figure 3.6) is offered as a tool to design a robot from scratch to guide through five important topics that need to be covered in robotic product design: robot tasks, human-robot interaction, robot morphology, robot behaviour, and robot parts. In the ideation phase, the plan is used to focus on the conceptual design only with sketches and models. Later on, in phases like prototyping and evaluation, maker technology is used to build working prototypes. Pictures help in grasping abstract concepts, thus can be used throughout the process, however, instructors should be aware of their influence on young people's design ideas, thus, it is better to avoid bias and carefully spur creativity.

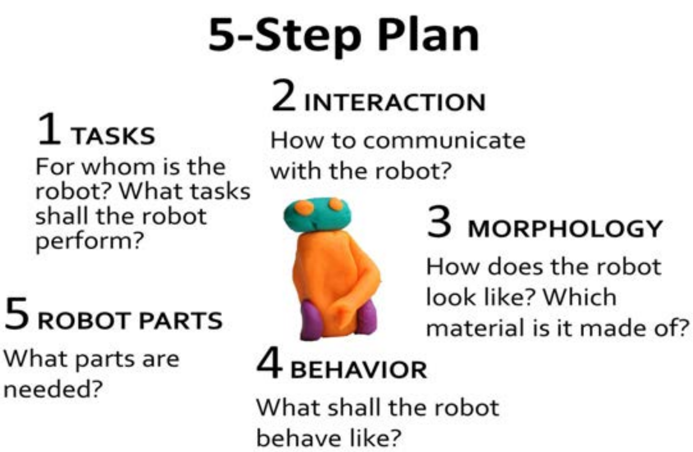


Figure 3.6 5-step plan overview: 1. Robot tasks, 2. Human-robot interaction, 3. Robot morphology, 4. Robot behaviour, and 5. Robot parts

After completing the five steps, it is important to turn back to step 1 and iterate the steps in a cycle to improve ideas and concepts, i.e. after conceptualizing the robot's tasks, interaction modalities, morphology and behaviour, all mechanic and electronic parts that are needed in order to build a working prototype, young people should think if everything fits together by turning back to step 1 and going through the other steps again. While for some children, this top-down thinking comes natural, some prefer to start with the robot parts first by thinking of available technologies (bottom-up) (for a comparison see (Crespi et al., 2008)). Although the 5-step plan was designed for top-down thinking, it also allows bottom-up design when the conceptualization starts with step 5 robot parts.

As a matter of fact, top-down or bottom-up thinking alone are not sufficient, the ideas need to diverge and converge alternatingly (as elaborated on in section 3.2). As Stevens and Brook (1998) also underline, top-down meeting bottom-up or vice versa in the end, sometimes referred to as middle-out design, brings out the best concepts. Nevertheless, for creative solutions and real innovation, it is important that in ideation phase technical or financial limits are not the main concern and the focus is on the user's needs (divergent thinking), while later iterations concern themselves with feasibility (convergent thinking) pointing to technologies that need to be developed or areas of research that need to be followed (e.g. (Brown, 2009)).

Step 1 – Robot Tasks

In the first step, young people are invited to think about a robot that they would like to design. The first question is "for whom is the robot"; it could be the young person, someone in the family, or some other group of people with a problem. It is easier to start with a user group that young people know well to define their needs or identify problems, so they are encouraged to imagine a robot for themselves. The next question than follows: "What would it do for you? Different robots have different tasks; some vacuum clean, some mow, some help in factories, and some help older people in their homes" (examples of real robots). Young people are told that they can imagine a robot that does anything they want. At the end of each step there is a short discussion. Every idea is valuable in this phase and not discarded as useless or undoable. Young people are rather encouraged to think about real-life problems and solving them with the help of robotic technology. In order to do that, they first identify their user group and the specific needs that their solution will address.

Step 2 – Human-Robot Interaction

The second step is about how to interact with the robot. The discussion first evolves around interaction modalities that young people are aware of, e.g. speech, button, touch screen, and then expand towards other ways of human-robot interaction that are not well known, like gesture, mimic or mind control: "How would you tell your robot what to do? Would you talk to it in a secret language or with signs? Would the robot understand your thoughts? Or would you use an app to control it?" Known and not yet invented applications are both encouraged equally. Young people discover that some ways of interaction still need to be developed or improved by scientists, some others exist already as applications and can be built into the robots by engineers.

Step 3 – Robot Morphology ("looks and materials")

In order to explain the word "morphology", the third step is divided into two parts. One is the exterior design of the robot ("looks"), the other is the material(s) used for it.

When young people are asked how their robot looks like, their answers will most probably be influenced by images from media and science fiction (e.g. (Kriz et al., 2010)). In this step, they are guided into different directions with four categories of robot morphology from Fong and colleagues (2003): "Robots can look like machines, like cartoon characters, like animals (zoomorphic) or similar to humans with a head and body (anthropomorphic). How would your robot look like?". Pictures from real and fictional robots help in conveying the ideas. However, there can also be a fifth category: "What if your robot looks totally different from machines, cartoons, animals or humans?". In order to convey the importance of a robot's appearance and depending on the on-going discussion with the children, scientific works that study the influence of robot appearance on human perception (e.g. (Haring et al., 2013)) or Mori's uncanny valley (Mori et al., 2012), when a robot's appearance resembles a human's appearance so closely that it is perceived as uncanny, are very useful.

Producing and manipulating materials has historically been tide to the development and advancement of societies. Material scientists develop and synthesize new materials. Material engineers create new products or systems using existing materials; they also develop techniques to process materials (Callister and Rethwisch, 2013). Materials and material science have a significant impact on future technology and products. Thus, as a second facet of morphology, young people are introduced to different materials used in robotics, as also suggested by Eisenberg (2004). Samples to touch and experiment with in order to discuss properties are very helpful. When not available, young people are encouraged to talk about different materials robots they know are made of, e.g. metal, plastics or wood, and describe some properties: "They can feel smooth, hard, furry, etc. How would your robot feel like?"

Step 4 – Robot Behaviour

In the fourth step, the abstract concept of autonomous behaviour needs to be explained in a manner that young people understand. Humans have a long history of fascination with intelligent machines (Oh and Park, 2014). They, in general, tend to attribute animacy to non-living objects, especially when those move in stroking and oscillating patterns (Kuwamura et al., 2014). Robot movement that is interpreted as behaviour can be an important factor of acceptance and should be considered carefully in robot design (e.g. (Beer, 2011)). There are two complementary paths used to introduce young people to robot behaviour and encourage them to reflect upon it critically: personas (social roles) and the laws of robotics.

First, a vigorously defined and clearly communicated robot personality (persona) serves as a mental model of the robot and facilitates interaction (Meerbeek et al., 2009). Young children are more inclined to attribute animacy to robots that demonstrate autonomous behaviour (e.g. (Okita and Schwarz, 2006) (Levy and Mioduser, 2008)), and they may have other preferences than adults regarding a robot's behaviour, thus its personality or social role (e.g. (Zaga et al., 2015) (Huber et al., 2014) (Woods, 2006) (Bhamjee et al., 2010)). Personas or social roles that are well known to young people are used to describe certain sets of behaviour: "Would you like your robot to be rather like a butler or a friend? A teacher or a tutor? Maybe a protector? Or a pet? Or something completely different?" Once they have decided on the role, young people describe the robot's behaviour: "How does your robot behave?"

Second, regarding laws of robotics, young people are introduced to the legal and ethical aspects of robotics to understand behaviour and rules. Asimov's Three Laws of Robotics (1950) are comprehensive, short, and often well known through media:

1. *A robot must not hurt a human or allow a human get hurt.*
2. *A robot must do everything you say, except when a human gets hurt by its actions.*
3. *A robot must protect itself, except it obeys an order or protects a human from being hurt.*

Discussions encourage critical thinking by evolving around contradictory topics, like the ethical use of robotics regarding drones with weaponry or the use of force when a person's robot protects its owner from malicious people. The EPRSC / AHRC principles of robotics[5] are useful as a general guide throughout these discussions:

1. *Robots are multi-use tools. Robots should not be designed solely or primarily to kill or harm humans, except in the interests of national security.*
2. *Humans, not robots, are responsible agents. Robots should be designed, operated as far as is practicable to comply with existing laws and fundamental rights and freedoms, including privacy.*
3. *Robots are products. They should be designed using processes which assure their safety and security.*
4. *Robots are manufactured artefacts. They should not be designed in a deceptive way to exploit vulnerable users; instead their machine nature should be transparent.*
5. *The person with legal responsibility for a robot should be attributed.*

Step 5 – Robot Parts

This step is probably the most complex one if handled in detail and requires knowledge that young people probably have not acquired yet. There are already many approaches that focus on teaching robotics (e.g. (Matarić, 2004)) that are useful and established. When kept very simple, parts are reduced to three elements that all robots have in common: sensors ("the senses"), a computer ("the brain"), and actors ("the moving body"). Especially in the first iteration of ideation phase, the focus is on the holistic (top-down) view of the product developer who needs to know what parts are needed and what they are for without getting too much involved into details of integrating them. Thus, in the 5-step plan workshops, this step is done briefly and young people are given following explanation:

"All robots have a brain (the **computer**) and at least one of three **senses** (visual, audio and haptic sensors). Software tells the hardware what to do. Some robots have wheels or legs, some fly (for locomotion or navigation), and some have arms and hands (for manipulation); **actors** (motors and gears) are needed to move these parts. A battery gives the robot energy in order to work, like food gives you energy to think, run and talk. Finally, the robot has a body, where all these parts need to fit together (which is not an easy thing to do), covered by a hull to make it look attractive and nice to touch."

[5] http://www.epsrc.ac.uk/research/ourportfolio/themes/engineering/activities/principlesofrobotics/

Figure 3.7 shows robot parts as they were presented in the workshops:

“Robots are made of hardware, which can be touched, and software, which cannot be touched in a common sense. Hardware is made of mechanical parts (e.g. shafts, joints, bearings) and electronic parts (“robot brain” like micro controller or computer, “robot senses” like camera, microphone or touch sensors, interaction output like speakers, and motors, batteries, etc.). All these parts are built together in a robot. Software controls the hardware (low-level code for the micro controller, or high-level code for commands like GO TO). A nice hull makes the robot look agreeable.”

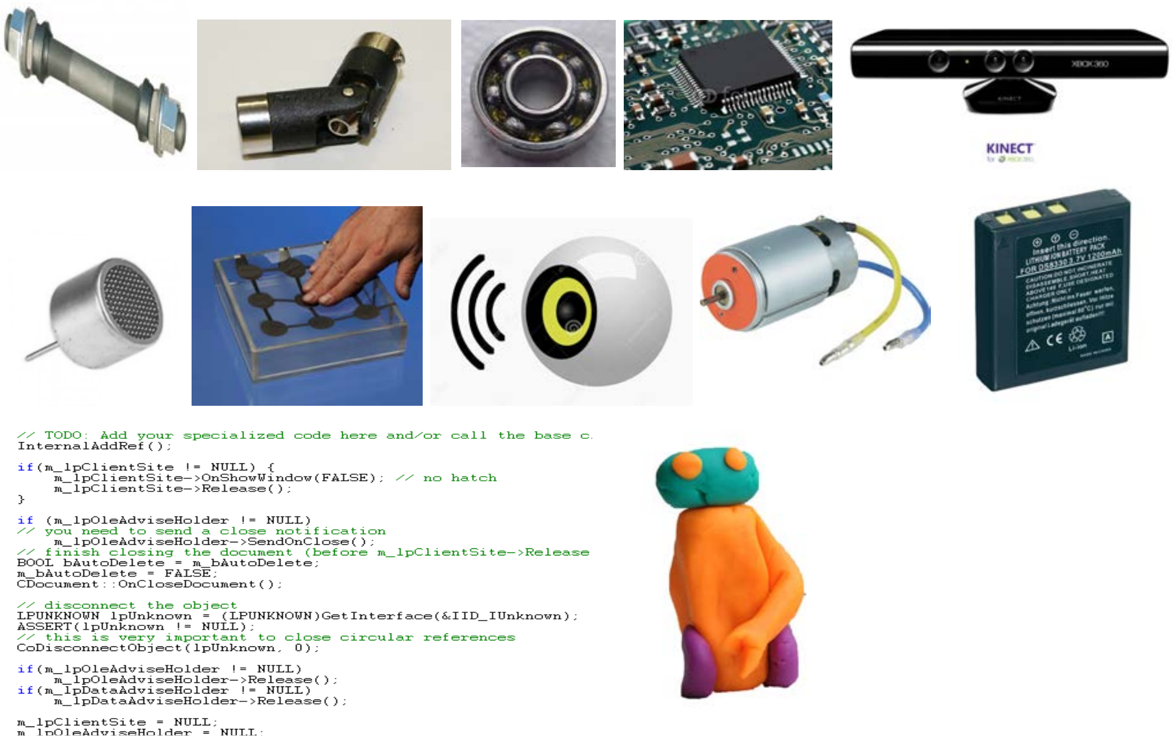


Figure 3.7 Robot parts (left to right top down): kink, hinge, bearing, micro controller, 3D camera, microphone, touch sensor, speaker, motor, battery, software, and hull.

It is very important to connect the different steps to Step 5, for example, if the interaction modality is speech, the robot will need an audio sensor (microphone) and an audio output (speaker), also a program that interprets the spoken words so that the computer understands what is said, etc. Another example, if the robot should help with homework, it should have a visual sensor (camera) and a program again to “read” and “understand” the homework, etc. This is the step where young people are introduced to the **concept of linking user needs to requirement specifications** (e.g. (Gause and Weinberg, 1989)) and they learn it first-hand by applying it to their robot idea.

After young people are introduced to robotic product development, had some discussions, took notes and made some sketches, they turn to the hands-on part of the 5-step plan session and start building a low-tech prototype with modelling clay and other art materials to take home and show family and peers. They are not constrained by the limits of technology; there are no limits for their robot's capabilities.

Optionally, in an expanded 5-step plan concept with follow-up workshops which move from idea generation to prototyping, Step 5 is a starting point to go into more detail by using simple technology (e.g. maker electronics) to work out technically feasible solutions. The "Inspirational bits" approach from Sundström and colleagues (2011), where product designers explore simple technology parts like sensors for better understanding and creativity, offers a good starting point. Considering a split of the complete robot design into small-scale and short turn-around design problems, as the *designiettes* from Wood and colleagues (2012) are used, is an effective way to deal with difficulties.

3.3.1.3 Reflection phase

Once through all five steps and having built a tangible artefact, young people are encouraged to go back to Step 1 and check if the robot has all parts to accomplish the tasks it was assigned to, then Step 2 to check the interaction modalities, then Step 3, etc. In some workshops, the low-tech prototype is presented to others and discussions evolve around topics that have been elaborated on in the sections before. The message is that robots are developed in iterations and one best starts quickly with a simple and cheap prototype or partial solution to build new ones from the lessons learned.

The 5-step plan introduces young people to real-life problem solving by slipping into the role of robotic product developers. It encourages top-down thinking and offers a child-appropriate structure to conceptualize a robot from scratch. In this work, it is used in individual and teamwork projects throughout different studies (pilots and main studies). In Chapter 5 section 5.5.3, we report on the findings regarding the 5-step plan as a tool under research question three (RQ3).

3.3.2 Multi-disciplinary teamwork with Mattie robot platform

The second instrument of the Crazy Robots concept is the employment of multi-disciplinary teamwork which is realised with the Mattie robot platform developed in the course of this work. In research and industry, the increasing complexity of products, services and experiences make it necessary that the "*lone creative genius*" is replaced with the "*enthusiastic interdisciplinary collaborator*" (Brown, 2009). Design teams are composed of experts from different backgrounds, thus are **multi-disciplinary**. Ideally, they are structured to create positive interdependences among team members who – as individuals – perceive that they can reach their goals only if the other team members also reach their goals. Teamwork helps to develop communication, problem solving, cooperation and collaboration skills (Johnson and Johnson, 1995). Collaborative learning theories also support these arguments, furthermore collaborative learning leads to active and creative learning by solving problems together, and thus creates a sense of community (e.g. (Denis and Hubert, 2001) (Johnson and Johnson, 1987)).

There are many educational robotics technologies that are also used in collaborative learning environments (examples in Chapter 2 section 2.1.3). The teaching medium is important, its particular properties limit or enhance what young people can build, create, and learn (Resnick et al., 2000). Besides the "black box" and "white box" considerations (see Chapter 2 section

2.3.1 for details), expenses also play an important role in the use of robotics technology. While commercially available robotics kits can be expensive, building a robot from scratch can be exhaustive (e.g. (Vandevelde, 2015)).

The Mattie robot platform (Hirschmanner et al., 2015), as seen in Figure 3.8, is a “black-and-white box” solution that attempts to combine the advantages of both perspectives, black box and white box. It is a platform with pre-defined elements so that young people do not have to start from scratch while they realize their first ideas of robotic products, and it was designed for junior high school students (11-14 years old) with the following considerations:

1. Young people should receive an introduction to robotics from different perspectives to find their interests (human-robot interaction, design, sales & marketing, engineering and research & development)
2. The design should be simple and the employed materials easily accessible, so that everyone can replicate the robot at home and pursue own ideas
3. The exposed complex parts should show that “real” technology is not magical but intelligible when broken down into parts

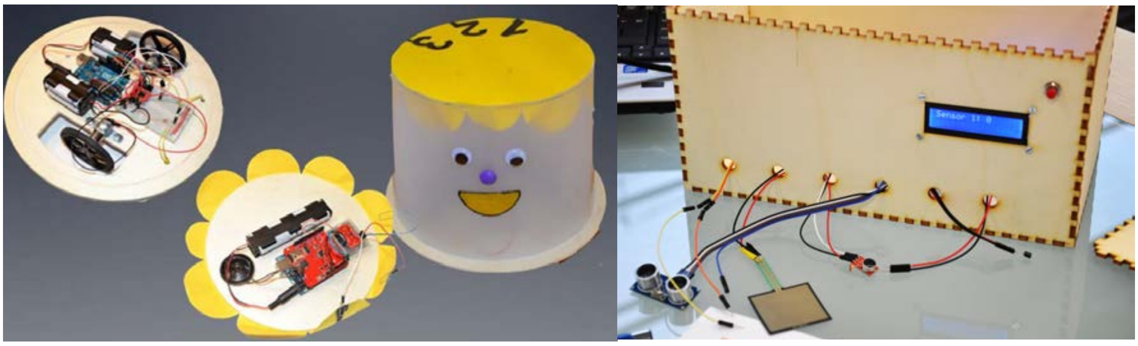


Figure 3.8 The Mattie robot platform. From left to right: first version of the Mattie robot’s parts (chassis, touch-to-sound interface, hull), and the sensor box

The Mattie robot platform is built out of simple everyday materials that children (or their parents) have access to: a round wooden platform as chassis and an almost cylindrical shaped plastic hull (bucket cut on both ends) which is closed on the top by a carton lid. The chassis has two motors with wheels controlled by an Arduino board and a motor driver, as well as a ball caster. There is an infrared receiver for remote control and two light sensors for the robot to follow light. In a second version, the robot has also one ultrasound sensor in the front to stop when approaching an obstacle and a Bluetooth receiver for remote control with an Android mobile phone.

Besides navigation, human-robot interaction is possible via touch buttons that are painted on the robot using conductive paint or attached with tin foil. A capacitive touch sensor registers if a button is touched, and an MP3-player on a second Arduino plays the previously recorded sound files. In a second version, a commercial solution (the BARE Conductive touchboard[6]), has replaced the MP3-player plus Arduino combination and a gripper was also added to the back of the chassis. The designs for navigation, manipulation, and human-robot interaction and the level of autonomy are kept very simple to allow children the replication at home. The

[6] http://www.bareconductive.com/shop/touch-board/

sensor box (Figure 3.8, right) is not a part of the Mattie robot itself but as a construct for the research & development team to explore different kinds of sensors an important part of the platform (see section 3.4.11). More details on the Mattie robot's structure and concept is found in (Hirschmanner et al., 2015).

The main focus on the Mattie robot's design, besides its replicability at home, is that it supports the learning of the robotic product development process. There are five teams that work on different parts of the robot or other tasks concerning the robot: the engineering team works on the chassis and the research & development team on the sensors. The human-robot interaction team designs buttons or areas that react to touching with sound, the design team is concerned with the hull of the robot, and the sales & marketing team keeps an eye on the user needs and the whole concept of the robot. At the end, all parts come together and need to be integrated. However, the different teams need to talk to each other before they even start with the process. Otherwise, they develop parts that do not fit each other. For example, if the design team does not have a look on the technical parts before designing the hull, the hull may not fit the chassis correctly or could block a sensors' view.

The simulation of real robot integration is important. The group learns the ups and downs of teamwork as it is in real product development. Even in a team, supporting different styles of playing, designing, and thinking is important (Resnick and Silverman, 2005) as is encouraging students to use both their brain halves and their whole bodies for problem solving, which leads them to become aware of their cognitive style and appreciate the thinking skills of others (Faste, 1994). In Chapter 5 section 5.5.3 under research question three (RQ3), we elaborate on how the Mattie robot's teamwork encouraging structure has influenced the Crazy Robots workshops.

3.3.3 Workshop Series Structure based on Design Phases

The third instrument in the Crazy Robots concept is the workshop structure based on design phases. Each workshop is a distinctive phase of the product development process, e.g. the 5-step plan workshop simulates the ideation phase of robotic product development and serves as a first workshop in a workshop series that continues with further phases. In the main study, the Crazy Robots concept workshop series consists of three consecutive workshops that simulate three incisive phases of product development: ideation, prototyping, and evaluation (Figure 3.9). While ideation is the phase where ideas are generated, and sketches and models discussed, in prototyping phase a first working prototype is built. The final evaluation phase is for extensive testing of this prototype from technical and user perspectives.

Figure 3.9 Crazy Robots workshop series structure

With the workshop series structure, the three instruments of the Crazy Robots concept are described. In the next sections, the Crazy Robots concept as it was deployed during the main case is elaborated on, by using the structure of the activity plan template by Yiannoutsou and colleagues (2016) to have a pedagogically sound presentation of the activity, to better emphasise the detailed reflections concerning the decisions around the conceptualization, and to provide comparability with other approaches.

3.4 Crazy Robots Activity

Crazy Robots is a three workshop series for high school classrooms to introduce young people to real-life problem solving in multi-disciplinary teams. It uses the previously described theory, related work and three instruments. The description below follows the educational robotics activity plan template (Yiannoutsou et al., 2016).

3.4.1 Title of the Activity as it is mediated to students

Crazy Robots – the creative hands-on lab: lovely or crazy – how do I design my own robot?

3.4.2 Description of the Scenario

The activity is a workshop series consisting of three consecutive workshops designed for junior high school classes. It uses the instruments 5-step plan, multi-disciplinary teamwork with the Mattie robot platform, and the workshop series structure based on design phases. Teachers choose to participate together with their classes during technical handicraft or physics lessons because they find the topic of hands-on and robotics fitting to these subjects and the loss of curricular activities especially in physics more than covered by the gain of the extra-curricular activities. The workshops are conducted in one school semester (half year) and the series consists of three consecutive workshops with about two to three hours each. There is also a half hour visit to the robot lab with a demo of the Romeo robot[7] after the second workshop.

3.4.3 Domain of the Activity

With robotic product development as the core of the approach, the main domain is **technology**. However, product development as well as robotics involve many domains, e.g. design (**arts**), **engineering**, research & development (engineering **science**), project management, human-robot-interaction and **business** administration (social sciences) as well as **mathematics** (formal science), ethics (humanities) or any other domain where the product is applied like medicine (natural or applied science).

3.4.4 Objectives

The main objective of the activity is to introduce young people to real-life problem solving in multi-disciplinary teams. In the short amount of time, they cannot be taught skills in depth, however, at least during their exposure to the activities they can be introduced to diverse concepts and empowered to believe in their capabilities as individuals who are able to work in teams and achieve difficult goals.

3.4.4.1 Subject related objectives

The activity objectives related to school subjects are following:

- Designing a robotic product from scratch (technology design)
- Designing, executing and presenting a user study (science, user-centred design)

[7] https://www.aldebaran.com/en/cool-robots/romeo

- Developing a marketing and sales strategy (business)
- Basic understanding of circuits and sensors (engineering)
- Designing a robot's exterior hull and interaction with humans (art, science, technology design)

Some mathematical or physical concepts are also touched, like the Pythagoras theorem to find the angle of deviation of the robot on a straight line or the relationship between time, distance and velocity.

3.4.4.2 Social and action related objectives

The skill concepts that are introduced during the activity are so-called 21st century skills, i.e. collaboration and team work, critical thinking and problem-solving, communication, and creative thinking skills (4Cs) as well as design thinking (e.g. (Eguchi, 2014a) (Grammenos, 2015)). At the same time, students learn about the meaning of technology, the different application areas of robotics, the complexity of robotic products, the necessity of teamwork, and how they can contribute with their unique talents in a robotic field that they find interesting.

The concept also empowers young people to develop self-confidence and persistence by solving a real-life problem together with their peers without the teacher instructing them in every step. Given the short time frame of the activity, students can only build prototypes and present their ideas, they cannot build solutions close to products. Consequently, even though the activity in the first workshop is an open-ended task to foster creative thinking, the students also need to learn that resources are limited as in real life and deal with constraints.

The learning theories behind the activity – constructionism, project-based and design-based learning – harmonize well with the concepts of the Maker Era where young people are "creators instead of consumers". In the Crazy Robots activity, students learn to create a solution to a real problem, translate their ideas into a tangible artefact, test it from technical and user perspectives, and present it to their peers or robot experts and teachers.

3.4.4.3 Technology use related objectives

In the Crazy Robots concept, technology is a means to an end, a tool that helps humans or makes their lives easier. The objective is to show young people this meaning of technology. Robotics technology is used because robots or automatons are fascinating to humans since ages and also because robotics covers many domains. A robot is also a very complex technology that requires many experts from different fields working in a team, and building a prototype is only a part of the process. Thus, in the first workshop, instruments like the 5-step-plan and storyboard are used with modelling clay instead of complex technology. In the second and third workshops, the Mattie robot platform is employed with the purpose to facilitate the prototyping process so that the students have a sense of achievement at the end of the workshop series. The product development task is guided with the 5-step plan template and other work sheets for each group.

3.4.5 Students Info (target audience)

Table 3.1 summarises the information about the student target audience, including gender, age, prior knowledge, nationality and cultural background, social status and environment, and special needs and abilities.

Table 3.1 Student Info (target audience)

Gender and Age	Boys & girls, 10-14 (with adaptions also possible for younger or older children)
Prior knowledge	No prior knowledge required
Nationality and cultural background	Austrian, cultural background diverse, capital city and surrounding
Social status and social environment	Mainstream public high schools
Special needs and abilities	-

3.4.6 Space Info

The space information is concerned with the physical characteristics of the space as well as the organizational and cultural context. All activities are indoors. Two activities are workshops conducted in the schools, either in the classroom or the craft room. One activity is a workshop at the university with a visit to the TU Wien Vision for Robotics Lab.

3.4.7 Social Orchestration

3.4.7.1 Population

Students are orchestrated in groups of 10 to 25. Big groups require more tutors, are more chaotic and demanding, but they work. Two tutors are required to assist the activities, more in big groups. The teachers can also act as tutors when appropriate.

3.4.7.2 Grouping

Grouping can be adapted to different indoor settings. First, students need to watch a beamer presentation, thus need to sit in rows towards a screen. Second, students split into the Mattie robot platform teams subject (engineering, research & development, human-robot interaction, design or sales & marketing). The grouping criteria is preference of subject.

3.4.8 Kinds of Interaction during the Activity (emphasis)

There are different actions to encourage interaction during the activity: the exchange of ideas, dialogue, negotiation, and debating. The relationships are orchestrated to be collaborative. There are no specific roles for the groups or teams defined, they emerge with time. Tutors support the students where needed. The students solve the problems and present it as their solutions.

3.4.9 Teaching and Learning Procedures

3.4.9.1 Workshop instructor's role

The workshop instructor's role is changing. In the beginning, the role is that of an expert who presents and encourages questions and discussions. Then, the instructor becomes a tutor during group work who mentors or observes.

3.4.9.2 Teaching methods

The teaching is partly instructionist (especially during the presentation), and partly constructionist. The teaching methods are based on constructionist, project-based and design-based learning approaches, and encourage the construction of knowledge, the use of problem-solving and critical thinking skills, and offer student choice. They cultivate student engagement, use scaffolds to guide student learning, support collaborative learning, and have multiple solutions to lead students to confront and resolve conflicting ideas.

3.4.9.3 Student activity processes

Students are observing in the beginning and are introduced to different concepts. Then, they are start actively creating, and finally, they actively present.

3.4.10 Student Learning Processes

Table 3.2 gives information about the student learning processes, such as designed conflicts and misconceptions, the learning processes that are emphasised, and the expected relevance of alternate knowledge.

Table 3.2 Student Learning Processes

Designed conflicts and misconceptions	All five different teams work on the same robot. If they do not communicate, the things they do will not fit together properly, they need to communicate and align through the whole process, and they need to make decisions that concern all. The activity is designed in a way that they learn this by experience, guidance is only offered when students are trapped in dead ends.
Learning processes emphasised	Design thinking, real-life problem solving, and multi-disciplinary teamwork are emphasized.
Expected relevance of alternate knowledge	Depends on the robot concept the class comes up with, e.g. one group did a robot for children with down-syndrome, and one student from the class (with a sibling having down-syndrome) was their expert, so they learned about the needs of children with down-syndrome.

3.4.11 Student Productions

Table 3.3 gives an overview on the different student productions created during the Crazy Robots activities. All productions are tangible.

Table 3.3 Student Productions

Production	Description
5-step plan template	In the first workshop of the series, students conceptualise a robot on their own, either for themselves or for a target group that they choose, with the help of the 5-step plan. They use the template to write down their ideas or sketch their robots.
Storyboard	The storyboard is a design technique to create a visual manifestation of a verbal story and originates from the film industry. It can be a supportive method to simplify or bring clarity to concepts (Wikström, 2011). It is also used as an educational tool in various contexts (e.g. (Faste, 1994)). It is a complementary tool to the 5-step plan. In storyboard activities, students imagine a day with their robot and visualize their story on a storyboard with 4-6 scenes.
Clay model	In the first workshop of the series, students translate their ideas on the robot they describe with the five steps into a clay model.
Robot	In the second workshop, students conceptualise a robot together as a class (by using the 5-step plan), and then build their prototype with the Mattie robot platform. Besides the concept of the robot, student productions are the hull (with the design of the touch buttons) and the robot sound files that are played when certain buttons are touched.
Presentation	After the first workshop, the robot concepts are presented in the classroom and the class gives feedback for improvement. During the second and third workshops, students discuss the concept of the robot or work on finding solutions to the specific tasks at hand and present their solutions at the end. Sometimes, teachers use time between workshops for presentations and discussions to deepen the learning process.

3.4.12 Sequence and Description of Activities

3.4.12.1 First Workshop Ideation

Duration: 100 min (= two school hours)

Orchestration: presentation, assembly discussion, each student works on clay model

Description: The researchers introduce themselves as robot experts and explain that in this workshop, the students will learn how to design robots while the researchers will learn from their ideas how to build better robots in the future. This workshop follows the 5-step plan as elaborated on in section 3.3.1. The concepts of technology and robots are introduced so that students broaden their views of technology as "*something that we build to make our lives* *easier*", think about "*true robots acting autonomously*" and start thinking critically about technology and robots. They are also introduced to the idea that "*Real robots are highly complex and designed by a team of experts from different disciplines (designers, human-robot-interaction experts, programmers, engineers, etc.)"*. Different phases of product development are briefly mentioned ("how do robot experts translate their ideas into a product?"), and the students are directed to the first phase of idea generation. They are encouraged to think as product designers during "ideation" phase and offered the 5-step plan to conceptualize a robot from scratch.

As an introduction, the 5-step plan is explained by the researchers by involving the class in group discussions around the five different steps. Then, each student receives a 5-step plan template to think about his or her own ideas. Briefly afterwards, they also receive the materials, i.e. modelling clay, little stones in different shapes and colours, feathers, and plush wire. Each student then builds a robot prototype with modelling clay to take home and show family and peers. The students are not constrained by the limits of technology.

3.4.11.2 Second Workshop Prototyping

Duration: 100 minutes + approx. 30 min lab visit

Orchestration: presentation, assembly discussion, group work

Description: The workshop starts with a brief theory session to repeat concepts and constructs introduced in the first workshops: what is technology, what is a robot, how do robot experts translate their ideas into a product (i.e. the three incisive stages "ideation", "prototyping", and evaluation). The five steps are also repeated and the focus of the workshop underlined: prototyping and getting deeper into different robot parts.

It is also an important topic of this workshop to introduce the students to robot experts: "What kind of people are they? What do they know? Robot experts work in different fields of robotics. Besides the mostly known two fields, mechatronics and computer science, there are also sociology, psychology, design, or ethics." Robot experts are people with different characters. They are either thinking or feeling types, some of them are extraverts, others are introverts (Myers and Myers, 1995). Some robot experts are interested in how all puzzle pieces come together, some prefer to focus on details (Sternberg, 1999). They are talented in different areas, they can be logical-mathematical, musical, naturalist, spatial, intrapersonal, linguistic, bodily-kinesthetic, interpersonal or existential, or different combinations of those (Gardner, 2011). Each robot expert contributes to different aspects to the team. So can you."

An overview of Gardner's multiple intelligences is presented in Figure 3.10.

After the introduction, the "CEO of Crazy Robots Inc." (the workshop instructor) charges the "Mattie robot project manager" (the other instructor) with the project assignment to build a robot for children with a budget of 300 Euros. The project manager explains the concept of the Mattie robot, and then divides the students in groups.

3. Crazy Robots Concept

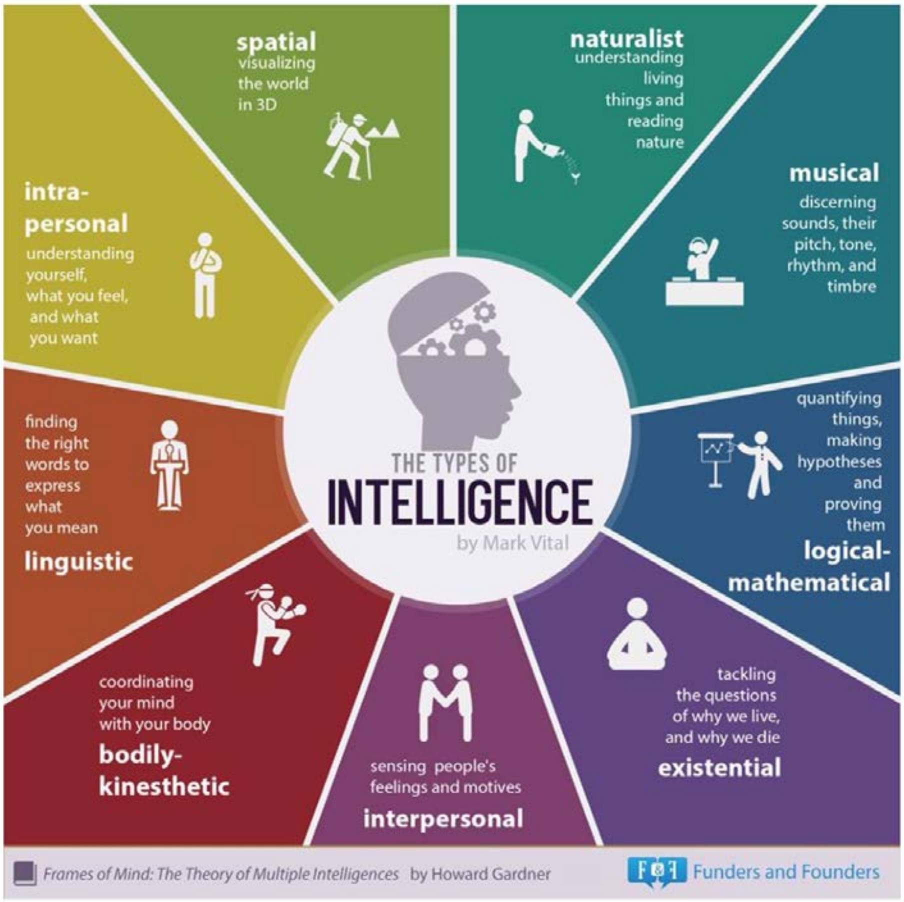


Figure 3.10 Multiple Intelligences of Howard Gardner who suggests in the theory of multiple intelligences that each person has a certain combination of nine different intelligences. These are logical-mathematical, musical, naturalist, spatial, intrapersonal, linguistic, bodily-kinesthetic, interpersonal and existential. Graphic source: http://www.fundersandfounders.com/

Each group has different tasks that are described in the following:

Sales & Marketing

In this task, students first define a target customer group (e.g., children at a specific age or with special needs as users and their parents, grandparents or other relatives as buyers) and analyse their needs. Then, they define the tasks of the robot that helps the target group along with its design and behaviour. They have to coordinate their ideas with all other groups. They discuss with the design group which materials are available, with the engineering and research groups the capabilities of the existing technology and with the human-robot interaction group the best way of interaction with the target group. They learn about the 4 Ps of marketing (product, price, place, promotion) and think of a marketing strategy for their product.

Engineering

This is a typical task for children interested in STEM and robotics. The students connect the electronic parts using jumper wires, a breadboard and step-by-step instructions. They need to figure out how the motors need to turn for the robot to drive straight or turn left or right. The microcontroller is programmed beforehand because of time constraints. Optionally, in an expanded workshop or for older children, students code the microcontroller themselves. This is a classical technical assignment with a predetermined goal that has to be achieved.

3. Crazy Robots Concept

Human-Robot Interaction (HRI)

The students in this group need to define the interaction of the robot with humans. What kind of sounds will the robot make when which kind of button is touched? The students need to plan the types of sound files the robot will play and think of an interaction interface design. They need to coordinate with the sales & marketing and design groups, so that their sound files and buttons match the overall concept and design of the robot. When all agree, this group records the sound files and assists the design team that creates the buttons.

Research & Development

This group represents the research & development department of a company or a research institution where experts develop new sensors. For this task, students first get acquainted with real sensors and learn what to do with sensor readings – a number which represents a voltage. In a wooden box six sensors are connected to a display that shows the current sensor readings. The box serves this group as a testing base, while the engineering team works on the chassis of the robot. First, students have to identify the different sensors by stressing them. Then, they help the engineering team choose the right sensors for the Mattie robot to follow light. They discuss how to use the other sensors on the robot and what additional sensors can be developed. For groups that finish their tasks quickly, there is an optional task: the students connect a tilt sensor with an LED to the robot chassis and test it as a possible anti-theft solution.

Design

The task of this group is the design of the robot, especially the body or hull – the transparent bucket, cut on top and bottom – with decoration materials. Before the group can start crafting, they need to decide with the other groups whom the robot is for and what tasks it should complete. The design needs to fit the robot concept and the customer (user) group. The designers also help the HRI group to finalize their buttons on the robot with conductive paint or tin foil.

At the end of the group sessions, when the design, interface, and chassis are finished, the robot is assembled together. Using the Mattie robot has the advantage that in the end, there is a working prototype after two hours. However, there is also a disadvantage. The form, the type of locomotion and manipulation are pre-given. This sets various constraints on the ideas of the students. From a pedagogical perspective, this is a real-life problem and real-life problems have constraints. Real experts have to deal with constraints, too, and in this case, the CEO of the Crazy Robots Inc. only has given two hours and 300 Euros. So, the product developers do their best to come up with an idea, adjust it to the given circumstances, and thus are creative to convince the CEO that their idea is worth pursuing.

After the workshop, the class visits the Vision for Robotics (V4R) Lab at the TU Wien and are shown a demonstration of the Romeo robot from the company Aldebaran[8]. The students see a robot prototype that is worth 300.000 Euros and are demonstrated its capabilities, also involving its vision related sensors like 3D cameras. The researcher demonstrating the robot emphasizes that the robot is still a prototype (and that the prototype fails often and then needs to be restarted), that many experts have been working on it for years, and that still many

[8] http://projetromeo.com/

including him work on it to improve it. The message here is: “You can too, if you want to. Just be curious and persistent”.

3.4.11.3 Third Workshop Evaluation

Duration: 100 minutes (in some cases +50 minutes when teacher could organize next class hour)

Orchestration: group work

Description: In the third workshop, groups can complete unfinished tasks from the second workshop, especially the design team needs the time to finish buttons or other parts of the robot. The theory part is kept very short, again repeating definitions and concepts from previous workshops, and finally shortly explaining what evaluation is. Then, some students are given the unfinished tasks from the second workshop. The rest of the class is divided into two teams: technical evaluation and product (or user) evaluation. When students finish previous unfinished tasks, they join these teams.

The technical group evaluates the chassis, e.g. average speed of the robot, maximum distance of the infrared receiver, reliability of the ultrasound sensor for detecting objects, or average deviation on a straight line. The user group is again divided into user study experts and marketing experts. While the user study experts design a user study and prepare questionnaires and interview guidelines, the marketing experts design a product poster and marketing strategy presentation. When design and buttons are finished, the whole robot is put together for the user study which is conducted either with classmates or students recruited from other classes. Then, the presentations follow: Product presentation, robot demonstration and presentation of evaluation results.

3.4.13 Assessment Procedures

For the assessment of the Crazy Robots activities following instruments are used: 5-step plan template, storyboard, clay model, feedback rounds (interview), questionnaire, robot artefacts and observation notes. An extended elaboration on the evaluation of the concept together with the research questions is given in Chapter 4 Research Design.

3.5 Summary

In this chapter, we described the Crazy Robots concept. Young people are introduced to real-life problem solving by playing through three incisive phases of the product development process: ideation, prototyping, and evaluation. As robotic product developers, they use the 5-step plan to conceptualize a robot from scratch in a multi-disciplinary team that reflects different areas of robotics. With the Mattie robot platform, they build a first prototype of their idea, which they then evaluate from two perspectives: technical and user-centred. Finally, they present their prototype and evaluation results along with their marketing strategy to the researchers, teacher and peers.

The Crazy Robot concept fills in the gap in the educational robotics landscape where Boyans are addressed but Lisas are left out. By offering a top-down approach in combination with bottom-up tasks with constructionist and design-based learning methods, it addresses all young learners. If Lisa participated in a Crazy Robots workshop, she would probably join the sales & marketing team to work on the concept of the robot or in the user evaluation team to make sure that the user's voice is heard, or she could discover how much fun it is to program the robot to interact with humans in order to teach them how to keep their oceans clean.

Naturally, the approach also has its challenges, e.g. for local thinkers the holistic concept does not make sense, they want to focus on their special tasks, or the task is overwhelming when the group is big and discussions do not end. In Chapter 5 section 5.5.3 under research question three (RQ3), the Crazy Robots concept's usefulness and influence on the students as well as other findings regarding the introduction to real-life problem solving, and working in multi-disciplinary teams are discussed.

Chapter 4

Research Design

In this chapter, the reader will be guided through the research design and given a rationale regarding the decisions. The research is based on qualitative data analysis methodology (e.g. (Miles et al., 2013) (Tellis, 1997) (Yin, 1994)) and follows a rigorous design which is structured through a conceptual framework. The research design is the link between the Crazy Robot concept as introduced in the previous chapter and the two claims of the research:

1. Addressing all young learners (C1), and
2. Introducing young people to real-life problem solving and multi-disciplinary teamwork (C2)

As a first step of the research, a conceptual framework is defined to understand the different interdependencies between the target group of young people and the subjects to be studied. From this conceptual framework of interdependencies, a set of questions evolves. These questions will help guide the reader through the rationale of the research and follow the evidence towards the claims. The conceptual framework grouped into seven question topics is elaborated on in section 4.1.

In a second step, the seven question topics are again grouped into clear research questions. This grouping helps to converge the focus towards the two claims which are supported by the research questions and has evolved through the different cycles of research on educational theories and related work in educational robotics, conducting studies with different groups of young people, and data analysis. Section 4.2 explains the relationship between the conceptual framework and the research questions.

In the following sections, the qualitative data analysis methods and instruments are further explained. Section 4.3 presents the nine case studies that have been conducted and explains why the research is built on case studies. In section 4.4, the multiple-case sampling is briefly analysed to highlight its limitations. Section 4.5 presents the different data collection instruments and explains where, why and how they are used. A full documentation of the instruments is given in the Appendix. Finally, in section 4.6, the data analysis in four sequential cycles with analytic memoing (Miles et al., 2013) is elaborated on. These four cycles are used to answer the research questions that support the claims as well as to improve the Crazy Robots concept.

4.1 Conceptual Framework

The research in this work is structured through a conceptual framework which is defined to understand the different interdependencies between the target group of young people and the subjects to be studied. It is a simple and descriptive framework that has evolved through the four cycles of research on educational theories and related work in educational robotics, conducting studies with different groups of young people, and data analysis. Figure 4.1 shows the last version of the conceptual framework displaying the key factors to be studied and their influences.

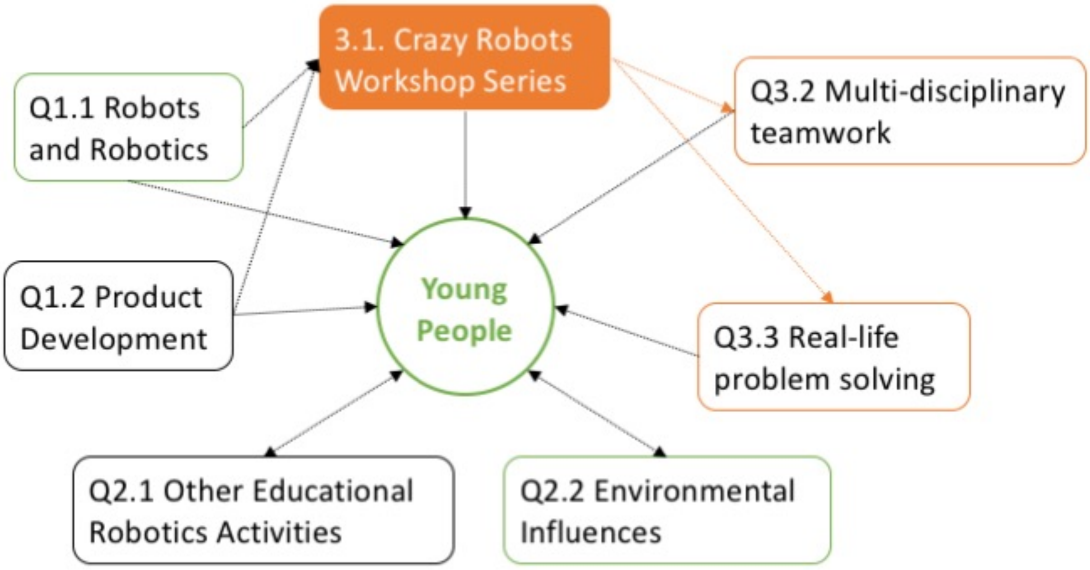


Figure 4.1 Conceptual framework: Young people are influenced by different subjects in the context of educational robotics: Robots and robotics (Q1.1), design-based learning and maker activities summarised as product development (Q1.2), other educational robotics activities (Q2.1) which are again shaped by young people's feedback, environmental influences (Q2.2), like family or peers, that go both ways; the Crazy Robots workshop series (Q3.1) is built on robotic product development (Q1.1 and Q1.2) and introduces young people to multi-disciplinary teamwork (Q3.2) and real-life problem solving (Q3.3).

In the centre of the framework, as it is in this work, are **young people**. They are influenced by different factors in the context of educational robotics: **Robots and robotics (Q1.1)** are successfully used as motivational factors in education, at the same time media and science-fiction have an important continuous influence, where the word robot often connotes the meaning "human imitation" or "human replacement". On the other side, **product development (Q1.2)** (or design-based learning) approaches are rare in educational robotics, positioned rather as art and tinkering like in the Maker Movement. Participatory design with children involves technological product development, even robotics, but learning is not the primary goal in these approaches. Given the popularity of educational robotics, there is a chance that young people are at some point influenced by **other educational robotics activities (Q2.1)**, and in return, their feedback and attendance rates have an influence on the shaping of these activities. There are also continuous **environmental influences (Q2.2)** on young people, like family, peers, and teachers. This influencing goes both ways.

The **Crazy Robots workshop series (Q3.1)** has a short influence on young people touching them three times over a period of a few months. It is built on the elements robots and robotics (Q1.1), as well as product development (Q1.2), and it offers real-life problem solving (Q3.3) in multi-disciplinary teams (Q3.2). Collaborative learning methods are used in educational robotics activities, however, team roles are mostly focused on engineering roles, thus the **multi-disciplinary (Q3.2)** aspect that connects with other domains is missing so far, and needs to be introduced. **Real-life problem solving (Q3.3)** has found its way into educational robotics through constructionist activities, though the connection to something meaningful in young people's life is often limited by technical problem-solving (bottom-up) tasks around navigation, manipulation, and human-robot interaction.

All the above described factors influence young people one way or another, at one point in their lives or continuously, and thus should be considered during the analysis of the Crazy Robots approach which, in comparison, is a brief one-time influence. In order to deepen the analysis, consequently, a set of questions evolves around the influences which help follow the evidence towards the claims. Following questions emerge from this conceptual framework grouped into the topics demonstrated in Figure 4.1:

Robots and Robotics (Q1.1)

- Why should the concept use robots and robotics to introduce young people to real-life problem solving in multi-disciplinary teams?
- What makes robots different than other motivating contexts?
- Can robotics be used for real-life problem solving?
- Are there multiple disciplines and fields covered by robotics?
- How can young people connect their individual talents and interests to these fields?
- Would robots and robotics address all young learners?

Product Development (Q1.2)

- Why should the concept use product development to introduce young people to real-life problem solving in multi-disciplinary teams?
- Product development is used for real-life problem solving, but is product development also applicable to contexts with young people?
- Are there multiple disciplines and fields covered by product development?
- How can young people connect their individual talents and interests to these fields?
- Would product development address all young learners?

Other Educational Robotics Activities (Q2.1)

- What other educational robotics activities are there?
- How do these address young people?
- In what way do they influence young people's interests, beliefs and expectations towards robots, robotics, product development, real-life problem solving, multi-disciplinary teamwork or the Crazy Robots workshop series itself?

Environmental Influences (Q2.2)

- What kind of environmental influencing factors need to be considered in the evaluation of the Crazy Robots concept?
- How do these factors shape young people's interests, beliefs and expectations towards robots, robotics, product development, real-life problem solving, multi-disciplinary teamwork or the Crazy Robots workshop series itself?

Crazy Robots Workshop Series (Q3.1)

- How will the Crazy Robots concept introduce young people to real-life problem solving in multi-disciplinary teams?
- Are the offered structures and tools sufficient?
- What are the drawbacks of such an approach?
- How will the workshop series influence young people's interests, beliefs and expectations towards robots, robotics, product development, real-life problem solving, multi-disciplinary teamwork or other educational robotics activities?

Multi-Disciplinary Teamwork (Q3.2)

- Why should young people learn multi-disciplinary teamwork?
- How can it be implemented in an educational robotics workshop?

Real-life Problem Solving (Q3.3)

- Why should young people learn real-life problem solving?
- How can it be implemented in an educational robotics workshop?

During the related work research and study of theoretical frameworks, as well as during the conceptualisation and implementation of the Crazy Robots concepts, these questions have served as a helpful guidance to follow the evidence towards the claims. They are also used in the data analysis where the concept is thoroughly illuminated, especially considering its one-time influence in young people’s lives compared to other different factors. In the next section, this set of questions is grouped into clear research questions. This grouping helps to converge the focus towards the two claims which are supported by the research questions.

4.2 Research Questions

The seven groups of questions derived from the conceptual framework are grouped into three main research questions:

4.2.1 First Research Question (RQ1)

Does an approach combining robotics and product development cover a sufficient range of fields so that young people can find their interests in the activities?

This research question supports the first claim (C1) that postulates that the **Crazy Robots approach addresses all young learners**. In order to answer the question, first the questions why and how we should use robots, robotics and product development to address all young learners are explored, and three educational robotics activities are studied with participatory observation. “Addressing all” means that through one field or another, young people find at least one topic that connects to their lives and interests. The question why it is important to connect young people’s interests to the topics they are learning through the theoretical framework of learning theories is also explored. Then, this understanding is applied to the design of the Crazy Robots approach and the rational behind the design decisions is given. Finally, the collected data is analysed and compared to theory in order to reach conclusions.

4.2.2 Second Research Question (RQ2)

What kind of influences on young people need to be considered during analysis?

This research question is concerned with both claims (C1 and C2): The **Crazy Robots approach addresses all young learners and introduces young people to real-life problem solving and multi-disciplinary teamwork.** Yet, the Crazy Robots workshop series is a one-time event compared to environmental influencing events or people in young people's lives. In order to answer the question, other educational robotics activities are studied with participatory observation and related work in educational robotics or child-computer and child-robot interaction is used for further answers. Finally, following questions are used during the data analysis to thoroughly question the findings:

- What influence do parents or family have?
- What influence do teachers or school settings have?
- What influence do peers have?
- What influence do other educational robotics activities have?
- What influence do media and science fiction have? (also links to RQ.1 with the influence of robots and robotics)

4.2.3 Third Research Question (RQ3)

Does the approach offer an introduction to real-life problem solving in multi-disciplinary teams with robotic product development?

This research question supports the second claim (C2) that postulates that the **Crazy Robots approach introduces young people to real-life problem solving and multi-disciplinary teamwork**. In order to answer the question, first the question why and how we should introduce real-life problem solving and multi-disciplinary teamwork to young people is explored by reviewing the theoretical framework of these skills. Other educational robotics activities are studied with participatory observation regarding these two skills. Then, this understanding is applied to the design of the Crazy Robots approach and the rational behind the design decisions are given. Finally, the collected data is analysed and compared to theory in order to reach conclusions.

Table 4.1 gives an overview on the conceptual framework linked to the research questions and claims.

Table 4.1 Conceptual framework linked research questions and claims

Conceptual Framework Questions	Research Questions	Addressed Claims
Q1.1 Robots and Robotics	**RQ1.** Does an approach combining robotics and product development cover a sufficient range of fields so that young people can find their interests in the activities?	**C1.** addresses all young learners
Q1.2 Product Development		

Conceptual Framework Questions	Research Questions	Addressed Claims
Q2.1 Other Educational Robotics Activities	**RQ2.** What kind of influences on young people need to be considered during analysis?	**C1** and **C2**
Q2.2 Environmental Influences		
Q3.1 Crazy Robots Workshop Series	**RQ3.** Does the approach offer sufficient structure and tools for an introduction to real-life problem solving in multi-disciplinary teams with robotic product development?	**C2.** introduces young people to real-life problem solving and multi-disciplinary teamwork
Q3.2 Multi-disciplinary Teamwork		
Q3.3 Real-life Problem Solving		

4.3 Case Study

During the research, the Crazy Robots concept or its elements were applied, challenged, and tested in different settings with different groups of young people between ages 7 to 16 from 2013 to 2015 in Vienna, Austria. These groups are summarized in a multiple case study (seven pilots and a main study in two parts) which helped to illuminate the concept design decisions: why they were taken, how they were implemented and with what result (Schramm, 1971). Since the primary goal was science communication, it was preferred to have no control on behavioural events but rather to collect a full variety of evidence: documents, artefacts, interviews, questionnaires, and observations. For this reason, the case study methodology was chosen. Nine studies with different groups of young people were used in a multiple-case study to analyse the collected data towards answering the three research questions.

The collected data was sequentially analysed in four cycles (Miles et al., 2013) while using codes which evolved over time into the conceptual framework structure. The first two cycles were concerned with six pilot studies, while the second two cycles were concerned with the two parts of the main study, a pilot with a different age group, and an experiment.

In the first cycle, educational robotics approaches were explored through research of related work, theoretical frameworks, and participatory observations including one robotic product development approach (pilot studies 1-3). In the second cycle, an unobtrusive data collection strategy was used to test materials and robotic product development instruments, and further educational robotics approaches were explored (pilot studies 4-6). In these two cycles the main concern was RQ1. During the work, however, we realized that other factors were influencing the hypotheses and concepts, like other educational robotics activities, peers, or family, thus RQ2 was stipulated to take these factors into consideration during planning, execution, and analysis.

In the third cycle, the complete Crazy Robots concept was tested with the Mattie robot in the three workshop series as the first part of the main study. In this cycle, RQ3 was added to the considerations and the Crazy Robots concept was improved with the findings of the first three cycles. In the fourth cycle, the improved approach was tested again as the second part of the main study. Furthermore, the concept was additionally tested with older children and an experiment was performed to compare the 5-step plan with the storyboard instrument. As a final step of this last cycle, all research questions were reviewed with all data to confirm or dismiss findings.

As a main distinction between the first and last two cycles, the first two cycles were exploring by doing research, developing the concept and improving it, while the last two cycles were concentrated on the data analysis to challenge and test the developed materials and concepts. Consequently, the pilot studies are carried out as exploratory case studies where other educational robotics activities, the robotic product development concept, and its materials and instruments were explored without evaluating for clear, single set outcomes; and the main study is carried out as a descriptive case study because the Crazy Robots concept is described in the real-life context in which it occurred (Yin, 2013). The studies were not designed to have control over behavioural events, however, a few elements of the concept were changed half-way through the main study, first, to ameliorate the workshops from lessons learned in the first half, and second, to test the effectiveness of the 5-step plan against a storyboard exercise. In some cases, mixed methods were used to back up the descriptive analysis with quantitative values, also including pilot studies PS4 and PS5.

Table 4.2 lists the different studies, participants and settings in an overview. In the next section, the case study workshops are introduced in detail.

Table 4.2 Overview of case study: lists the names, time frames, types, participants, and environment of the different studies as well as their connection to the data analysis cycles and their research question focus

Cycle of Data Analysis	Name	Time frame	Type of study	Participants	Environment	Research Question Focus
First cycle	PS1. Kinderuni Technik	July 2013	exploratory	boys and girls, 7-12 years	TU Wien room	**RQ1**
	PS2. Kinderuni Technik	July 2013	exploratory	mainly boys, 10-12 years	TU Wien room	
	PS3. Robocup Junior Austrian Open	April 2014	exploratory	boys and girls, 10-19 years	TU Wien room	
Second Cycle	PS4. Genderfair Technike	July 2014	exploratory	girls, 10-14 years	TU Wien room	**RQ1 + RQ2**
	PS5. Kinderuni Technik	July 2014	exploratory	boys and girls, 7-12 years	TU Wien room	
	PS6. Kinderuni Technik	July 2014	exploratory	boys, 10-12 years	TU Wien room	

Cycle of Data Analysis	Name	Time frame	Type of study	Participants	Environment	Research Question Focus
Third Cycle	MS1. Schräge Roboter first semester	Oct 2014 - Jan 2015	descriptive	boys and girls, 11-14 years	classroom and TU Wien room	**RQ3**
Forth Cycle	PS7. Schräge Roboter project day	February 2015	exploratory	boys and girls, 14-16 years	classroom and TU Wien room	**RQ1-RQ3**
	MS2. Schräge Roboter second semester	Mar - Jun 2015	descriptive	boys and girls, 11-14 years	classroom and TU Wien room	

4.3.1 Studies in First Cycle of Data Analysis PS1-PS3

In the pilot studies PS1-PS3, cases and possibilities were explored, and ideas were tested. Data analysis focused on the first research question RQ1 concerned about the use of robotics and product development to address all young learners.

4.3.1.1 Kinderuni Technik "How do I design my robot?" (PS1)

In July 2013, a pilot workshop was developed to test the idea with the 5-step plan. As part of a week long event at the TU Wien 25 children, ages 7-12, attended the 90-minute workshop in a large room with a lot of light, a creative working space for architecture students. The 5-step plan was explained with a PowerPoint presentation; each step was discussed with the group. Then, the children were divided into five groups according to their ages and worked briefly through the 5-step plan with a tutor who answered their questions. Then, materials (modelling clay, sticks, toilet paper roll, eyes, and decoration) were distributed. Each child had the same set of materials and 45 minutes to translate ideas into a low-tech prototype.

Summary of data for the pilot study PS1:

Time frame	July 2013
Type of study	exploratory
Setting	outside school workshop for 90 minutes
Participants	25 children, boys and girls mixed, between ages 7 and 12
Environment	TU Wien lecture room
Instrument(s) of data collection	participatory observation, interview, and physical artefact

4.3.1.2 Kinderuni Technik "Why do robots drive by themselves?" (PS2)

In July 2013, there was an opportunity to participate in another educational robotics workshop as a tutor during the same event week where PS1 took place. The workshop instructor started with a PowerPoint presentation showing different pictures and videos of robots, and explained the difference between robots and other machines. After this brief theoretical part, the hands-on part started. The task was to build a robot that could follow a line, either with one sensor or two sensors. The children were divided in groups of three and each group received a Lego

Mindstorms Educational set and a plan how to wire motors and sensors to the Mindstorms brick. In order to control the robot and test the design immediately, the brick had already two programs (one sensor or two sensors) on it. In the end, the children could compete whose robot finished the path fastest.

Summary of data for the pilot study PS2:

Time frame	July 2013
Type of study	exploratory
Setting	outside school workshop for 90 minutes
Participants	approximately 20 children, boys and girls mixed, mainly boys between ages 10 and 12
Environment	TU Wien lecture room
Instrument(s) of data collection	participatory observation and interview

4.3.1.3 Robocup Junior Austrian Open (PS3)

In April 2014, there was an opportunity to participate in the Robocup Junior Austrian Open as an event assistant, mainly watching over and assisting in case of problems. There were two different age groups Primaries (10-14) and Secondaries (15-19), and three categories soccer, rescue and dance. Students from Austria and other countries (e.g. Croatia or Iran) competed during a weekend in the rooms of the FH Technikum in Vienna.

Summary of data for the pilot study PS3:

Time frame	April 2014
Type of study	exploratory
Setting	outside school event for a weekend
Participants	number of children unknown (over 100), boys and girls mixed, ages 10-19, also other nationalities than Austrian
Environment	FH Technikum buildings and rooms
Instrument(s) of data collection	participatory observation and interview

4.3.2 Studies in Second Cycle of Data Analysis PS4-PS6

In the pilot studies PS4-PS6, ideas were developed into concepts and instruments and tested. Further cases and possibilities were explored. Data analysis focused on the first and second research questions RQ1 and RQ2 concerned about the use of robotics and product development to address all young learners and addressing influences interfering with the objectives of the approach.

4.3.2.1 Genderfair Technike "Cute or Crazy - How do I design my dream robot?" (PS4)

The Robot Design workshop took place in July 2014. Beforehand, girls aged 10 to 14 were invited via homepage and brochure with following text:

"Cute or crazy – how do I design my dream robot? The design team of the Vision for Robotics Lab at the Vienna University of Technology needs you to develop a robot for girls aged 10 to 14. After a brief introduction into technology and robotics, and how to work in a team of experts, you will design a first robot together with other girls. After this warming-up-assignment, you will create your own "low-tech" prototype by using modelling clay and other materials, and then explain in an exciting presentation what your robot can do. As a reward, you take your prototype home."

We paid attention to underline that the workshop was about design and tinkering with art materials, and not making with technology.

The workshop took place in a seminar room with artificial light. Twelve girls aged 9 to 13 who had chosen the workshop topic attended. There were one workshop instructor (researcher) and three tutors (students) present. The workshop time was divided into three hours in the morning, a one-hour lunch break, and two hours in the afternoon. The research purposes were explained to the children in the beginning. There was no filming; only photographing of prototypes and some audio recording of presentations.

The workshop was divided into three main parts: (1) Greeting, workshop timeline and meeting games followed by a storyboard exercise in teams of two (similar aged); (2) introduction to robotics with the 5-step plan (as PowerPoint presentation) followed by a robot design exercise in teams of four (similar aged); and (3) building of the low-tech prototype and its presentation to the group.

In the storyboard exercise the girls were shown an example of a storyboard with four scenes and then asked to imagine a day with their robot in teams of two. The student tutors also built a team. Then, all groups exchanged ideas in a speed dating session. Each girl from one team became "designer" and told about her robot to a "customer" from another team for a minute. Then roles were switched, so each girl talked to every other girl twice, once as the designer and once as the customer. This session was intended to warm the girls up to think as robot designers, work in teams and talk about their ideas.

In the robot design exercise, teams of four had each the assignment to design a robot for their age group and then present it to the company's CEO (the researcher). They had a template (5 step-plan plus space for a sketch) to help them structure their ideas. The educational focus of this session was team work and collaboration.

In the last part, each girl was given the possibility to fill out a 5-step plan template for her own robot (A4 format without drawing), and then work on her own low-tech prototype (50 minutes in total). This template was, first, for helping the girls write down ideas that they could not materialize as they wished, and second, the link to the ideas along with a photograph of the prototype. The materials provided were modelling clay in two colours for each girl and a selection of decoration (stones, feathers, plush wire and foam craft shapes) for all to choose from. After all prototypes were presented to a photographer, each girl had three minutes to talk about her robot to the group. The presentation was audio recorded.

At the end of the workshop, the girls could fill a feedback questionnaire with generic questions about the workshop and one question about what they would like to do as robot experts. This question was intended to engage the girls to think about different robotic fields in which they could see themselves.

Summary of data for the pilot study PS4:

Time frame	July 2014
Type of study	exploratory
Setting	outside school workshop for five hours
Participants	12 girls between ages 10 and 14
Environment	TU Wien lecture room
Instrument(s) of data collection	participatory observation, documentation, interview, physical artefact, and questionnaire

4.3.2.2 Kinderuni Technik "How do I design my robot?" (PS5)

This workshop concept was the same as PS1 with some slight adaptation regarding materials and data collection. It took place in July 2014. Beforehand, it was promoted to children aged 7 to 12 via brochure and web page with following text: "How do I design my own robot? How do engineers materialize their ideas into products? What is technology? In this workshop, we explain you what a robot is. Then you can build a first model of your ideas with modelling clay and take it home. --- Especially suits children who do not have experience with technology."

The workshop took place in a small seminar room with artificial light on a hot summer day. 22 children aged 7 to 12 attended. There were one workshop instructor (researcher) and five tutors (students) present. The workshop time was limited to 1,5 hours. The research purposes were explained to the children in the beginning. There was no filming, only photography of prototypes and 5-step plan templates.

The workshop started with the 5-step plan "theory" (PowerPoint presentation with discussion), then the participants were split into five groups according to their age. With the support of one tutor per group, each child had 50 minutes to fill out a template with the 5-step plan (A4 format), answer one question about what he or she would like to do as a robot expert, and to build a low-tech prototype with art materials. The template's purpose was, first, to support the participants by writing down ideas that they could not materialize as they wished, and second, to collect the children's ideas with a photograph of their prototypes.

The materials provided were modelling clay in two colours for each child and a selection of decoration (stones, feathers, plush wire and foam craft shapes) for all to choose from. At the end of the workshop, there was no time for a post-phase with presentations; only pictures of each prototype and template were taken. The templates had codes with age and gender of the child.

Summary of data for the pilot study PS5:

Time frame	July 2014
Type of study	exploratory
Setting	outside school workshop for 90 minutes
Participants	15 boys and 7 girls, between ages 7 to 12
Environment	TU Wien lecture room
Instrument(s) of data collection	participatory observation, documentation, interview, and physical artefact

4.3.2.3 Kinderuni Technik "Why do robots drive by themselves?" (PS6)

This workshop was the same as PS2 and took place in July 2014 during the event PS5 was part of. The task was to build a robot with LEGO Mindstorms that could follow a line, either with one sensor or two sensors. Although the workshop was offered for both genders, there were only boys who had signed up for it.

Summary of data for the pilot study PS6:

Time frame	July 2014
Type of study	participatory observation
Setting	outside school workshop for 90 minutes
Participants	approximately 20 boys, between ages 10 to 12
Environment	TU Wien lecture room
Instrument(s) of data collection	participatory observation and interview

4.3.3 Study in Third Cycle of Data Analysis MS1

In the third cycle, all research, observations, and testing ideas were synthesised into the Crazy Robots concept as a workshop series and tested. Data analysis focused on the third research question RQ3 concerned with the usefulness of the concept, real-life problem solving and multi-disciplinary teamwork.

4.3.3.1 FWF Science Communication Part I Schräge Roboter first semester (MS1)

This classroom workshop series took place from October 2014 to January 2015. It belonged to a national science communication project named *Schräge* Roboter (or Crazy Robots in English) and involved the cooperation of TU Wien with five different general high schools in Vienna and surroundings. The teachers had assigned the classes and informed the students about the project. The first and third workshops either took place in the handicrafts room or in the classroom (physics) during two class units with 50 minutes each and a short break in-between. The second workshop took place at the TU Wien and also involved a visit to the Vision for Robotics (V4R) Lab.

Four classes participated with their handicrafts teachers (13-15 students each) and one class with their physics teacher (24 students). In sum 80 children (age range 10-14) attended, 54 boys and 26 girls. There were two workshop instructors and one teacher present during the workshops. The research purposes were explained to the children in the beginning. There was static filming for audio purposes in some classes, a questionnaire, interviews, and photography of all templates (coded with gender and age) and some prototypes.

The sequence of activities is described in Chapter 3 section 3.4.12. Following points can be added to that description: The children were given a voluntary assignment to send in pictures of their models along with a 5-step description of their robot for an online exhibition. Teachers had the possibility to let students present their prototypes and discuss the five steps with them in following classes. They also sent feedback regarding the workshop and were interviewed in a group discussion.

Summary of data for the main study MS1:

Time frame	October 2014 to January 2015
Type of study	participatory observation
Setting	workshop series for classrooms in school and in university lab
Participants	five junior high school classes, in sum 80 students (54 boys and 26 girls) between ages 10 and 14
Environment	school classroom, TU Wien lecture room
Instrument(s) of data collection	participatory observation, documentation, interview, physical artefact, and questionnaire

4.3.4 Studies in Forth Cycle of Data Analysis PS7 and MS2

In the forth cycle, the Crazy Robots workshop series was compressed into a project day and tested with older students in the pilot study PS7. Furthermore, the improved Crazy Robots concept was tested again in the main study second part MS2, and the 5-step plan instrument was compared to the storyboard instrument in an experiment which was also part of MS2. As main study part one MS1 did, the pilot study PS7 and the main study second part MS2 also belonged to a national science communication project named Schräge Roboter (or Crazy Robots in English). Data analysis focused, first, on the third research question RQ3 concerned with the usefulness of the concept, real-life problem solving and multi-disciplinary teamwork. Second, all data was combined to analyse all three research questions RQ1-RQ3.

4.3.4.1 FWF Science Communication Part II – Schräge Roboter Project Day (PS7)

In-between the two parts of the main study MS1 and MS2, three groups of high school students aged 14-18 participated in a Crazy Robots project day each, where the workshop series was compressed into one day. The teachers had assigned students of two senior high school classes and divided them into three gender separated groups. In sum 31 students attended. The project day took place in a seminar room of the TU Wien. There were four tutors (two researchers, one teacher, one 18-year-old high school student) present. The research purposes were explained to the students in the beginning. There was static filming for audio purposes, photography of all templates and the Mattie robot prototypes.

The project day started early in the morning with ideation. The students were introduced to storyboarding and the 5-step plan, and then conceptualized different robots and brought their ideas to paper. After ideation, students were separated into smaller groups, the Mattie robot teams of sales & marketing, engineering, design, human-robot interaction, and research & development. They worked on the prototype until it was finished. Unfortunately, there was not time for evaluation or presentation, however the students could play with their creation at the end and visit the V4R lab to watch the Romeo robot demo. There was also a short feedback round.

Summary of data for the pilot study PS7:

Time frame	February 2015
Type of study	participatory observation
Setting	project day, 6 hours
Participants	two groups of boys and one group of girls, in sum 31 students (17 boys and 14 girls) between ages 14 and 18

Environment	school classroom, TU Wien lecture room
Instrument(s) of data collection	participatory observation, documentation, interview, and physical artefact

4.3.4.2 FWF Science Communication Part II Schräge Roboter second semester (MS2)
This classroom workshop series took place from March to June 2015. The same teachers as in MS1 had assigned other classes and informed the students about the project. The first and third workshops either took place in the handicrafts room or in the classroom during two class units with 50 minutes each and a short break in-between. The second workshop took place at the TU Wien and also involved a visit to the Vision for Robotics (V4R) Lab.

Three classes participated with their handicrafts teachers (9-10 students each) and one with their arts teacher (24 students). In sum 52 children (age range 10-14) attended, 30 boys and 22 girls. In each workshop, there were two workshop instructors and one teacher present. The research purposes were explained to the children in the beginning. There was static filming for audio purposes in some classes, a questionnaire, interviews, and photography of all templates (coded with gender and age) and some prototypes.

The sequence of activities is described in Chapter 3 section 3.4.12. This workshop series was the same as the workshop series MS1, except for following differences: In the first workshop "ideation" of MS2, the students did another activity before the 5-step plan, a storyboard exercise with the theme "a day with my robot". This was in order to see if the 5-step plan added any value to the creative activity or not. In the second workshop, the students visited the V4R lab *after* the workshop and not before as in MS1. This was a lesson learned on the organizational part regarding disappointments of some children who saw the Romeo robot and thought that they would be working with such an advanced robot and then "had to work" with Mattie robot. The other way around worked better, especially because the price difference of 300 EUR to 300.000 EUR was underlined, as well as the many years that robotics experts worked on Romeo compared to the two hours that the students had with Mattie robot.

Summary of data for the main study MS2:

Time frame	March to June 2015
Type of study	participatory observation
Setting	workshop series for classrooms in school and in university lab
Participants	five junior high school classes, in sum 52 students (30 boys and 22 girls) between ages 10 and 14
Environment	school classroom, TU Wien lecture room
Instrument(s) of data collection	participatory observation, documentation, interview, physical artefact, interview, and questionnaire

4.4 Sampling

Nine different data samplings were used in the multiple-case study. There were 18 different groups of young people in the seven pilot studies and two main studies in varying contexts. Evidence in form of observations was collected from all of these nine cases that involved in sum over 360 children. All the observation data was used in the qualitative analysis of the concept.

Data beyond observations, like documents, artefacts, interviews or questionnaires, was reduced to five cases and collected in three of the pilot studies and both main studies. In these five cases, five different groups of young people were involved in the pilot studies and another nine different groups of young people coming from five schools of different Viennese districts participated in the main studies. From this perspective, the reduced sampling of 197 young people with 81 female and 116 male participants in 14 groups is heterogeneous, the students are from different backgrounds and have various interests and talents.

A thorough understanding of the sampling is important for generalisations of findings as well as the interpretation of the mixed-methods analysis results done with the reduced sampling. So, the sampling is considered to be heterogeneous, however, there is a gender imbalance which is attributed to the fact that the participating groups were from backgrounds favouring science and technology, which in Austria is assigned to males. E.g., two of the schools were natural science oriented general high schools and one school had the technical handicraft subject separated from textile handicraft (i.e. children had to choose one of them), thus groups from these schools had more boys than girls in their classes. Parents signing their children for an activity at the TU Wien are also assumed to have a preference towards science and technology.

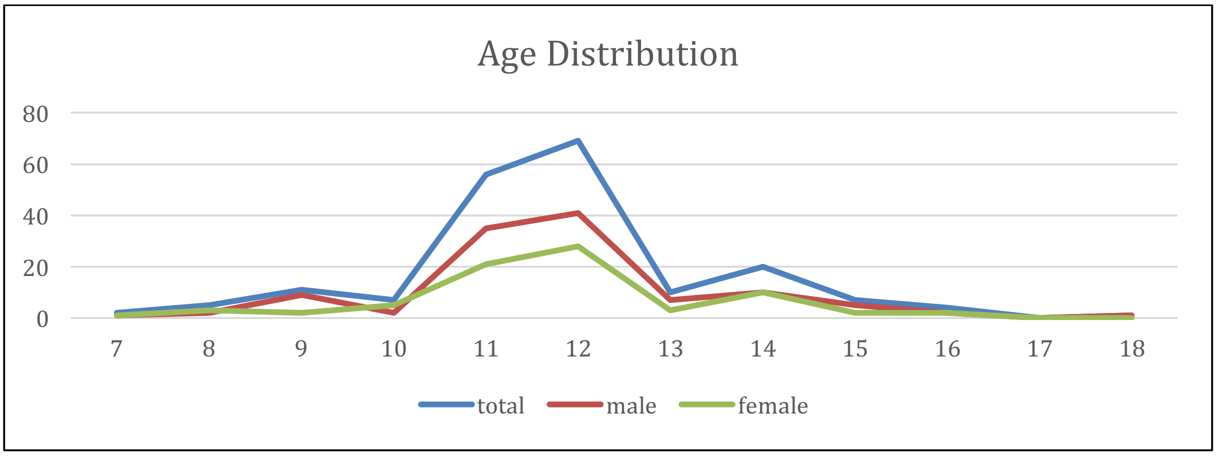


Figure 4.2 Age distribution of the reduced sampling of 197 young people from five cases

The main sampling is also limited to Vienna, a capital city in Europe, thus influenced by Austrian culture (and beliefs and expectations regarding technology) and the Austrian education system. Additionally, the age distribution is concentrated between 11 and 12, with an arithmetic medium of 11,78 (Figure 4.2 shows the age distribution), an age teachers recommended for students' cognitive abilities and openness for new experiences being well balanced. When looking at quantitative data, these limitations should be considered. Generalisations are possible for countries with similar cultures and education systems, like Germany. However, for the qualitative data analysis, which involves the main sampling as well as the data from the pilot cases, analytic generalizations are made based on the theoretical frameworks explained in Chapters 2 and 3.

4.5 Instrumentation

As is often the case with qualitative data analysis and case study research (Miles et al., 2013), multiple sources of evidence are used to give the researcher a maximum amount of data for the analysis of the developed methods and concepts in order to reach the conclusion if the two claims are confirmed or disputed. Gillham (2000) also sees the use of multiple sources of evidence as a "*key characteristics of case study research*". In this work, following sources of evidence are used:

1. Observations (notes, photographs, static video or audio)
2. Documentation (5-step plan templates, storyboards)
3. Interviews (group discussions, feedback rounds)
4. Physical artefacts (clay models, Mattie robots)
5. Questionnaires (Technike questionnaire, robot expert questionnaire)
6. Theoretical frameworks
7. Related work

Observations, documentation, interviews, physical artefacts, and questionnaires are data collection instruments. These are backed up with evidence form theoretical frameworks and related work presented in Chapters 2 and 3. In the next sections, each of the data collection instruments are elaborated on, highlighting materials and sample cases with explanations about how and why they were used in which context. A full documentation of the instruments is given in the Appendix. Table 4.3 shows the sources of evidence matrix with the case studies.

Table 4.3 Sources of evidence matrix with the case studies

Source of Evidence	Type of Evidence	Pilot Studies							Main Study	
		PS1.	PS2.	PS3.	PS4.	PS5.	PS6.	PS7.	MS1.	MS2.
Notes	Observation	x	x	x	x	x	x	x	x	x
Photograph	Observation	x			x	x		x	x	x
Static video or audio	Observation				x				x	x
5-step plan	Documentation				x	x			x	x
Storyboard	Documentation				x			x		x
Group discussions	Interview	x	x	x	x	x	x		x	x
Feedback rounds	Interview							x	x	x
Clay model	Physical artefact	x			x	x			x	x
Mattie robot	Physical artefact							x	x	x
Technike	Questionnaire				x					
Robot expert	Questionnaire								x	x
Theoretical frameworks	Theory	x			x	x		x	x	x
Related Work	Theory		x	x			x			

4.5.1 Observations

Observation methods provide researchers opportunities to look for nonverbal expressions of feelings, determine who interacts with whom and how participants communicate with each other, and better understand statements from interviews and answers in questionnaires (e.g. (Kawulich, 2005)). Participatory observations were made during all nine cases. Notes, photographs, static video or audio was used to support the researcher's memory. As the researcher was at the same time the workshop instructor and part of the case study, a certain bias was always present. In the analysis, this bias along with the different influences explained in section 4.1 were taken into consideration. Observations gave beautiful insights on all three research questions.

4.5.2 Documentation

Document analysis is a form of qualitative research in which documents are interpreted by the researcher to give voice and meaning around the assessment topic. Analysing documents incorporates coding content into themes (e.g. (Bowen, 2009)). Two different 5-step plan templates were developed to document the robot concepts of the participants as well as their understanding and implementation of the five steps. In one 5-step plan template, an additional question about robotic fields was added (see also section 4.5.5). In three cases, a storyboard activity was done on a A3 sized paper and documented. Storyboards were used for their holistic storytelling component and compared to the 5-step plan templates. Figure 4.3 shows one filled 5-step plan template and one storyboard by different female participants in group work, and Figure 4.4 shows a two paged 5-step plan template filled by an 11-year-old male participant. Documentation showed the researchers the understanding of the students regarding concepts and instruments, but also about children's needs and the types of robots they imagine.

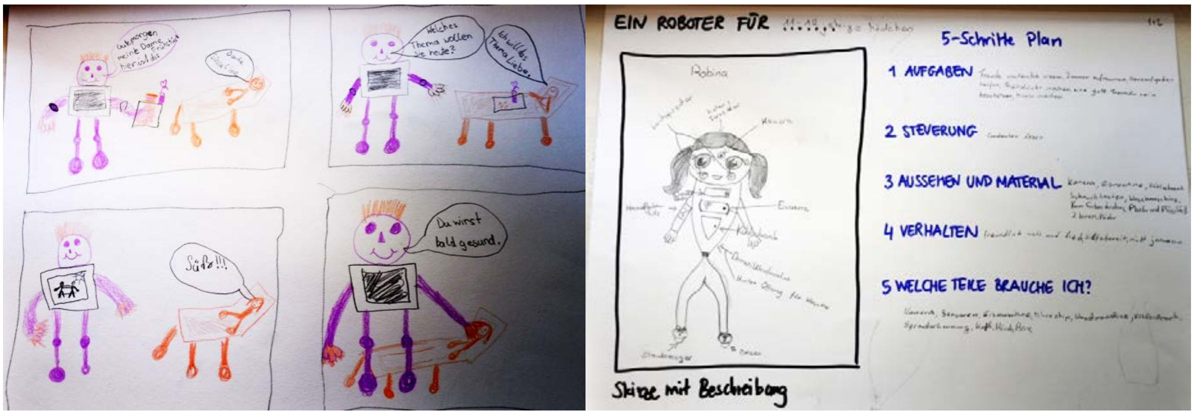
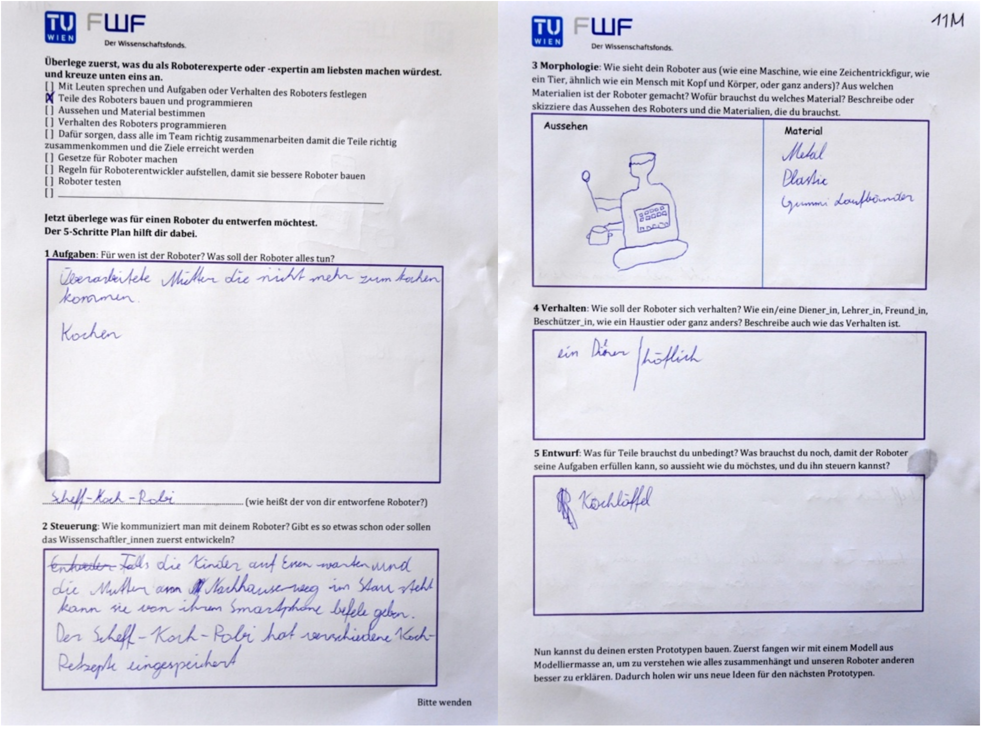


Figure 4.3 Storyboard and 5-step plan template examples. (Left) storyboard in A3 format of two girls (9 and 10); (right) 5-step plan in A3 format of four girls (10 to 12)

4.5.3 Interviews

The purpose of a research interview is to explore the views, experiences, beliefs or motivations of individuals on specific matters (e.g. (Silverman, 2000)). In this work, unstructured and semi-structured interviews were carried out during different activities or at the end of workshops. The intention was two-fold, first, involving students to actively participate in the workshops and also give their feedback, second, understanding the participants in the context of what was going on and what they were saying. Group discussions and feedback rounds were used for this purpose. Interviews complemented the observations and gave beautiful insights on all research questions.


TU WIEN FWF Der Wissenschaftsfonds.

Überlege zuerst, was du als Roboterexperte oder -expertin am liebsten machen würdest. und kreuze unten eins an.

[ ] Mit Leuten sprechen und Aufgaben oder Verhalten des Roboters festlegen
[X] Teile des Roboters bauen und programmieren
[ ] Aussehen und Material bestimmen
[ ] Verhalten des Roboters programmieren
[ ] Dafür sorgen, dass alle im Team richtig zusammenarbeiten damit die Teile richtig zusammenkommen und die Ziele erreicht werden
[ ] Gesetze für Roboter machen
[ ] Regeln für Roboterentwickler aufstellen, damit sie bessere Roboter bauen
[ ] Roboter testen
[ ] ______

Jetzt überlege was für einen Roboter du entwerfen möchtest. Der 5-Schritte Plan hilft dir dabei.

1 Aufgaben: Für wen ist der Roboter? Was soll der Roboter alles tun?

Überarbeitete Mütter die nicht mehr zum kochen kommen.
Kochen

Scheff-Koch-Robi (wie heißt der von dir entworfene Roboter?)

2 Steuerung: Wie kommuniziert man mit deinem Roboter? Gibt es so etwas schon oder sollen das Wissenschaftler_innen zuerst entwickeln?

~~Entweder~~ Falls die Kinder auf Essen warten und die Mutter am Nachhauseweg im Stau steht kann sie von ihrem Smartphone befele geben. Der Scheff-Koch-Robi hat verschiedene Koch-Rezepte eingespeichert

Bitte wenden

TU WIEN FWF Der Wissenschaftsfonds. 11M

3 Morphologie: Wie sieht dein Roboter aus (wie eine Maschine, wie eine Zeichentrickfigur, wie ein Tier, ähnlich wie ein Mensch mit Kopf und Körper, oder ganz anders)? Aus welchen Materialien ist der Roboter gemacht? Wofür brauchst du welches Material? Beschreibe oder skizziere das Aussehen des Roboters und die Materialien, die du brauchst.

Aussehen	Material
	Metal Plastic Gummi Laufbänder

4 Verhalten: Wie soll der Roboter sich verhalten? Wie ein/eine Diener_in, Lehrer_in, Freund_in, Beschützer_in, wie ein Haustier oder ganz anders? Beschreibe auch wie das Verhalten ist.

ein Diener | höflich

5 Entwurf: Was für Teile brauchst du unbedingt? Was brauchst du noch, damit der Roboter seine Aufgaben erfüllen kann, so aussieht wie du möchstes, und du ihn steuern kannst?

Kochlöffel

Nun kannst du deinen ersten Prototypen bauen. Zuerst fangen wir mit einem Modell aus Modelliermasse an, um zu verstehen wie alles zusammenhängt und unseren Roboter anderen besser zu erklären. Dadurch holen wir uns neue Ideen für den nächsten Prototypen.

Figure 4.4 Two-page 5-step plan template in A4 format filled by a boy (11) describing a cooking robot for overworked mothers

4.5.4 Physical artefacts

Artefacts enable us to communicate meaning. Interpretive methods base their inquiry on the presupposition that human meaning is embedded in the artefacts of creation and that those artefacts enable their creators to communicate meaning (e.g. (Yanow, 2006)). Two different physical artefacts were created during the different study activities. In one case, robot ideas were given shape as clay models where each student worked on his or her own. Figure 4.5 shows some examples of robot models made by children aged 11 to 12. In the second case, the robot concept of the student group was transformed into the Mattie robot's design and interaction modalities of touch buttons and sound files. Figure 4.6 shows two Mattie robot designs. Physical artefacts told the researchers about the understanding of the students, their capabilities, their interests and talents, as well as their needs and expectations.

Figure 4.5 Examples of robot designs by children aged 11-12

Figure 4.6 Examples of Mattie robot designs from junior high school classes

4.5.5 Questionnaires

Both qualitative and quantitative research use questionnaires to collect data. They have the advantage that closed-ended questions are easy to evaluate and open-ended questions allow participants to provide a more complete or comprehensive response, even though those are more difficult to analyse. Anonymity is another benefit of questionnaires. On the other hand, the responses only provide a very limited picture of the situation to the researcher and it is frequent that respondents select socially desirable rather than truthful responses (e.g. (McClure, 2002)).

In the case study PS4, a questionnaire was distributed at the end of the activity as a mandatory assessment tool for the workshop instructors. The questionnaire, provided by the organisation responsible for the workshops, included very general questions with a smiley-scale about if the participant liked the workshop, the instructor's talking speed, the quality of the materials, etc. In order to profit from the mandatory questionnaire, two specific questions were added that asked participants to self-assess their personality and specify their interests in the context of educational robotics activities.

In the first question, participants were asked to imagine that they were musicians in an orchestra. Which of the three would they rather be: the first violinist, the conductor, or the composer? The purpose of this question was to see if the children assessed themselves as specialists or generalists (in other words, local or global thinkers (Sternberg, 1999)). The conductor and composer had hidden another thinking style from Sternberg (1999), executive or legislative. The executive thinking style is attributed to CEOs of companies, while the legislative thinking style is attributed to entrepreneurs.

In the second question, participants could choose one or more of the fields that they would prefer to work on as robot experts:

- ☐ Define tasks of the robot and scenarios
- ☐ Build parts of the robot and program them
- ☐ Define design and materials of robot

- ☐ Program the behaviour of the robot
- ☐ Make sure, that all robot parts come together well
- ☐ Make robot laws
- ☐ ……… (left blank for participants to fill out)

When the evaluation of this questionnaire from pilot study PS4 showed interesting findings regarding the diversity of the participants, it was decided to distribute a similar questionnaire in the main study as well. One A4 page with questions about personality and interests was distributed to the students of the main studies MS1 and MS2 after the second workshop. This questionnaire included following questions:

Which fields do interest you? Choosing more than one possible.

- ☐ mechanical engineering
- ☐ electrical engineering
- ☐ mechatronics
- ☐ computer science
- ☐ law
- ☐ industrial design
- ☐ human-robot interaction
- ☐ medicine
- ☐ biology
- ☐ philosophy (ethics)
- ☐ physics
- ☐ chemistry
- ☐ philology
- ☐ … (left blank for participants who were interested in other fields)

Please choose one:

How do you decide? (thinking or feeling type (Myers and Myers, 1995)

- ☐ with the head (focusing on things)
- ☐ with the heart (focusing on people)
- ☐ depends

What are you curious about? (global or local thinker (Sternberg, 1999))

- ☐ how everything is connected
- ☐ only a few things, but these things in detail

How do you get your energy? (extrovert or introvert (Myers and Myers, 1995))

- ☐ from a lot of people
- ☐ alone or with one person that you know well

Which skills do you have? Choosing more than one possible. (multiple intelligences (Gardner, 2011)

- ☐ language
- ☐ logical-mathematical
- ☐ visual-spatial
- ☐ inter-personal
- ☐ musical
- ☐ naturalistic
- ☐ intra-personal
- ☐ bodily kinesthetic

In which team did you work?

- ☐ Engineering
- ☐ R&D
- ☐ Design
- ☐ HRI
- ☐ Sales and Marketing

The purpose of these questions was not to have a personality evaluation of the participants, but rather a means for the students to reflect upon the things that they had learned about themselves and as eventual future robot experts. For the research, the answers give valuable insights regarding RQ1 to determine the diversity of the participants and the robotic fields that they are interested in.

4.6 Data Analysis

The data, collected by instruments described in section 4.5, was sequentially analysed in four cycles with analytic memoing while going through evidence and coding it into themes. As Miles and colleagues (2013) describe, codes are "*labels that assign symbolic meaning to the descriptive or inferential information compiled during a study*" and coding is deep reflection about the data, and thus a deep analysis and interpretation of its meanings. The first two cycles were concerned with six pilot studies, while the second two cycles were concerned with the two parts of the main study, a pilot with a different age group, and an experiment. Coding was used throughout all four cycles, and finally condensed into the seven topics of questions of the conceptual framework, as described in section 4.1.

4.6.1 First Cycle – Pilot Studies 1-3

In the first cycle, data analysis was done by going through observations, interviews, and physical artefacts from pilot studies 1 to 3 and by doing theory research. The three groups in the first cycle analysis had different characteristics and participant expectations. Table 4.4 gives an overview on the participant groups of the first cycle. In this cycle, first ideas for the conceptual framework were generated, and from these data CODES were deducted to help sort through research data (deductive coding) and start defining research questions.

Following steps were pursued to explore the three cases:

1. First testing (PS1) of conceptualizing a robot with children by using the the 5-step plan – TOP-DOWN design and LOW-TECH prototyping (→ Q3.1)
2. Study of other educational robotics approaches and concepts through related work research (details in Chapter 2), and participatory observations and interviews (PS2 and PS3) looking for BEST PRACTICE and SHORTCOMINGS of other approaches while comparing to PS1 (→ Q2.1)
3. Special focus on the question why to use ROBOTS and ROBOTICS (→ Q1.1)
4. Gaining new insights regarding the INFLUENCE of other educational approaches and environmental factors like peers, media or family on expectations, and developing counter-measures (→ Q2.1 and Q2.2)

Table 4.4 Study group characteristics PS1-PS3

Study	Size	Characteristics	Expectations	Tutor dynamics	Teacher dynamics
PS1	25	17 boys and 8 girls, ages 7 to 12, summer holidays mood, partly voluntary participation, partly inscribed by parents	building a "real" robot, learning about robots, having fun	tutors instructed and prepared	N/A
PS2	20	many boys, a few girls, ages 10 to 12, summer holiday mood, partly voluntary participation, partly inscribed by parents	building a "real" robot, learning robotics, having fun	tutors instructed and prepared	N/A
PS3	N/A	boys and girls mixed, ages 10 to 19, varying backgrounds (e.g. technical or general high school), competitive mood, voluntary participation	winning, spending time with peers, learning robotics, making new friends, having fun	N/A	varying, from teachers having built the complete robot to teachers who only act as mentors and supporters

4.6.2 Second Cycle – Pilot Studies 4-6

In the second cycle, an unobtrusive data collection strategy was used to test materials and robotic product development instruments, and further educational robotics approaches were explored (pilot studies 4-6). The data CODES from the first cycle were continued to be used and adapted when new insights occurred (inductive coding). Following steps were pursued:

1. Developing a data collection strategy as unobtrusive as possible
    a. Two instruments to give the creative process a structure and collect data at the same time: 5-step plan template and storyboard (documentation)
    b. Low-tech prototype (physical artefact) complementary to 5-step plan template
    c. Presentation of ideas and group discussion as part of the learning process, and data collection at the same time (interview)
    d. General feedback questionnaire with two questions added about personality type and interests
    e. Linking 5-step plan template and physical artefact of the same participant with simple participant coding
2. Study of theory (related work and theoretical frameworks) regarding REAL-LIFE problem solving and multi-disciplinary TEAMWORK, and their link to skills that young people LEARN or practice (details in Chapter 3). Focus on question about why it is important that young people solve real-life problems in teams and how can it be implemented in educational robotics activities (→ Q3.2 and Q3.3). Adding PRODUCT development (→ Q1.2) as a new layer (details in Chapter 3).
3. Improve PS1 from insights of first cycle (PS5)
4. Conduct pilot study with a different workshop format (PS4) and pilot study with improved 5-step plan workshop format (PS5) with two different groups of young people as presented in the overview in Table 4.5. Data analysis through observations, documentation (5-step plan and storyboard), physical artefacts (clay model), interview (group discussions) and questionnaire (Technike) to further understand:
    a. TOP-DOWN design and LOW-TECH prototyping (→ Q3.1)
    b. ROBOTS and ROBOTICS (→ Q1.1)
    c. INFLUENCE and strategies of counter-measures (→ Q2.1 and Q2.2)
    d. REAL-LIFE problem solving (→ Q3.3)
    e. Multi-disciplinary TEAMWORK (→ Q3.2)
    f. PRODUCT development (→ Q1.2)
5. Further emerging codes: COMPETITION, OPEN-ENDED problem, BOTTOM-UP task, CLOSED problem, LEARNING, SPECIALISATION, ADRESSING, BLACK-BOX, SELECTIVE EXPOSURE, WHITE-BOX, CONSTRUCTIONISM, PROJECT-BASED learning, DESIGN-BASED learning, COLLABORATIVE learning.
6. Comparing analytic memos from first to second cycle: Any further insights, confirmations or inconsistencies? Anything to be added by theoretical frameworks and related work?
7. Participatory observation of another educational robotics approach (PS6) for further insights or confirmation of findings from PS2. Table 4.5 gives an overview on the second cycle study group characteristics.

8. Additional layer added to the qualitative analysis: mixed-methods with quantifications to back up qualitative findings
    a. Gender and age of participants and robotic fields that they are interested in (Technike questionnaire, 5-step plan) (→ Q1.1)
    b. Self-assessment of participants if global or local thinker (Technike questionnaire, 5-step plan) (→ Q1.2)
    c. 5-step plan structure (how many steps have the children answered?) (→ Q3.1)
    d. What kind of robots do kids imagine? (→ Q3.3)
9. First definition of claims, conceptual framework and research questions

Table 4.5 Study group characteristics PS4-PS6

Study	Size	Characteristics	Expectations	Tutor dynamics
PS4	12	girls only, ages 10 to 14, summer holidays mood, partly voluntary participation, partly inscribed by parents	designing a robot, learning about robots, having fun	tutors instructed and prepared, participated in workshop activities
PS5	22	15 boys and 7 girls, ages 7 to 12 (17 children were 9 years or younger), summer holidays mood, partly voluntary participation, partly inscribed by parents	learning about robots, having fun, still some expecting "real" robots	tutors instructed, preparation not sufficient
PS6	20	boys only though offered for mixed gender, ages 10 to 12 partly voluntary participation, partly inscribed by parents	building a "real" robot, learning robotics, having fun	tutors instructed and prepared

4.6.3 Third Cycle – Main Study 1

The main difference between the first two cycles and third and forth cycles was that the first two cycles were exploring by doing research, developing the concept and improving it, and third and forth cycles were concentrated on the data analysis to challenge and test the developed materials and concepts. In the third cycle, lessons learned and findings from the pilot studies were used to develop the Crazy Robots workshop series incorporating three important phases of product design. Matthias Hirschmanner developed the Mattie robot platform (Hirschmanner et al., 2015) to suit the Crazy Robots workshop series. In the third cycle, the complete three workshop series was tested as the first part of the main study MS1. Data was collected through observations, documentation, interviews, physical artefacts, and questionnaires, as well as supported by theory. The data CODES from the first two cycles were continued to be used. Following steps were pursued:

1. Data collection instruments
    a. Observations including photographs of student works like different robot sketches as design suggestions, marketing strategies, sales posters, or user questionnaires.
    b. 5-step plan template (documentation)
    c. Clay model (physical artefact) complementary to 5-step plan template
    d. Mattie robot (physical artefact)
    e. Presentation of ideas and group discussion as part of the learning process, and data collection at the same time as well as feedback rounds (interview)
    f. A mid-way through questionnaire “robot expert” about interests and self-assessment of personality
2. Conduct main study (MS1) with five different junior high school classes. Table 4.6 gives an overview on the third cycle study group characteristics. Data analysis through observations, documentation (5-step plan), physical artefacts (clay model, Mattie robot), interview (group discussions, feedback rounds) and questionnaire (robot expert) to further understand:
    a. TOP-DOWN design and LOW-TECH prototyping (→ Q3.1)
    b. INFLUENCE and strategies of counter-measures (→ Q2.1 and Q2.2)
    c. REAL-LIFE problem solving (→ Q3.3)
    d. Multi-disciplinary TEAMWORK (→ Q3.2)
    e. PRODUCT development (→ Q1.2)
3. Further emerging codes: PEER pressure, Team PERSONALITY
4. Comparing analytic memos from cycles 1, 2 and 3:
    a. Any further insights, confirmations or inconsistencies?
    b. Grouping codes into categories or themes, causes/explanations, relationships, theoretical constructs (related work)
5. Mixed-methods with quantifications to back up qualitative findings (combined with data from Cycle 2)
    a. Gender and age of participants, fields that they are interested in, and Mattie team group they have chosen (5-step plan, robot expert questionnaire) (→ Q1.1)
    b. Self-assessment of participants if global or local thinker (robot expert questionnaire) (→ Q1.2)
    c. 5-step plan structure (how many steps have the children answered) (→ Q3.1)
    d. What kind of robots do kids imagine? (→ Q3.3)
6. Claims, conceptual framework and research questions defined

Table 4.6 Study group characteristics MS1

Study		Size	Characteristics	Expectations	Tutor dynamics	Teacher dynamics
MS1	A	13	9 girls, 4 boys, assigned by teacher, high school with business focus, handicraft class	learning about robots, having fun, not having school, visiting TU Wien and robot lab	tutors instructed and prepared	teacher new to concept
	G	15	1 girl, 14 boys, assigned by teacher, high school, technical handicraft class (boys handicraft bias)	building a "real" robot, learning about robots, having fun, not having school, visiting TU Wien and robot lab	tutors instructed and prepared	teacher new to concept
	H	15	3 girls, 11 boys, assigned by teacher, high school with natural science focus, handicraft class	building a "real" robot, learning about robots, having fun, not having school, visiting TU Wien and robot lab	tutors instructed and prepared	teacher new to concept
	K	13	6 girls, 7 boys, assigned by teacher, high school, handicraft class	learning about robots, having fun, not having school, visiting TU Wien and robot lab	tutors instructed and prepared	teacher new to concept
	R	24	7 girls, 17 boys, assigned by teacher, high school with natural science focus, physics class	learning about robots, having fun, not having school, visiting TU Wien and robot lab	tutors instructed and prepared	teacher new to concept

4.6.4 Forth Cycle – Pilot Study 7 and Main Study 2

In the fourth cycle, the improved Crazy Robots concept was tested as the second part of the main study MS2. Furthermore, the concept was additionally tested with older children (PS7) and an experiment was performed to compare the 5-step plan with the storyboard instrument. Data was collected through observations, documentation, interviews, physical artefacts, and questionnaires, as well as supported by theory. The CODES from the first three cycles were grouped. The last cycle was used to understand the concept and its implications, thus as a final step, all research questions were reviewed with all data to confirm or dismiss findings. Following steps were pursued:

1. Testing concept of Crazy Robots format compressed into a project day and older age group (PS7). Data analysis through observations, documentation (storyboard), physical artefacts (Mattie robot), and interview (feedback round). Testing improved Crazy Robots concept (MS2). Data analysis through observations, documentation (5-step plan and storyboard), physical artefacts (clay model, Mattie robot), interview

(group discussions, feedback round), and questionnaire (robot experts). Table 4.7 gives an overview on the forth cycle study group characteristics.

2. Understanding following questions
    a. Are the offered **structures and tools sufficient**? (→ Q3.1)
    b. What are the **drawbacks** of a robotic product development approach? (→ Q3.1)
    c. How will the Crazy robots workshop series **influence** young people's interests, beliefs and expectations towards robots, robotics, product development, real-life problem solving, multi-disciplinary teamwork or other educational robotics activities? (→ Q3.1)
    d. Why should young people learn multi-disciplinary teamwork? How is it implemented in Crazy Robots? (→ Q3.2)
    e. Why should young people learn real-life problem solving? How is it implemented in Crazy Robots? (→ Q3.3)
3. Final data CODES that evolved over time into the conceptual framework structure
    a. ROBOTS and ROBOTICS
    b. PRODUCT DEVELOPMENT
    c. INFLUENCE "TYPE" ("type" = other educational robotics activity OR environmental factors like peers, family or teacher)
    d. Concept BEST PRACTICES and SHORTCOMINGS
    e. REAL-LIFE PROBLEM SOLVING
    f. MULTI-DISCIPLINARY TEAMWORK
4. Comparing analytic memos from cycles 1, 2, 3, and 4 with back up from mixed-methods (Final Analysis and Findings):
    a. Any further insights, confirmations or inconsistencies?
    b. Cross-case analysis pilots and main study
    c. Were all young people addressed with robotics and product development? (→ RQ1)
    d. How much influence did other workshops and environmental factors have? Could they be addressed? (→ RQ2)
    e. How effective is the 5-step plan to solve real-life problems with robotics? (→ Q3.1 and Q3.3)
    f. How effective is a storyboard exercise to solve real-life problems with robotics? (→ Q3.3)
    g. How effective is the 5-step plan structure compared to the storyboard exercise? (→ Q3.1)
    h. What kind of robots do children imagine? Thematic coding of the qualitative data from the 5-step plan templates and categorizing into meaningful themes as well as analysis of the Mattie robots (→ Q3.3)
    i. How did the teamwork with Mattie robot work out? (→ Q3.2)
    j. What effect did the changes between MS2 and MS1 have?
    k. How suitable is the concept for teenagers in a project day context?
    l. Does the Crazy Robots concept introduce young people to real-life problem solving in multi-disciplinary teams? (→ RQ3)
5. Discussion of Findings and Conclusions

Table 4.7 Study group characteristics PS7 and MS2

Study		Size	Characteristics	Expectations	Tutor dynamics	Teacher dynamics
PS7	M	14	girls, ages 14 to 16, assigned by teacher, high school with natural science focus, partly not motivated	learning about robots, having fun, not having school, visiting TU Wien and robot lab	tutors instructed and prepared	N/A
	B1	8	boys, ages 14 to 15, assigned by teacher, high school with natural science focus, curious	learning about robots, having fun, not having school, visiting TU Wien and robot lab	tutors instructed and prepared	N/A
	B2	9	boys, ages 14 to 18, assigned by teacher, high school with natural science focus, partly not motivated	building a "real" robot, learning about robots, having fun, not having school, visiting TU Wien and robot lab	tutors instructed and prepared	N/A
MS2	A	9	3 girls, 6 boys, assigned by teacher, high school with business focus	informed by peers and teacher, learning about robots, having fun, not having school, visiting TU Wien and robot lab	tutors experienced	teacher experienced with concept
	G	9	2 girls, 7 boys, assigned by teacher, high school, technical handicraft class (boys handicraft bias)	informed by peers and teacher, learning about robots, having fun, not having school, visiting TU Wien and robot lab	tutors experienced	teacher experienced with concept
	H	10	5 girls, 5 boys, assigned by teacher, high school with natural science focus, handicraft class	informed by peers and teacher, learning about robots, having fun, not having school, visiting TU Wien and robot lab	tutors experienced	teacher experienced with concept
	K	24	12 girls, 12 boys, assigned by teacher, high school, arts class	informed by peers and teacher, learning about robots, having fun, not having school, visiting TU Wien and robot lab	tutors experienced	teacher experienced with concept

4.7 Summary

In Chapter 4, we elaborate on the research design based on qualitative data analysis methodology and structured through a conceptual framework. We show how the research questions are linked to the claims and help to scientifically evaluate the Crazy Robots concept. As part of the multiple-case study in four cycles of sequential analysis, nine case studies are presented in detail: seven pilot studies to understand the problem, develop and test different instruments and ideas, and a main study to test and improve the Crazy Robots concept. The case study design uses multiple sampling from nine cases and the instruments observation, documentation, physical artefact, interview, and questionnaire, as well as further evidence from theoretical frameworks and related work. The data is analysed with analytic memoing in four cycles. The qualitative analysis is backed up with quantitative findings where applicable. In Chapter 5, the reader is guided through the findings and discussions with the same structure.

Chapter 5

Findings and Discussion

This work claims that the educational robotics concept “Crazy Robots” addresses all young learners and introduces them to real-life problem solving in multi-disciplinary teams. In the following chapter, we elaborate on why these claims hold by presenting findings during the case study backed by theoretical research. In order to do this, the chapter is structured into sections based on the four cycles of sequential analysis. The reader is guided case by case through the findings of each study based on qualitative analysis backed up by mixed-methods where applicable, highlighting the main aspects which follow the codes of the same cycle as defined in Chapter 4 section 4.6. and following subsections.

In section 5.1, the findings of the first cycle are presented. In this cycle, educational robotics approaches were explored and first ideas for the conceptual framework were generated. From these explorations data codes were deducted to help sort through research data (deductive coding) and start defining research questions.

The second cycle findings are presented in section 5.2. In this cycle, materials and robotic product development instruments were tested with an unobtrusive data collection strategy, and further educational robotics approaches were explored. The data codes from the first cycle were continued to be used and adapted when new insights occurred (inductive coding).

In section 5.3, the findings of the third cycle are presented. In the third cycle, lessons learned and findings from the pilot studies were used to develop the Crazy Robots workshop series incorporating three important phases of product design. The complete series was then tested by collecting data through observations, documentation, interviews, physical artefacts, and questionnaires. The data codes from the first two cycles were continued to be used.

The forth and last cycle findings are presented in section 5.4. In this cycle, the improved Crazy Robots workshop series as well as the concept adapted to older children were tested, and an experiment was performed to compare the 5-step plan with the storyboard instrument. The codes from the first three cycles were grouped into the final codes which became the seven aspects of the conceptual framework as elaborated on in Chapter 4 section 4.1.

The last cycle was used to understand the concept and its implications, thus as a final step, all research questions were reviewed with all data to confirm or dismiss findings. This is presented in section 5.5.

Finally, in section 5.6, the findings are discussed under the three research questions that were designed to support the claims.

5.1 First Cycle – Pilot Studies 1-3

In the first cycle, data analysis was done by going through observations, interviews, and physical artefacts from pilot studies 1 to 3 and by doing theory research in order to understand the use of robots and robotics (Q1.1), influences of other educational workshops (Q2.1), the environment (Q2.2), and the Crazy Robots concept and instruments (Q3.1). Codes of this cycle were TOP-DOWN design, LOW-TECH prototyping, BEST PRACTICE and SHORTCOMINGS of other approaches, ROBOTS and ROBOTICS, and INFLUENCE.

5.1.1 Kinderuni Technik "How do I design my robot?" (PS1)

In this workshop, the 5-step plan concept (section 3.3.1) was tested for the first time with 17 boys and 8 girls, in sum 25 children, aged 7 to 12, who were in a summer holidays mood, and participated mostly voluntarily, i.e. they had chosen the workshop together with their parents. Expectations were building a "real" robot, learning about robots, having fun or combinations.

The TOP-DOWN design of the concept based on product design approaches and participatory design methods that empower children (section 3.2) worked well with younger children but also with older children who were generalist thinkers and were prepared by their parents what to expect from the workshop. There were interesting questions and remarks during the group discussions when each step was explained that showed the level of understanding and reflections from the side of the children. Mostly, they were happy to conceptualise a robot for themselves and give it a shape with clay and other materials. Only, the few specialist thinking children had problems with this approach, especially since in this workshop the connection to bottom-up thinking (the robot parts in step 5) was done very briefly in theory without real mechatronic parts.

LOW-TECH prototyping on its own, in a workshop at a technical university with the name ROBOT in it, involving kids over ten years, is bound for some disappointments (SHORTCOMINGS) because of expectations and INFLUENCES from other educational activities. It is crucial to underline the top-down (product design) nature of the workshop in its description, so that laypersons also understand that in the ideation phase of product development experts work with sketches and models before investing money into expensive prototypes.

The translation of robot ideas into 3D models out of clay is a demanding task on its own which forces children to adapt their ideas and become creative to overcome limitations. When looking at the artefacts, one can see that the designs are imitations of things that children know: many models are anthropomorphic, some zoomorphic, some cartoon-like (examples of designs are shown in Figure 5.1). However, this procedure when generating new ideas is not unique to children. Ward (2002) proposes a model that suggests that people predominantly retrieve "*specific known instances of the relevant concept and project the properties of those instances onto the novel idea*". Consequently, children use robot images that they know or imitate animate beings. An interesting finding regarding the artefacts is the influence that provided materials have on the design, e.g. the shape of the clay provided is sometimes used without any changes or all robots have eyes made of the provided eye stickers, as seen in Figure 5.1.

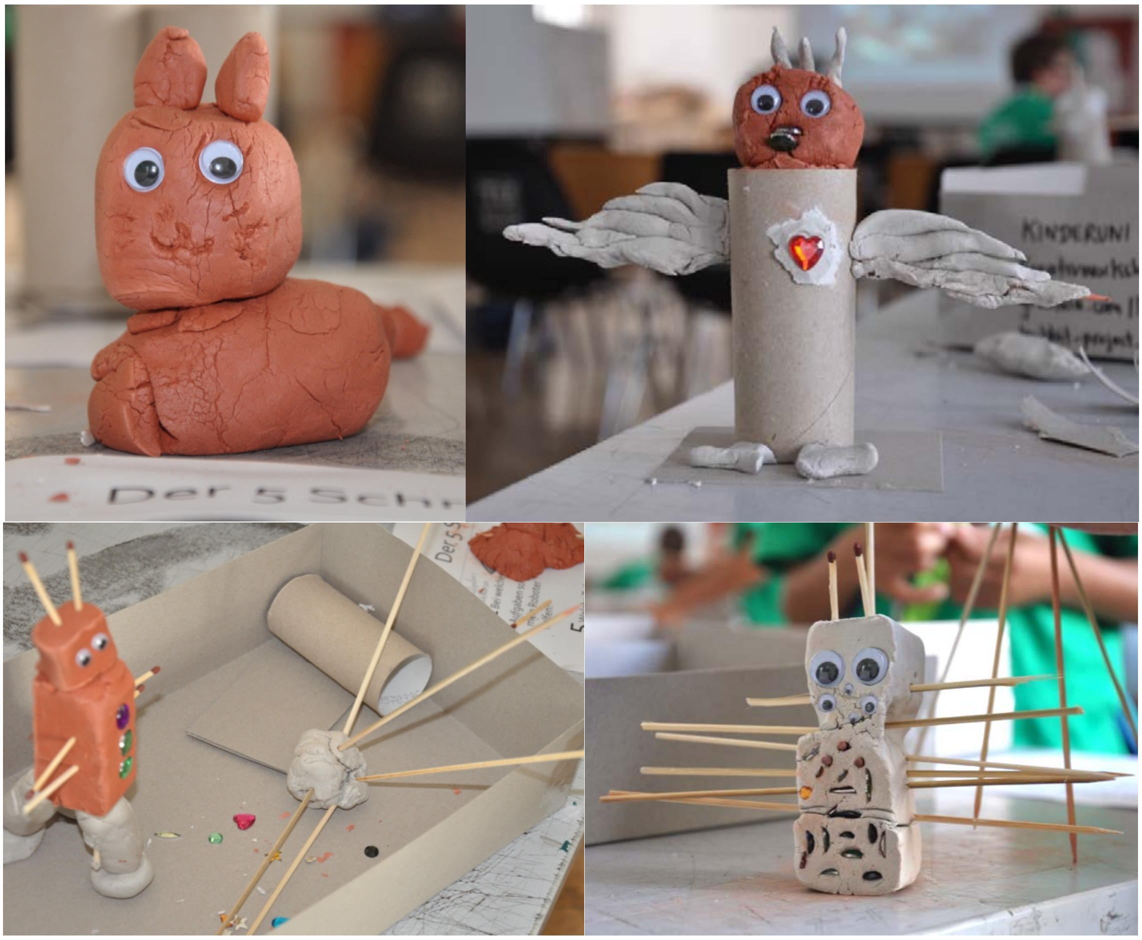


Figure 5.1 Low-tech prototypes from pilot workshop PS1 (top down, left to right): cuddly friend (girl, 8), singing and flying friend (girl, 12); household robot with four arms and protector robot with spikes (boy, 7), household robot for everything with many arms and sensors (boy, 7)

In conclusion, this case study showed the potential of a top-down approach to address all children. The attendance of girls in relation to boys with 1:2 is high compared to other voluntary educational robotics activities (BEST PRACTICE) which indicates that different young people including age and gender are addressed. However, the first testing of the concept also shows that while global thinkers like the top-down thinking, local (specialist) thinkers should not be forgotten and provided with bottom-up tasks in order to address all young learners.

5.1.2 Kinderuni Technik “Why do robots drive by themselves?” (PS2)

In this workshop, 18 boys and 2 girls, aged 10 to 12, who where in a summer holidays mood, participated mostly voluntarily, i.e. they had chosen the workshop together with their parents. Expectations were building a "real" robot, learning robotics, having fun or combinations.

The task was a classical robotics bottom-up task that involved navigation and was worked on with a LEGO Mindstorms robot. Though this black-box robot kit has its limitations, it works wonderfully to teach young students about robot navigation in a short period of time. The competition element also works very well (BEST PRACTICE) for most of the children who participate, although it reinforces dominant behaviour, especially in teamwork, for example, extrovert children dominate introvert ones. Since the technical task and competition elements are widely used in educational robotics activities, the girls to boys ratio of 1:10 is not surprising (SHORTCOMINGS). Furthermore, the shown ROBOT videos are very motivating and fascinating for all participants.

In summary, the workshop concept implies that robotics is engineering and engineering only needs specialist thinkers (INFLUENCE). Since many educational robotics activities are designed this way, these observations confirm the reluctance of girls or children not interested in STEM to participate. It seems that the advantages robots have as educational tools for all young learners are not leveraged upon sufficiently.

5.1.3 Robocup Junior Austrian Open (PS3)

This educational robotics activity was chosen for further observations regarding the attractiveness of robotics competitions. There are three categories in this competition: soccer, rescue and dance. All connect to real-life problem-solving: soccer and dance connect to hobbies young people are interested in, and rescue connects to a real-life application of service ROBOTICS. In all three categories, young people have the possibility to develop TOP-DOWN along with bottom-up thinking skills. For example, in the dance category, the choreography dictates the robot design and movements top-down, or in the soccer category, the rules of the game and playing strategy dictate the robot design and tasks top-down. Working on these movements or tasks with the restriction of technology, time, and money is then the bottom-up perspective to the solution. Winning robot designs are often the ones where both strategies are used and “meet in the middle” (see also section 3.3.1).

In this competition, LEGO Mindstorms can be regarded as the LOW-TECH where mechanics and programming are limited by the concept of the bricks and the programming language. Self-made robots using electronics and mechanical parts have more flexibility, and are thus more advanced technology in this sense. The competition element is combined with teamwork, where a group of young people works towards the goal of successfully finishing a parkour, a dance or beating another group at a soccer game (BEST PRACTICE). However, as in PS2, team dynamics can get rough in a competitive environment. The observation from Melchior and colleagues (2004) regarding girls only engaging in organizational tasks in the robot competition team and leaving technical tasks to boys can be confirmed with the observations in the dance category of this competition. Girls made up the majority in all competing teams in the dance category and were responsible for choreography and costumes, while the few boys in those teams were responsible for the robots.

Competition rewards winners. This can be a winning team beating the others in soccer or a team finishing the rescue parkour with their robot first. Only in the rescue category, finishing the parkour at all is also rewarding. Consequently, this educational robotics activity requires hard work and specialisation from a very early age (SHORTCOMINGS). Therefore, technical high schools with their own robots dominate over general high school students and their “simple” LEGO Mindstorms robots. This gives the impression that robotics is only about engineering, and engineering is only for specialists or “nerds”.

5.1.4 Summary of First Cycle

Studies in the first cycle and related work indicate that many educational robotics activities fail to address all young learners. These findings are also confirmed by Kandlhofer and Steinbauer's (2016) conclusion that young people who participate in voluntary educational robotics activities are already interested in STEM. The analysis in this cycle shows that the focus on specific tasks like navigation, manipulation, and human-robot interaction with bottom-up task solving in competitive environments attracts certain type of young people, but not all. The robotic product development process with the 5-step plan addresses the others, the global thinkers and the ones who need other connections to robotics than engineering. However, specialist thinkers with certain expectations in a robotics workshop have problems with this approach. Table 5.1 gives an overview of important findings from the first cycle.

Table 5.1 Overview of important findings from the first cycle

Codes Cycle 1	Pilot Studies		
	PS1	**PS2**	**PS3**
TOP-DOWN	With low-tech materials only top-down possible: Works better with younger kids and older kids who are global thinkers. Local thinkers have problems with this kind of thinking.	Only bottom-up navigation task	Bottom-up and top-down thinking possible: top-down when task dictates robot concept and design, e.g. in dance when the choreography dictates robot concept or in soccer when the rules of the game and strategy dictate robot design
LOW-TECH	Translating robot ideas into a 3D model out of clay is not easy. Imitation of things that they know: many models anthropomorphic, zoomorphic, or cartoon-like	LEGO Mindstorms has limitations as black-box but very useful for navigation task	LEGO Mindstorms is low-tech in this case. Advanced teams have self-made robots from mechatronic parts
BEST PRACTICE	Girls to boys ratio (1:2)	Competition element (works really well for some children)	Competition element combined with team work, solving real-life robotics problems (navigation, manipulation, human-robot interaction)
SHORTCOMINGS	Clay model without any technology on it own is disappointing	Girls to boys ratio (1:10)	Kids need to be specialised very early on to win in the soccer competition (technical high schools with own robots dominate), similar in rescue. In mixed teams girls choose non-technical tasks.

Codes Cycle 1	Pilot Studies		
	PS1	PS2	PS3
ROBOTS / ROBOTICS	The name "robot workshop" associates with workshops where kids learn robotics or work with a tool that has electronic elements and moves	Fascinating robot videos are motivating	One important connection to real-life problem solving: rescue robots. The other two categories dance and soccer connect to hobbies
INFLUENCE	Kids' expectations to build a "real" robot and take it home	Robotics = engineering = for boys or for "nerds"	Robotics = engineering = specialists

5.2 Second Cycle – Pilot Studies 4-6

In the second cycle, additional data collection strategies as unobtrusive as possible were developed. Data analysis was done by going through observations, documentation, interviews, physical artefacts, or questionnaires involving pilot studies 4 to 6, and by doing theory research in order to understand the use of robots and robotics (Q1.1) and product development (Q1.2), influences of other educational workshops (Q2.1), the environment (Q2.2), and the Crazy robots concept and instruments (Q3.1), as well as multi-disciplinary teamwork (Q3.2) and real-life problem solving (Q3.3) in educational robotics. Codes of this cycle were TOP-DOWN design, LOW-TECH prototyping, ROBOTS and ROBOTICS, INFLUENCE, REAL-LIFE problem solving, multi-disciplinary TEAMWORK, and PRODUCT DEVELOPMENT.

5.2.1 Genderfair Technike "Cute or Crazy - How do I design my dream robot?" (PS4)

In this workshop, the 5-step plan concept (section 3.3.1) was tested together with the storyboard in different activities that evolved around product design. The description of the workshop targeted girls who liked to draw or sketch. 12 girls aged 10 to 14 were in a summer holidays mood, and participated mostly voluntarily, i.e. they had chosen the workshop together with their parents. Expectations were designing a robot, learning about robots, having fun or combinations.

The TOP-DOWN design and LOW-TECH prototyping worked well with this group. The self-assessment of the girls and the robotic fields that they were interested in were in-line with the workshop concept, and thus their feedback was very positive. Interestingly, only two girls identified themselves as first violins (local thinkers). One of these girls wanted to work on a specific part of a robot and program it, the other wanted to test robots. The other girls either identified themselves either as legislative (6 girls) or executive (4 girls) thinkers (Sternberg, 1999). Given that the workshop was promoted as a design workshop, it does not come as surprising that four of those girls only chose design as the robotic field that they wanted to work in, and four other girls chose design as one of the possible robotic fields together with others (multiple choices were possible). Among the girls, some were already very talented in design as seen in the examples in Figure 5.2 Generally, this group used the modelling clay well. However, some 3D models looked different than the sketches on the storyboards, which indicates that the ideas were either revised and changed during the design process, or had to be adapted in order to be materialized with clay.

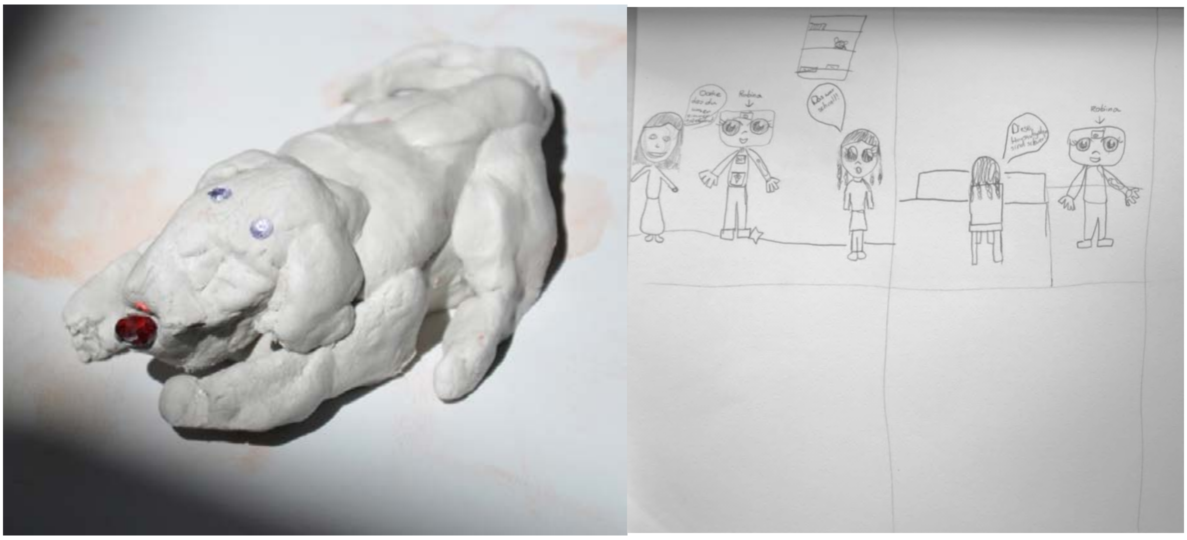


Figure 5.2 Dog robot of a 10-year-old girl (left) and the story board of two girls in a design team (10 and 11 years old)

The theme ROBOTS and ROBOTICS was well perceived. Eight girls wanted either more workshops with robotics or learn how to build a robot with real parts. It could be observed that, even though the girls knew that they were going to work with drawings and models, they would have loved to partially work with a tool that had at least some electronics or moving parts. The INFLUENCE of the common mind-set about robots or a robotics workshop could not be eliminated by the description. This influence is probably enhanced by parents, society, and other educational robotics workshops, because working with sketches and mock-ups in the ideation phase of product design is not well known by laypersons. An example observed by the researcher after the workshop confirms this: a girl presented her creation to her father saying “look, what robot I made!”, and he replied “this is not a robot”.

The storytelling worked also well in this group and connected to REAL-LIFE problem solving. The girls described a day with their robot on a storyboard and talked about their robot to others. The 5-step plan then offered a structure to their descriptions. One point that can be highlighted is about the robot tasks that the girls conceptualized. Play, entertain, be a friend, protect, bring joy, and help with homework were the most chosen tasks and they connect to real-life and real-life problems. A mixed-method analysis on the tasks and the 5-step plan structure is given in section 5.5 where data from all studies with 5-step plan templates is considered.

In this workshop format, the participants had two different possibilities of TEAMWORK. The storyboard exercise was done in teams of two. The robot conceptualization activity with the 5-step plan was done in teams of four. Especially in the teams of four, certain girls could be observed taking dominant team roles (Fischer et al., 1998). They were, however, very interested in the analysis of their teamwork skills and eager to learn how to become more thoughtful regarding their team mates. The observations and interviews showed that although collaborative learning environments were familiar to the participants, they did not have a deeper understanding of the processes behind them.

Finally, the concept and design of activities could not convey the idea of robotic PRODUCT DEVELOPMENT fully; it stayed top-down without any bottom-up elements. The 5th step regarding robot parts was only done in theory with pictures. This was clearly not enough for the participants to grasp the concept. Although, only one girl left out step 5 in her 5-step plan template, only five girls from twelve mentioned computer or microchip and sensors as robot parts, and two girls mentioned either computer or sensors. Many robot parts corresponded with human or animal body parts. These findings were further investigated in pilot study 5 (PS5).

5.2.2 Kinderuni Technik "How do I design my robot?" (PS5)

In this workshop, the same 5-step plan format as in PS1 was tested again with a similar group of participants. The main differences to PS1 were the announcement to the children and parents to attract top-down thinkers and children not interested in STEM, and the unobtrusive data collection strategy. 15 boys and 7 girls, in sum 22 children aged 7 to 12, were in a summer holidays mood, and participated mostly voluntarily, i.e. they had chosen the workshop together with their parents. Expectations were learning about robots, having fun or combinations.

The TOP-DOWN design and LOW-TECH prototyping worked well with this group. The self-assessment of the children and the robotic fields that they were interested in were in line with the workshop concept. As in PS4, very few (two boys) identified themselves as local thinkers. From the remaining children, nine were executive thinkers and eight were legislative thinkers. Interestingly, all girls who answered this question (six in number) identified themselves as composers (legislative thinkers). A possible explanation is that design and creative tinkering with art materials, two fields more often attributed to girls, have legislative thinking elements. There is also the possibility that the real-life image of a conductor of an orchestra is male, thus not chosen by the girls in this group. The robotic fields that the participants chose to be interested in also reveal that more global thinkers participated in this workshop than local thinkers. Most occurrences were robot design (4x) and robot law-making (4x), followed by robot tasks (3x), robot parts (2x), and robot behaviour (1x).

An interesting point is the girls to boys ratio of 1:2 in this workshop, which is similar to PS1 and unusual for a voluntary educational robotics activity. This can be interpreted as the concept attracting a diverse participant pool. Also, 17 out of 22 participants were nine years old or younger. The description of the workshop had been adjusted to align expectations to the activity, thus parents of younger children signed them up thinking that they might enjoy such a concept. However, there were still a few who thought that they were going to build "real" robots (INFLUENCE). This is interpreted as information loss along the way, when parents signed their children up but did not adjust the children's expectations by explaining the activity in detail.

The findings from the observation and interview data regarding the ROBOTS and ROBOTICS theme are very similar to the findings of PS1, which are elaborated on in section 5.1.1. Therefore, these findings will not be repeated here but continued to be used for further synthesis in the sequential analysis. In this workshop, there was no activity concerning teamwork, each participant worked on his or her own template and clay model. Additional findings worth mentioning are concerning the data collection strategy and findings on children aged nine and younger regarding the concept and the 5-step plan template. In the remainder of this section, these findings are elaborated on.

The data collection strategy was held simple by letting the children code the template with gender and age, and at the end of the workshop both the template and the clay model were photographed together. This worked well given that the children provided the correct gender and age. The data collected in this way was used, first to qualitatively analyse matching document (5-step plan template) and artefact (robot clay model) to gain insights about children's understanding of the concept, and second in a mixed-method analysis with data from all studies with 5-step plan templates for children's robot ideas and their use of the 5-step plan. Quantitative results are presented in section 5.5.

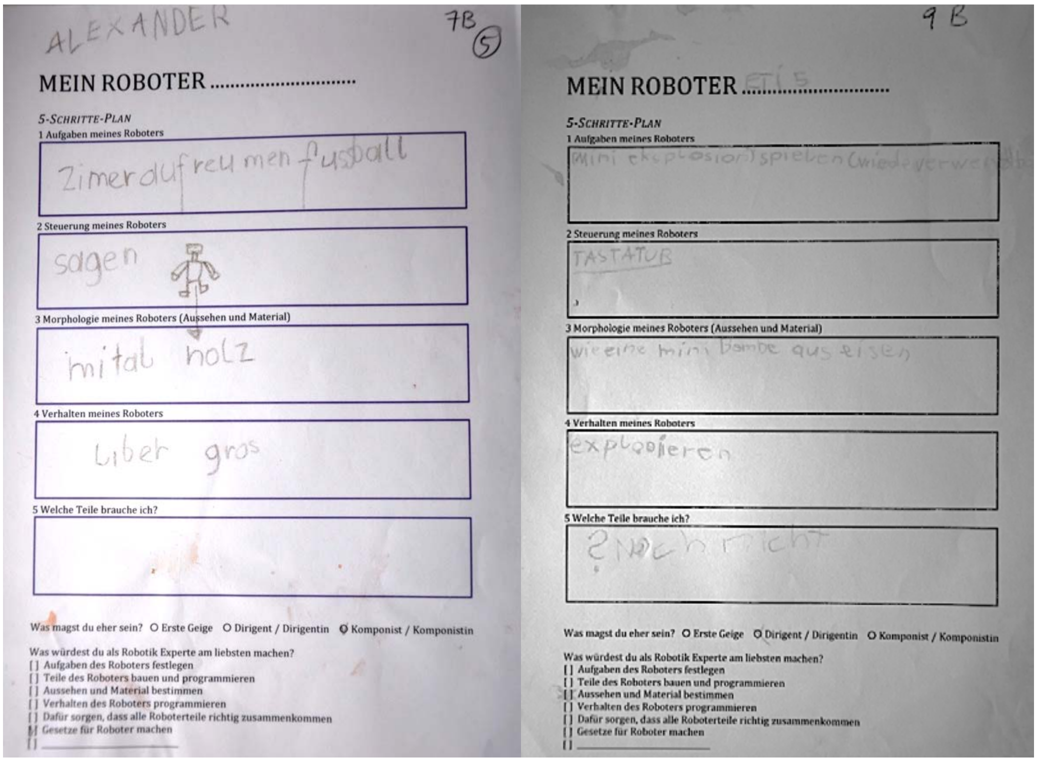


Figure 5.3 5-step plan templates with robot concepts from PS5. A robot playing soccer and cleaning the room from a 7-year-old boy (left), and ETI5 robot to play mini explosions from a 9-year-old boy (right)

The qualitative analysis of the 5-step plan templates and clay models revealed some interesting insights, especially regarding children aged nine and younger. For example, those children had difficulties filling out the template because their writing skills were limited and their cognitive skills not as developed as older children. They kept descriptions very short (mostly one word) as seen in Figure 5.3 In these cases, the materialisation of the ideas in the form of clay models was more successful and rewarding to the children as seen in Figure 5.4. The depicted examples also show that the workshop participants connected their robotic solutions to REAL-LIFE problems. A mixed-method analysis on the tasks is given in section 5.5 where data from all studies with 5-step plan templates is considered.

Figure 5.4 Robot clay models from PS5. A robot playing soccer and cleaning the room from a 7-year-old boy (left), and (right) ETI5 robot bomb from a 9-year-old boy (same robots as described in the templates in Figure 5.3)

An interaction with a 9-year-old boy and the researcher who was at the same time workshop instructor is worth mentioning to demonstrate the holistic concept of the approach connecting to young people's interests. During the discussion around the robot conceptualization, a 9-year-old boy told the researcher that he wanted to build a bomb robot. The researcher asked "OK, what would be the task of your robot? To teach you physics principles or chemistry?" The boy started thinking. "Just make sure, the robot obeys the Three Laws and does not hurt anyone", the researcher added. At the end, with the help of the 5-step plan, the boy imagined a small robot for playing that exploded and then rebuilt itself (Figure 5.4, right). However, the boy imagined to control his robot with a keyboard (as indicated in the template in Figure 5.3, right) but he did not build any keyboard into the model. This demonstrates the kind of holistic thinking this approach requires and that younger children can be introduced to it without complicated electronics by just being asked questions linking top-down to bottom-up thinking when the model is finished.

Similar as in PS4, the PRODUCT DEVELOMENT idea could not be conveyed fully because there was not enough time to change the perspective to bottom-up with the 5th step robot parts. The qualitative analysis indicated that not all children had understood this part. In some cases, however, technical parts that children were familiar with were remembered and connected to the correct function. For example, an 8-year-old girl controlled her pizza-shaped robot by speech ("I want to talk with the robot") and she mentioned microphone as a robot part after ears, eyes, and mouth (Figure 5.5). A mixed-method analysis on the 5-step plan structure is given in section 5.5 where data from all studies with 5-step plan templates is considered.

Figure 5.5 Robot clay model and corresponding 5-step plan template from PS5: Pizza-shaped robot named LUI of an 8-year-old girl (left) and the 5-step-plan template describing it as a robot for eating, cooking, playing and talking (right)

5.2.3 Kinderuni Technik “Why do robots drive by themselves?” (PS6)

In this workshop, the same format as in PS2 was observed a second time. There were no differences between PS6 and PS2, except this time 20 boys participated, ages 10 to 12. They were in a summer holidays mood, and participated mostly voluntarily, i.e. they had chosen the workshop together with their parents. Expectations were building a "real" robot, learning robotics, having fun or combinations.

The observations were very similar to the ones one year earlier with PS2. ROBOTS and ROBOTICS were a motivational factor for participation, there was no TOP-DOWN element in the activity, the task was a classical robotics bottom-up task that involved navigation. The participants worked with a black-box robot (LEGO Mindstorms), an excellent tool to teach young students about robot navigation in a short period of time. Offered for children ten years of age or older, this workshop concept attracted boys interested in STEM. Many of them either knew LEGO Mindstorms, had worked or were eager to work with it, or even had one at home. There were no girls. A possible reason for this is the limitation to the bottom-up robot navigation task which is very specific. There is a REAL-LIFE connection, because service robots need to navigate through their environments, but no connection to children’s lives and interests. Another possible reason is the chain effect, a competitive “boyish” environment does not attract girls, thus girls do not get involved, and consequently, the environment does not change. There are approaches who try to counteract this phenomenon by offering workshops only for girls (as in PS4). The pilot study PS7 was also designed in gender-specific groups and is reported on in section 5.4.1.

Analysed from a different perspective, the navigation task can be seen as a closed problem (contrary to an open-ended problem). This is crucial in technical problem solving; engineers need to divide open ended problems into solvable chunks. Thus, the rather big technical problem of robot navigation was divided into a solvable closed problem, i.e. let the robot follow a black line with one or two colour sensors. This is important, because the children need a sense of achievement when the workshop is over, which is very difficult with an open-ended problem. Consequently, while an open-ended problem may address many different interests and talents, a closed problem ensures a sense of achievement for students.

5.2.4 Second Cycle Summary

Studies in the second cycle show that educational robotics workshops with product or design focus attract young people who are global thinkers, like creative tasks as designing or tinkering with art materials, and probably would not participate in workshops with specific technical problem solving. However, even these participants have expectations from a robotics workshop involving at least some electronics or moving parts. The top-down approach works well with global thinkers, but not so well with local thinkers. Consequently, a product development approach that aligns top-down with bottom-up thinking is needed to address all young learners. Such an approach should not only involve real-life problem solving that connects to children's interests (as suggested by learning theories like constructionism or project-based learning), but also focus on multi-disciplinary teamwork that goes beyond collaborative learning to introduce young people to the psychological and social processes behind team dynamics. Table 5.2 gives an overview of important findings from the second cycle.

Table 5.2 Overview of important findings from the second cycle

Codes Cycle 2	Pilot Studies		
	PS4	**PS5**	**PS6**
TOP-DOWN	Works well with girls who are interested in design or creative tinkering	The concept attracts a diverse participant pool, more girls and younger children	Only bottom-up technical task solving, however, closed problems necessary in engineering
LOW-TECH	Translating robot ideas into a 3D model out of clay is not easy. This group handled it very well. There were some talented designers.	Low-tech prototyping helps younger children translate their ideas into tangible artefacts	LEGO Mindstorms robot (relatively advanced tech for this age group)

Codes Cycle 2	Pilot Studies		
	PS4	PS5	PS6
ROBOTS / ROBOTICS	Eight girls wanted either more workshops with robotics or learn how to build a robot with real parts. Though design workshop was clear, still expectations to handle some electronics or have moving parts.	Robot workshop still resonates in children's minds as working with something out of metal and moving	Robots and robotics are motivational factors for participation
INFLUENCE	Working with sketches and mock-ups in the ideation phase of product design is not well known by laypersons	Parents understand the workshop description and choose well for their children, but probably do not inform them sufficiently	Children already interested in STEM participate (100% boys)
REAL-LIFE	Play, entertain, be a friend, protect, bring joy, and help with homework were the most chosen tasks and they connect to real-life and real-life problems	Robot tasks like playing, cooking, talking as examples	Solving a real-life robotics problem (navigation), but not a real-life problem connected to children's lives
TEAMWORK	Although collaborative learning environments are familiar, participants do not have a deeper understanding of team dynamics	N/A	Competitive ("boyish") teamwork environment
PRODUCT DEVELOPMENT	The concept and design of activities could not convey the idea of robotic product development fully; it stayed top-down without any bottom-up elements	In some cases, children connect technical parts they are familiar with to the correct function	No product development, stays bottom-up

5.3 Third Cycle – Main Study 1

In the third cycle, lessons learned from the pilot studies were used to develop the Crazy Robots workshop series with the Mattie robot incorporating three important phases of product development with real-life problem solving and multi-disciplinary teamwork. Data analysis was done by going through observations, documentation, interviews, physical artefacts, or questionnaires involving main study 1, and by doing theory research in order to understand the use of product development (Q1.2), influences of other educational workshops (Q2.1), the environment (Q2.2), and the Crazy Robots concept and instruments (Q3.1), as well as multi-disciplinary teamwork (Q3.2) and real-life problem solving (Q3.3) in educational robotics. Codes of this cycle were TOP-DOWN design, LOW-TECH prototyping, ROBOTS and ROBOTICS, INFLUENCE, REAL-LIFE problem solving, multi-disciplinary TEAMWORK, and PRODUCT DEVELOPMENT.

5.3.1 FWF Science Communication Part I *Schräge Roboter* first semester (MS1)

In this study, the Crazy Robots concept and the Mattie robot were tested for the first time. The teachers had assigned the classes and informed the students about the project. Four classes participated with their handicrafts teachers (13-15 students each) and one class with their physics teacher (24 students). In sum 80 children (age range 10-14) attended the workshop series, 54 boys and 26 girls.

In the three-workshop series, the product development concept was approached from two perspectives: TOP-DOWN and bottom-up. In the first workshop, the 5-step plan workshop design (as in PS1 and PS5) was used for a top-down thinking approach with LOW-TECH prototyping. Between the first and second workshops, the teachers discussed the designs and models in the classes, especially regarding feasibility, and thus connected bottom-up to top-down. This connection was missing in the pilot studies (PS1, PS4, and PS5). Furthermore, in the second and third workshops, top-down and bottom-up thinking tasks were brought together in the multi-disciplinary team tasks of the Mattie robot.

The combination of top-down with bottom-up thinking worked very well. Besides the observations during the workshops by the researchers, findings from the robot expert questionnaires after the second workshops and the feedback interviews at the end of the series suggest that almost all young learners were addressed. To complement the observations, first, the robot expert questionnaire was evaluated regarding the diversity of the students (global or local thinkers, introverts or extroverts, fields they were interested in). Second, their answers regarding what they liked most and what they thought could be better were analysed. Finally, and third, the interviews with students and feedback from teachers were considered to confirm or contradict previous findings. In the following, this analysis is elaborated on.

First, the students' self-assessment of their personality and interests was examined. From 77 answered questionnaires, 72 assessed their global or local thinking, 65% of which believed to be global thinkers, and 35% local thinkers. This showed that specialised tasks in educational robotics were important, yet, top-down holistic tasks were also needed, actually remarkably more than specialised ones. Interesting for the teamwork dynamics was the distribution of students' self-assessed intro- (51%) and extroversions (49%), which in this case was well balanced.

The chosen robotics fields of interests were also diverse with electrical and mechanical engineering being mentioned most often. This should not surprise after a visit to the faculty of electronics and information systems with the impressive robot demonstration. The analysis in section 5.5 cross-examined if this hold true with the participants of the main study second part who visited the lab and Romeo robot after answering the questionnaire. Furthermore, the students preferred fields that were in-line with the Mattie robot groups they had chosen to be part of, with a few exceptions. A qualitative analysis of these exception cases showed the influence of peers, which is explained later in this section. The findings regarding the robotics field the students were interested in indicated that the participant pool of the workshops was diverse, thus participating children had also other interests than STEM or robotics.

The questionnaires were examined regarding the satisfaction of the participating classes of young people with different interests and talents. All children answered that they were happy or satisfied with the workshops. Their complaints were rather related to the groups in which they had worked. The creative teams (HRI and Design) needed more time. The technical groups (engineering and R&D) wished for more technical tasks or to build their own robots. The Sales & Marketing team who also coordinated the whole robot concept especially had a hard time in the class with 25 students. Their coordination task was demanding, however, with the help of the instructors and teachers, all sales & marketing teams managed this well and were very satisfied afterwards. Interestingly, where instructors and teachers reached their limits, the students loved the chaotic atmosphere that let them solve a problem on their own. One comment of an 11-year-old girl in this respect was: “Finally, we managed to do something almost on our own, without the teacher helping us that much.” Naturally, discussions occurred and were not handled well every time. Thus, in some comments in the questionnaires and also in the feedback interviews, the students showed their mischief about communication and collaboration problems (TEAMWORK).

The findings overall confirm that **the concept addresses all young learners**. The teacher feedback interviews affirm this. Generally, the teachers were very satisfied with the concept, especially to see their students’ capabilities in teams with minimal guidance. The students did not have much experience or no experience at all in teamwork. There was also valuable feedback regarding shortcomings, like adapting some tasks in the research & development group or doing the robot demo after the workshop and not before. In these interviews, one teacher also revealed that he had expected more technical workshops. This explained some disappointment encountered in his class, and thus showed the importance of aligning the expectations to the workshop (caused by other educational robotics activities or environmental factors) beforehand as much as possible.

Besides the remarkable INFLUENCE of the teacher on the class’s expectations on the workshops, another influence could be observed during the grouping for the Mattie robot tasks. Students wanted to be in the same groups as their friends, thus did not choose the fields that they were most interested in. This could also be seen on the answers in the questionnaires, when, for example a 12-year-old girl chose mechanical, electrical engineering, and chemistry as the fields that she was most interested in, but chose to go into a non-technical field (HRI) with her female peers. This behaviour was also confirmed by the teachers, some suggesting that a concept where each student worked in each group could be more effective. The numbers showed clearly that while boys preferred engineering and research & development, girls stayed away from these two groups. On a different note, for some children, the differences between the Mattie robot and the Romeo robot were unacceptable (although they were explained that all the talk and movement of the robot were pre-programmed); they rather thought that they could work on Romeo or build more advanced robots, which is why in the main study second part MS2, the robot demo was done after the workshop with the Mattie robot.

The findings about REAL-LIFE problem solving indicated that the students could connect problems out of their lives to robotic solutions that they transformed into tangible artefacts out of clay. Each student had at least one robot idea to solve a problem from his or her life, ranging from robots for parents with babies to transporter or cooking robots. Many robots referred to actual problems out of the children’s lives, e.g. being alone at home after school and needing help with cooking or homework, having entertainment or a playing partner, waking up, or getting transported from A to B. The quantitative analysis in section 5.5 provides the occurrences of robot tasks from all case studies with the 5-step plan templates.

The real-life solutions of each class with the Mattie robot platform also provided interesting insights and findings. Naturally, the students became frustrated after having all these unlimited ideas and then seeing the limitations of the Mattie robot. It helped a bit to encounter their frustration when being told that real experts had to deal with the same limitations and that the Mattie robot materials were available for everyone to build robots at home, however the prototyping aspect regarding, rapid prototyping and iterations, could not be conveyed sufficiently. Consequently, the students adapted their ideas to something very simple, a toy for small children with buttons, in three classes with arguments like “the robot cannot do anything”. However, two classes worked in the way intended and built working prototypes of their ideas, a robot for kids alone at home and a garbage robot for the handicraft class (as seen in Figure 5.6). The other three classes warmed up into the idea with time and developed impressive marketing posters and conducted user studies with self-made questionnaires (as seen in Figure 5.7). Interviews with teachers showed that the mind-set of the students can be influenced beforehand, which was done by the teachers in the main study second part MS2. Those robot concepts and prototypes are described in section 5.4.2.

Figure 5.6 Mattie robot designs from MS1: Pikachu robot (left) for kids alone at home that reads stories, helps with meal preparation, plays music, entertains, and gives advice; garbage robot (right) that collects garbage in the class, gives funny statements when touched, and cites environmental facts.

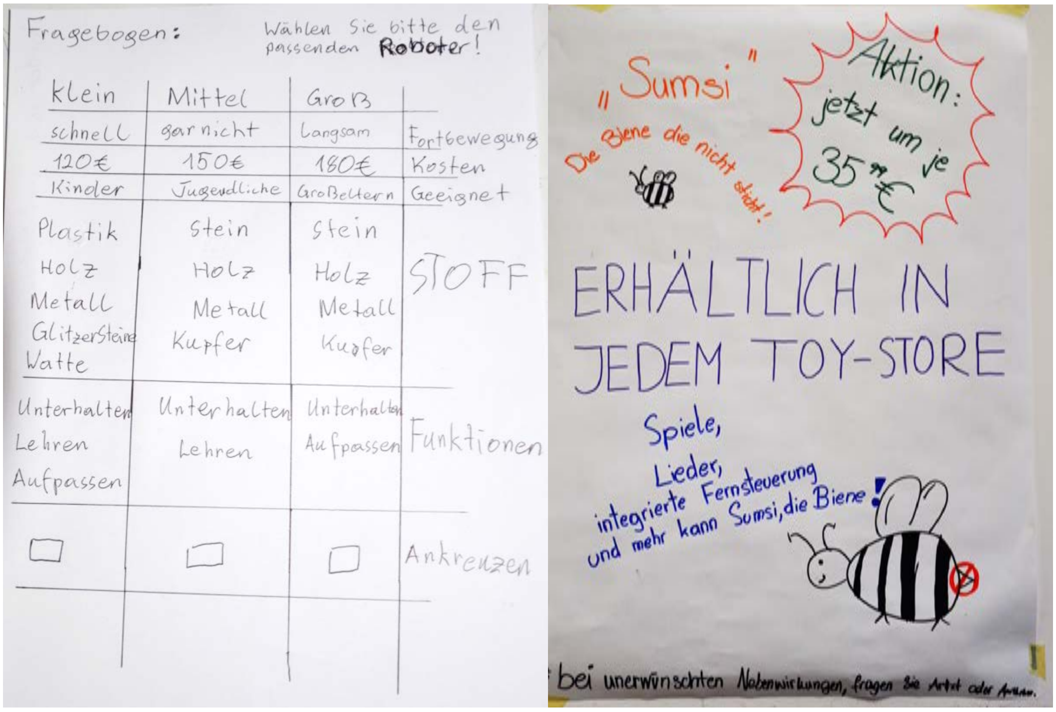


Figure 5.7 Students artefacts from MS1: Questionnaire of the user study for a robot toy (left), marketing poster of a robot bee toy (right)

The multi-disciplinary TEAMWORK aspect gave students the possibility to explore a robotics field that they found interesting. Findings showed that team dynamics in student teams were similar as it would be with adults, e.g. students who felt unheard became uncooperative or some students were more engaged than others. Some students even gave up and refused to help, which then frustrated the team mates who did not understand that behaviour. This also showed that students needed to learn the theories about team dynamics and how to collaborate with others, make themselves heard or listen to quiet ones. Although the first workshop of the series was very structured, the second and third workshops had many elements in parallel depending on the interests of the students, and thus were chaotic. This was demanding on the adults present but very much appreciated by the students ("it was great to do what we want and have to talk to the other teams").

In this study (MS1), students were given the choice if they wanted a sales & marketing team or not. Classes with that team achieved better consensus regarding the robot concept because the team members engaged a lot in coordination. Since this worked so well, it was then decided to have the sales & marketing team as a fix element in the main study second part MS2. Interestingly, all the hassle was forgotten once the students had the finished prototype driving around and making sounds that they had recorded previously. It gave them a feeling of having accomplished something really difficult. The teachers took the opportunity to reflect upon what had happened in the teams together with the students in follow-up classes. They let the students come up with strategies how teamwork could be better in the following workshop and in the future.

The different teams to develop the Mattie robot gave the students the possibility to see different aspects of robotics from a PRODUCT DEVELOPMENT perspective. Sometimes, they changed teams in the third workshop to see other aspects. Sometimes, they deepened their knowledge in the one field that interested them most, e.g. marketing or engineering. It was not easy for the students to first plan (agree with the other teams), then start working on their tasks. The limitations of the technology and design materials also frustrated from time to time. The top-down approach at the beginning of the second workshop (conceptualising the robot) was frustrating to all classes, yet, in the end all could accomplish this task to their satisfaction, which then empowered them. Also, in each class there were one or two disappointed children because the workshop content did not match their expectations, especially children who expected a more STEM-focused workshop. This was addressed by better briefing teachers beforehand. Nevertheless, the majority of the children thrived on the open concept to work on something that was meaningful to them and their lives, and also expressed this in their feedback. The children who intuitively preferred the top-down approach were more interested in robot design or behaviour than in building or programming details.

5.3.2 Third Cycle MS1 Summary

The main study part 1 (MS1) in the third cycle shows that the Crazy Robots concept aligns top-down with bottom-up thinking while incorporating different robotic fields with product development, thus addresses all young learners. While global thinkers identify themselves with conceptualising and coordinating, local thinkers concentrate on specific tasks that they are interested in, some in technical problem solving, others in tinkering with art materials. The proposed solutions, be it on the solo work or in teams, reflect real-life problems. The Mattie robot solutions handle the platform’s limitations very well; the prototypes are more than sufficient for concept demonstrations. The teamwork experience is very educational for the students, especially when reflection about it takes place with the help of a teacher or expert afterwards.

5.4 Fourth Cycle – Pilot Study 7 and Main Study 2

In the fourth cycle, lessons learned from the main study part 1 were used to improve the Crazy Robots workshop series with Mattie robot and also test the concept with older students in a Crazy Robots project day. Data analysis was done by going through observations, documentation, interviews, physical artefacts, or questionnaires research in order to understand if the Crazy Robots concept and instruments (Q3.1) introduced young people to multi-disciplinary teamwork (Q3.2) and real-life problem solving (Q3.3). The final codes of this cycle were ROBOTS and ROBOTICS (Q1.1), PRODUCT DEVELOPMENT (Q1.2), INFLUENCE (Q2.1 and Q2.2), Concept BEST PRACTICES and SHORTCOMINGS (Q3.1), REAL-LIFE problem solving (Q3.3), and multi-disciplinary TEAMWORK (Q3.2).

5.4.1 FWF Science Communication Part II – *Schräge Roboter* Project Day (PS7)

In a final pilot to test the concept with older students, three groups of high school students aged 14-18 participated in a Crazy Robots project day each, where the workshop series was compressed into one day. The teachers had assigned students of two senior high school classes and divided them into three gender-separated groups (14 girls, 8 boys, and 9 boys). In sum 31 students attended.

The effect of "boyish" environments or tasks on girls' motivation to participate in educational robotics activities was previously mentioned in section 5.2.3 (INFLUENCE). In this case study, an approach was used to counter-act this phenomenon by offering the workshop to gender-specific groups. In the girl's group, students had to be encouraged to go into the engineering and research & development teams, but afterwards solved the tasks very well. The tutor of the engineering group was astonished by the talent of one girl ("she is the best from all the groups I've seen"); she, however, claimed that she was "not really good" in technical fields but that her mother would encourage her to "do these things". Interestingly, in one of the boy's groups, students had to be convinced strongly to go into the design and human-robot interaction teams; they all wanted to be in the technical teams. This strong technical preference was also provided as feedback by one of the boys at the end of the workshop: "If you hadn't talked so much in the beginning, we could have worked on the interesting stuff longer."

Findings with this age group suggested that teenagers already had strong preferences and were reluctant to deviate from these (compared to the group of 11 to 12-year-olds who were more open to the new experience with robotic product development). The time was not sufficient to fully convey the idea of solving REAL-LIFE problems with robotic PRODUCT DEVELOPMENT. Strong theoretical background on teaching teenagers was needed to address all young learners of this age group and also interpret their behaviour and feedback correctly. Nevertheless, it was an interesting pilot study that suggested that the concept is expandable to older ages using more sophisticated tasks and more advanced art materials. For example, advanced materials resulted in impressive art work of the Mattie robot platform design as demonstrated in Figure 5.8.

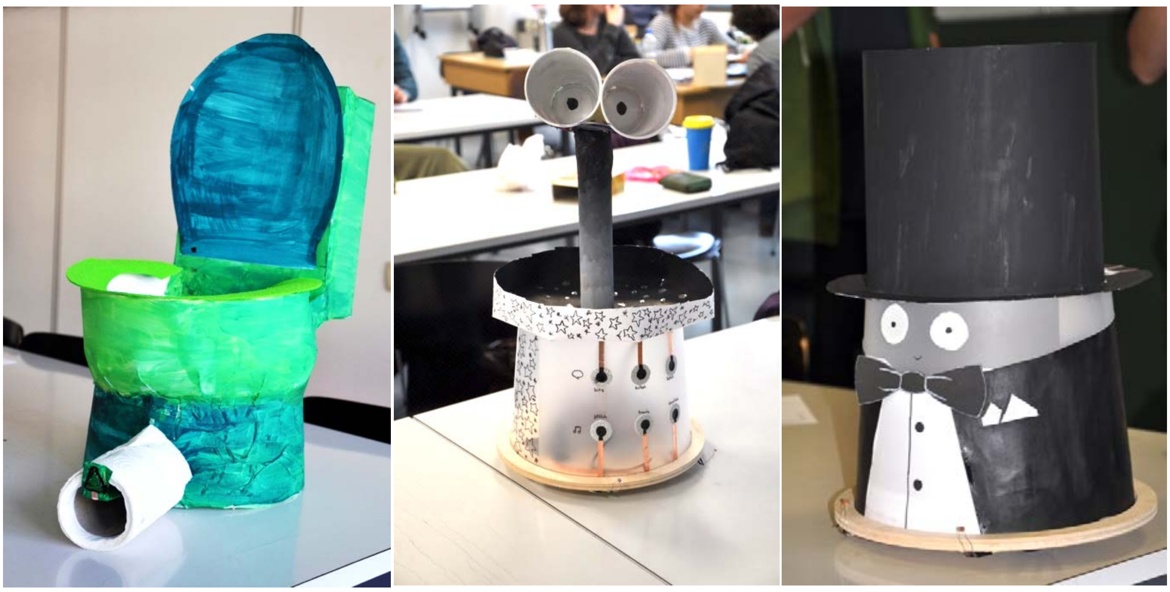


Figure 5.8 Mattie robot designs from PS7: A toilet robot with flushing noise as a teenager gadget (left); a drinks-serving Wall-E-inspired companion robot that plays music or tells a story or joke depending on the user's mood (middle); school recreation robot for teenagers that acts like a butler and helps with tasks like cleaning and serving (right)

5.4.2 FWF Science Communication Part II *Schräge Roboter* second semester (MS2)

For this study, both the Crazy Robots concept and the Mattie robot were improved guided by the lessons learned in MS1 and PS7. The three improvements of the concept were a storyboard exercise to support the 5-step plan (and also to cross-examine the efficiency) in the first workshop, the teachers preparing and influencing students before and in-between workshops, and the switched TU Wien V4R lab visit with the Romeo robot demonstration, after the workshop and not before. For the Mattie robot, additional tasks were prepared in the research & development group, as well as new parts added, a Bluetooth module, ultrasound sensors, and a gripper. The teachers assigned the classes and informed the students about the project. However, the Crazy Robots project was already popular in the participating schools, so the students were also "inaugurated" by their peers and informed about what was going to happen. Three classes participated with their handicrafts teachers (9-10 students each) and one with their arts teacher (24 students). In sum 52 children (age range 10-14) attended, 30 boys and 22 girls.

The Crazy Robot concept has three important instruments to introduce young people to robotic product development:

1. The 5-step plan to design a robot from scratch (section 3.3.1)
2. Multi-disciplinary teamwork with Mattie robot (section 3.3.2)
3. The product development process in three workshops ideation, prototyping, and evaluation (section 3.3.3)

In order to understand if the structure offered by the 5-step plan was sufficient to introduce young people to real-life problem solving, the collected data was analysed from different perspectives. Besides the qualitative analysis, mixed methods were applied as well as an experiment performed. In the experiment, a storyboard activity was added just before the 5-step plan in order to compare both. In this section, the findings on the comparison of these two instruments are reported. The analysis of the product development process structure is presented in section 5.5.

Storytelling has been used to facilitate collaboration in different contexts including design or children (e.g. (Benford et al., 2000) (Lutters, 2002) (Kahan, 2006)). It is the oldest method of knowledge transfer and popular through all ages (Katuscáková, 2015). Given this, it was surprising not to see real stories on the storyboards but only scenes with robot task descriptions (on 82 % of the storyboards). The findings suggest that storyboard activities were counter-intuitive to many students in classroom settings. Teachers said that the students had problems with the storyboard because they had never seen it before and never worked with it, except in one class, where the teacher had let the class do a storyboarding activity before the study, which was reflected in the quantitative results: 60% of the students of this class had robot descriptions, 40% had robot stories.

Besides analysing the storyboards on their own, a cross-examination was performed between storyboard and 5-step plan. Both support the creative process of developing a robotic product by giving it a structure, however, the storyboard structure is open-ended demanding more creativity, while the 5-step plan is a closed list. The findings show that in the storyboard the robot's tasks and the exterior design aspect of morphology were covered very well. The interaction modalities were not always described but could be guessed from the scenes. The two remaining steps of the 5-step plan, behaviour and robot parts, were not mentioned in the storyboards, unless the students had used the activity to draw a sketch of the robot and describe it. Additionally, the robot descriptions and information about the concept were more detailed when the 5-step plan was used. The students had a clear inclination towards answering a list of questions, probably because they were trained in school to do so.

Finally, the storyboard proved to be a good complement to the 5-step plan, addressing product development from the use case and scenario angle. Interesting insights into the children's lives could be gained by using both instruments. For example, in the storyboard activity, an 11-year-old boy told about how he never had time to play chess during the day because of school and other duties, and that in the evening his father would leave, so the boy would have no playing partner. In the 5-step plan, the boy explained in detail how the chess robot had to play with emotions and what parts were needed to build it, as can be seen in Figures 5.9a and 5.9b.

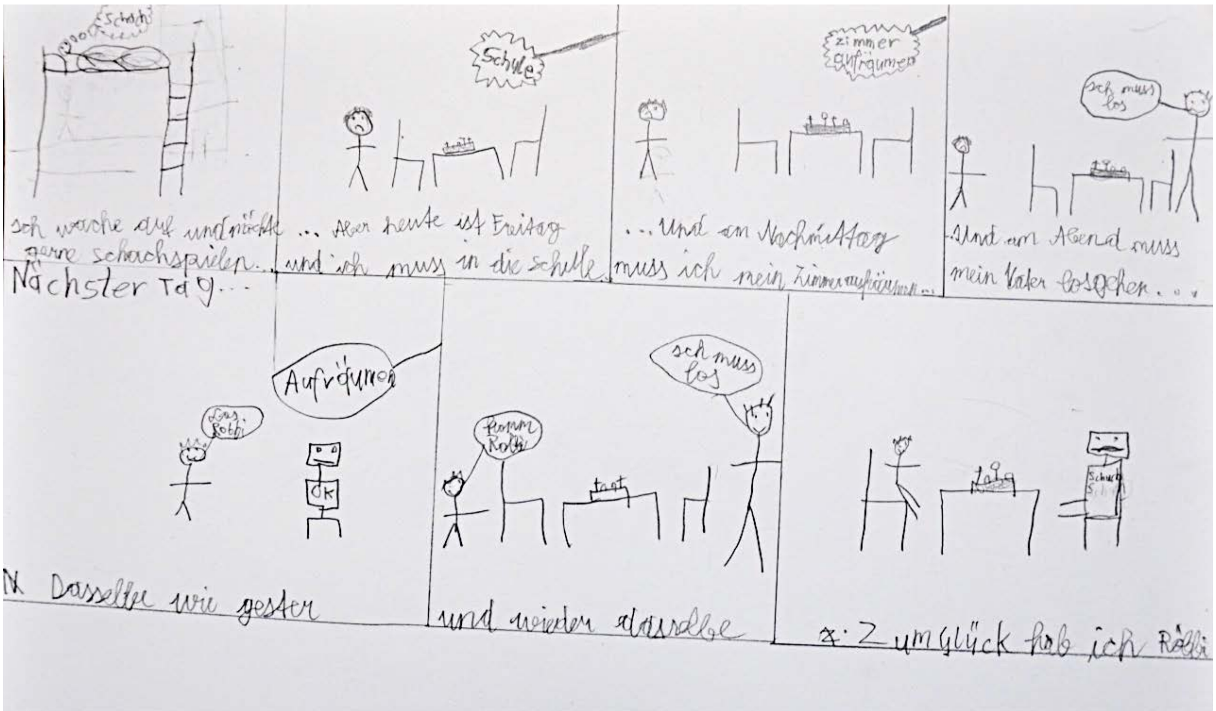
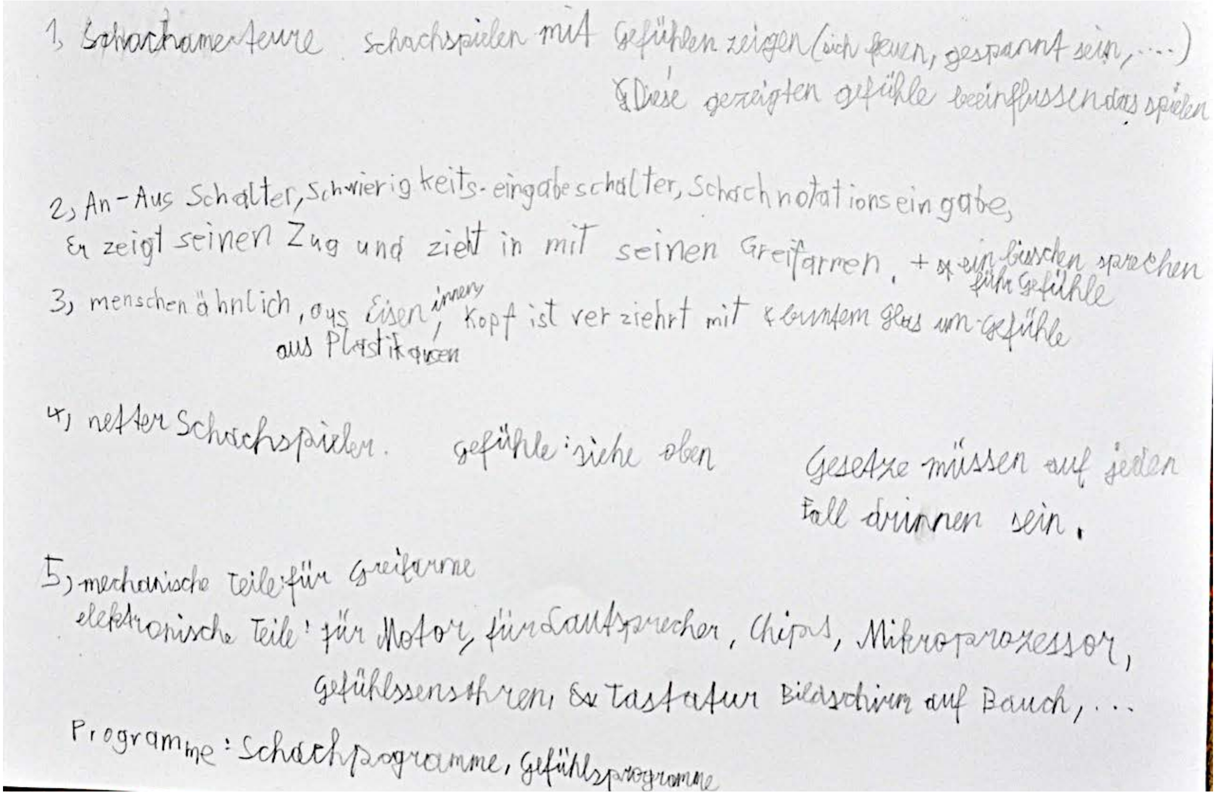


Figure 5.9a Storyboard from MS2 by an 11-year-old boy describing a day of his life and why he needs a chess robot (1- he wakes up and wants to play chess, 2- but he has to go to school, 3- then he has to tidy up his room, 4- in the evening his father has to go, 5- next day, same tasks, but the boy has a robot to help him tidy up, 6- and again his father has to leave in the evening, 7- fortunately there is Robbi to play chess with him)



1, Schachamateure . schachspielen mit Gefühlen zeigen (sich freuen, gespannt sein, ...)
& Diese gezeigten gefühle beeinflussen das spielen

2, An-Aus Schalter, Schwierigkeits-eingabeschalter, Schachnotationseingabe,
Er zeigt seinen Zug und zieht in mit seinen Greifarmen, + ein bisschen sprechen für Gefühle

3, menschenähnlich, aus Eisen innen, Kopf ist verziehrt mit buntem glas um gefühle
aus Plastik außen

4, netter Schachspieler. gefühle: siehe oben
Gesetze müssen auf jeden Fall drinnen sein.

5, mechanische Teile für greifarme
elektronische Teile: für Motor, für Lautsprecher, Chips, Mikroprozessor,
Gefühlssensoren, & Tastatur Bildschirm auf Bauch, ...
Programme: Schachprogramme, Gefühlsprogramme

Figure 5.9b. 5-step plan from MS2 by an 11-year-old boy who describes his emotional chess robot (1 Task: play chess with emotions, 2 Interaction: buttons and speech, 3 Morphology: anthropomorphic, made of metal inside and plastic outside, 4 Behaviour: friendly chess player obeying robot laws, 5 Parts: mechanics for gripper, electronics for motor, speakers, chips, micro controller, emotion sensors, keyboard, screen, and software with chess program and emotion program)

Data from this study was also analysed regarding the INFLUENCE of the Crazy Robots workshop series on young people. The students learned first-hand that fancy robots are not built in a day, by visiting the university lab with the robot demo and by building a simple robot with very limited functions themselves. The teachers reported increased interest towards studying a technical field in their classes. The Mattie robot product solutions from this case were more sophisticated and more specialised. In two classes, students built robots for children in need (either temporarily physically disabled by an accident or with down syndrome). Helping people in need was a big motivation for the girls to get involved. In another case, the students focused on the design of the robot and created three exchangeable skins. They also brought a legal agreement for the researcher to sign that granted them 20% on the profits with the robot. Some of these works can be seen in Figure 5.10.

The TEAMWORK aspect was most often criticised and discussed by the students, they expressed their feelings about things that did not go well, e.g. when team mates cut their words or did not listen. Overall, the classes were better prepared than in MS1 and knew what to expect. The teachers gave the researchers valuable help regarding class dynamics and pedagogy. Consequently, a collaboration with teachers should not only involve robot experts coming to school and explaining robots to students but there should be a common concept together with the teacher, where the teacher feels valued and involved, and thus gains confidence to carry out sessions with the concept on his or her own, and even develop concepts for future classes without help from outside.

Figure 5.10 Students artefacts from MS2: (Left to right, top down) ROBOSWAG for teenagers that brings stuff and plays music in three designs; ROBOSWAG marketing poster; BOB, your friend in the children's room marketing poster; BOB robot; Robot for children with down syndrome; Blubbi, the robot for injured and temporarily physically disabled kids; Blubbi sales pitch; user study for down syndrome robot

Finally, in order to analyse the diversity of the class, the students' self-assessment of their personality and interests was examined. From 52 answered questionnaires, 51 assessed their global or local thinking, 75% of which believed to be global thinkers, and 25% local thinkers. This again showed that specialised tasks in educational robotics were important, yet, top-down holistic tasks were also needed. The distribution of students' self-assessed intro- (44%) and extroversions (56%) were close to even. The chosen robotics fields of interests were also diverse with electrical and mechanical engineering as well as industrial design being mentioned most often. This suggests that the Crazy Robots workshops and the visit to the TU Wien had a positive influence on the students who participated. Furthermore, the students preferred fields that were in-line with the Mattie robot groups they had chosen to be part of, with a few exceptions as in MS1. These findings suggest that the participant pool of the workshops was diverse and the students were influenced by the workshop content towards robotics fields.

5.5 All Case Studies

As a final step in the fourth analysis cycle, all analytic memos from cycles 1, 2, 3, and 4 were compared for further insights to see if findings were confirmed or if inconsistencies emerged. In the qualitative analysis of the 5-step plan, the pilot studies and main study parts 1 and 2 were analysed cross-case as well to see if the changes had an effect on the outcome. Additionally, the qualitative findings on the 5-step plan structure and real-life problem solving were backed up with mixed methods to analyse what kind of problems young people wanted to solve and what kind of robots they imagined.

Although **the 5-step plan** remained the same from the first pilot study (PS1) to the last main study (MS2), the way it was presented was improved and adapted. Repetitions were used to strengthen the learning. The workshop participants especially had the most problems with the robot parts in the first studies. The findings of the cross-analysis between the 5-step plan templates of the pilot studies and the main study showed that the students learned better by repeating the product development phases, the definition of technology, the difference between a robot and other machines, the 5 steps with emphasis on the parts of a robot, especially sensors and micro controllers. The balance between theory and application was important.

In the mixed-method analysis, children’s robot ideas were analysed from the qualitative data of the 5-step plan templates (and partially from storyboards) derived from the studies PS4, PS5, PS7, MS1, and MS2, with 190 young people in total. 154 templates were collected and analysed. The details provided on each template differed from child to child varying from a few words or sketches to long descriptions using the complete space available. From 154 young people, 152 (99%) filled out the first step robot task; they knew very well what the robot should do. 147 children (95%) filled out the second step interaction. Children easily transferred existing means of technology interaction or control into an interaction modality with the robot. 134 children (87%) had an idea about how the robot should look like and could also describe or sketch it. 143 children (93%) were specific about the materials to be used for their robot. 144 children (94%) had clear expectations about the robot’s behaviour. Step 5, robot parts, was filled out by 137 children (89%). The numbers show that the 5-step plan activity was well understood and performed by the young people.

A cross-analysis between the 5-step templates in PS4, PS5, and MS1 to the templates in MS2 showed the following differences: First, the storyboard exercise interfered with the template by helping students to conceptualise their robot with scenarios and use cases but also by boring them with two similar tasks, thus they did not fill the 5-step plan out as detailed as they could have. And second, students provided more detailed and correct answers to the fifth step with the robot parts. This suggests that the improvements were successful.

Finally, to understand **what robots young people imagine**, the various robot tasks were categorised into meaningful themes, e.g. robots for different types of playing activities were collected individually in the robot for play category. This categorisation led to a quantification of the qualitative descriptions. The most wanted tasks were cooking or serving foods or beverages, playing or entertaining, and helping with homework or learning. Table 5.3 shows the most occurring tasks young people wanted their robots to carry out. The findings suggest that the young people in the studies addressed real problems out of their lives, some provided very specific descriptions of how their robots would solve their problem. For example, a robot to secure rock climbers with description and schematics as seen in Figure 5.11.

Table 5.3 Most mentioned ten robot tasks and their occurrences.

Task	Occurrence
Cook or serve food/beverages	46
Play or entertain	45
Help with homework or learning	45
Help in household	33
Wake up	27
Transport from A to B	27
Help or serve	22
Bring or carry stuff	22
Be a sports partner or helper (e.g. soccer, tennis, rock climbing, horse riding)	15
Talk or make conversation	14

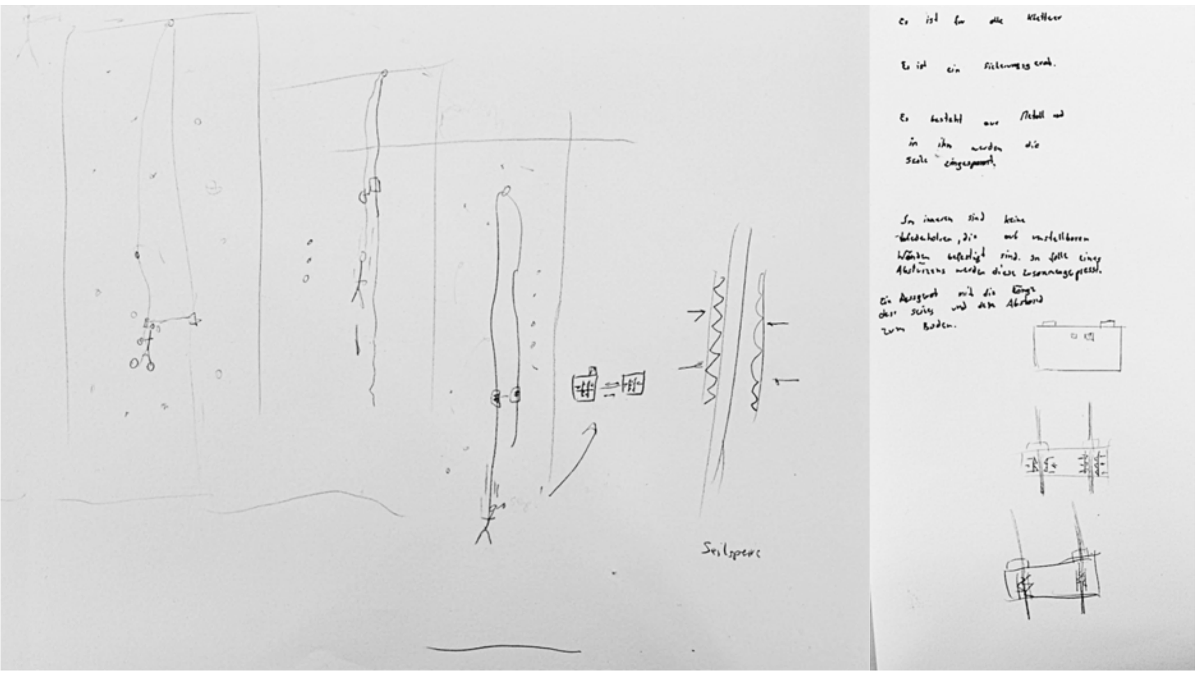


Figure 5.11 Robot concept from MS2: Robot for rock climbers that secures them automatically

5.6 Discussion

In the following sections, the findings of the multiple case study are discussed from the view point of the three research questions.

5.5.1 Research Question RQ1

The first research question asks if an approach combining robotics and product development covers a sufficient range of fields, so that young people can find their interests in the activities. This research question supports the first claim (C1) that postulates that the **Crazy Robots approach addresses all young learners**. “Addressing all” means that through one field or another, young people find at least one topic that connects to their lives and interests. Solving a real-life problem in a multi-disciplinary team is another connection to the adult world that they know and would like to be part of. Consequently, the first research question explores robotics and product development from these perspectives.

5.5.1.1 Robots and Robotics (Q1.1)

When developing a concept for educational purposes, the first question that comes to mind is why robots or robotics should be used. The most used argument claims that robotics involves more fields than other motivating educational contexts (Johnson, 2003), but so does automobiles or nanotechnology, for example. As elaborated on in Chapter 3, automobile development is not much different from robot development and involves similar fields. Nanotechnology even goes further on the subject of involved fields because robotics is a sub-field of nanotechnology. Yet, robotics has pushed through in education as a motivational factor. An important reason for this is that robots have one characteristic that automobiles and nanotechnology have not: They are animate, or in other words, because of robots’ autonomous behaviour, humans are more prone to attribute animacy to them than to automobiles or nanotechnology. Humans have a long history of fascination with intelligent machines (Oh and Park, 2014) and attributing animacy to non-living objects, especially when those move in stroking and oscillating patterns (Kuwamura et al., 2014).

This fascination for robots is leveraged upon in educational robotics to teach robotics, STEM and other subjects. There are many approaches as studied in Chapter 2 and most of them focus on teaching robotics or STEM. Many activities evolve around the tasks of navigation, manipulation or human-robot interaction. As suggested by leading theoretical frameworks used in educational robotics like constructionism and project-based learning, these activities connect to real-life problems that robot experts have to solve. This may explain why young people who sign up for educational robotics activities are already interested in STEM as Kandlhofer and Steinbauer (2016) have found out or why girls who sign up for a robotics activity like the First League prefer to deal with organizational stuff rather than the development of technology (Melchior et al., 2004). This gap has been addressed by adding gender-based materials (e.g. (Bredenfeld and Leimbach, 2010)) or gender-neutral multiple entry points (e.g. (Rusk et al., 2008)) to educational robotics activities. Consequently, these efforts have made robots more “genderless” than cars, for example. However, when the educational robotics activities remain outside school or after school on a voluntary basis, naturally, not all young learners will subscribe. In a classroom setting, where the teacher decides to participate, a more heterogeneous group of young learners can be found as explained in section 4.4.

Our findings suggest that the theme robotics is very well perceived by young people in general, but also in school classes with students who are not interested in STEM. Robotics is excellent to solve real-life problems as demonstrated in the previous sections.

5.5.1.2 Product Development (Q1.2)

A product development concept is rare in educational robotics, and if it is used, then it is rather positioned as art or maker movement tinkering. It brings more top-down thinking along with a business aspect to the usually technical problem-solving focused landscape of educational robotics. With constructionist methods and design-based learning theories, the product development concepts from industry that are concerned with real-life problem solving were adapted to a learning context for young people with five teams: sales & marketing, design, human-robot interaction, engineering, and research & development. These teams offer enough diversity to address all young people in a classroom. As the case of the sales & marketing team demonstrates, a group presenting the user side and coordinating the other teams' efforts to conceptualise the robot brings a new perspective to educational robotics. This team incorporates many interests, e.g. making a marketing video of the product, interviewing people, making cost calculations or graphic posters. Consequently, all five teams align five different perspectives of robotics. The more perspectives to robotics offered, the more the chance for young people to connect their interests and talents. Notably, global thinkers, who like to put many different puzzle pieces together, see the big picture with an approach that uses robotic product development. This is especially important in classroom contexts where more than two thirds of the students assess themselves as global thinkers.

There are two important topics that emerge when a product development approach with different teams to choose from is used in educational robotics. First, are the specialist thinkers and those students who are already interested in STEM sufficiently covered? Second, do young people receive enough chances to try out new areas that they do not know about but that they will like after trying them out? The findings show that the specialist thinkers and students interested in STEM were disappointed during the pilot studies when no technology at all was involved. Even children interested in design had expectations regarding a robotics workshop having hands-on with electronics. Those expectations could be addressed with the Mattie robot. In the Crazy Robot workshop series, the students had the possibility to switch teams in the third workshop, so that they could try another area of robotics. Some of them took advantage of this. However, as the findings also suggest, teams were often chosen by peer pressure and not by real interest. Following up on the teachers' suggestion to find a system where each student tries each team, will solve this problem.

5.5.1.3 Summary

The first research question RQ1 asks if an approach combining robotics and product development covers a sufficient range of fields, so that young people can find their interests in the activities. Our findings suggest that the fields covered by robotic product development (Q1.1 and Q1.2) are broad enough, so that every young person finds a connection to his or her interests and talents somewhere. In the case studies involving young people with different interests and talents (more global thinkers than local thinkers, children interested or not interested in STEM), this is shown clearly. Consequently, the Crazy Robots concept addresses all young learners (C1), so that the Boyans and Lisas of this world connect their interests and talents to robotic product development. As a matter of fact, in one case study a 12-year-old "Lisa" was found who imagined a robot that cleaned the environment as shown in Figure 5.12.

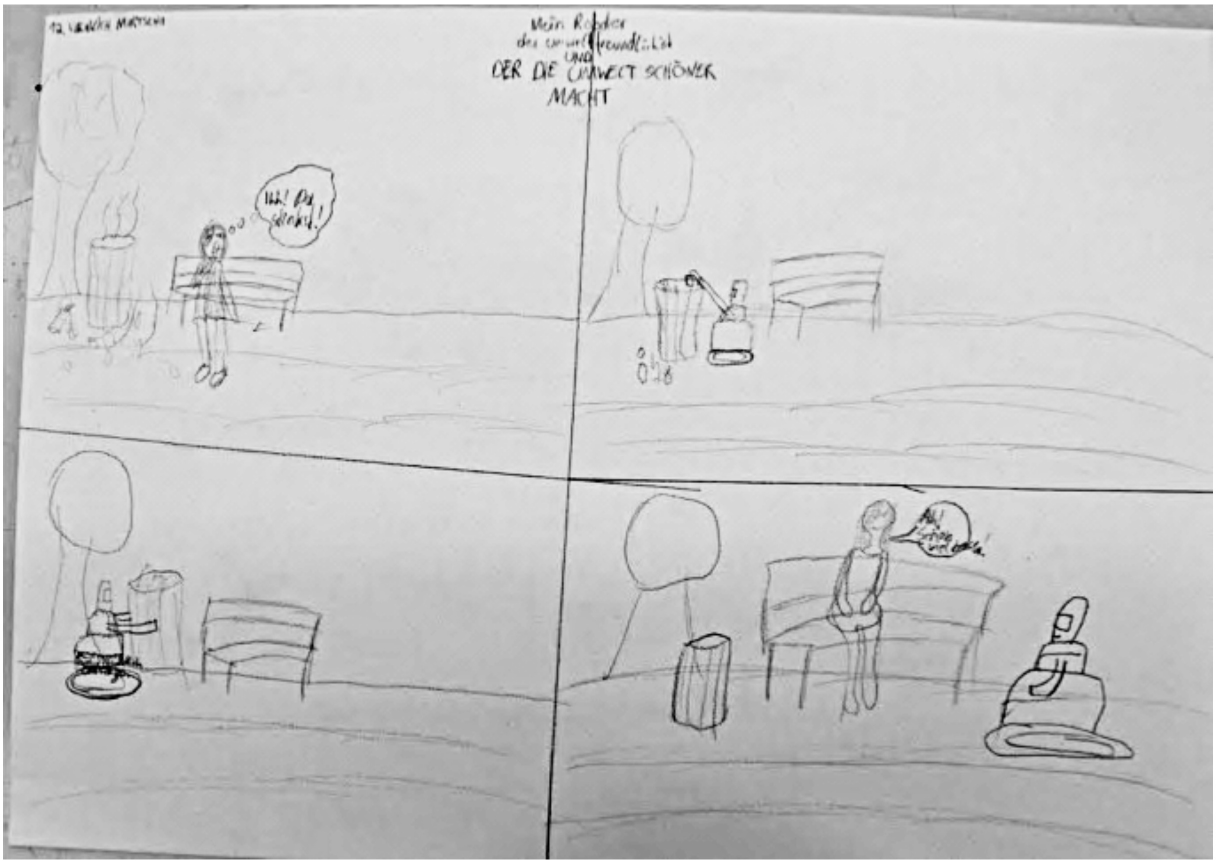


Figure 5.12 Robot "for all people because it makes the environment more beautiful" by 12-year-old girl. It has smell sensors to detect trash and is made of environment-friendly materials.

5.5.2 Research Question RQ2

The second research question is involved with the different influences on young people in the context of participating in an educational robotics workshop. In what way are young people's interests, beliefs and expectations towards robots, robotics, product development, real-life problem solving, multi-disciplinary teamwork or the Crazy Robots workshop series itself influenced? This research question supports both claims C1 and C2 which are concerned with the Crazy Robots concept addressing all children and introducing them to real-life problem solving in multi-disciplinary teams.

Since the Crazy Robots workshops are either a one-time event or only last over a few months, other influencing factors need to be understood in order to analyse the influence from the concept itself in a correct manner and eventually counteract influences with simple techniques during the workshops. Consequently, during the complete data analysis following influence factors on young people are considered:

- What influence do other educational robotics activities have?
- What influence do parents or family have?
- What influence do teachers or school settings have?
- What influence do peers have?
- What influence do media and science fiction have?

5.5.2.1 Other Educational Robotics Activities (Q2.1)

Since educational robotics is very popular, there is a chance that young people who participated in the Crazy Robots workshops already had participated in another educational robotics activity. This participation has an influence on young people and their expectations from a robotics workshop. The most striking influence noticed during analysis, was the expectation that a robotics workshop involves electronics. The 5-step plan workshop pilot case studies clearly show this. This was encountered by adding the Mattie robot to the Crazy Robots workshop series. Another influence is that children expect to build a "real" robot in two hours. The Crazy Robots concept uses a more realistic approach to counter this expectation: First, young people work on the simple Mattie robot platform (worth 300 EUR) that has very limited functions but is still difficult to build, so there is a great sense of achievement in the end. And second, they visit the V4R lab and see a real robot worth 300.000 EUR and real experts (role models) working on it, thus they see what is possible.

5.5.2.2 Environmental Factors (Q2.2)

Parents have a huge influence on children, especially on younger ones. When a father dismisses a girl's robot art as "this is not a robot", the whole positive effect of a day long workshop is gone. It is also the parents who sign their children to extracurricular activities or choose the schools the children go to. When parents are informed upfront or when educational robotics activities involve parents (completely or partially), a more lasting positive outcome is achieved. In Crazy Robots, teachers received feedback from enthusiastic parents on the positive impact of the activity on their children.

Peers influence many decisions of young people. In the Crazy Robots workshop series, they influenced students into what teams to go. It was also observed that the students consulted each other when working on the templates and questionnaires. The Crazy Robots concept was kept very flexible to help students choose the right teams and also change them if necessary.

Teachers also influence the students in their classes when they tell them about the activity. Depending on the teacher's expectations, the students are prepped to certain expectations of the educational robotics activity. This was clearly observed between the first and second main studies. In the main study second part MS2, teachers prepared their students better for what was to be expected, and thus influenced the outcome from their end.

Art is a subject in **school** and students are used to working and experimenting with different art materials. However, technology use is very limited (at least in Austria). Naturally, the students expect to work with technology when they participate in a robot workshop or visit a technical university. In order to counteract this influence, the workshop instructors need to clarify beforehand what materials schools use in everyday lessons and align expectations with what is offered.

Media and science-fiction have an important continuous influence, where the word robot often connotes the meaning "human imitation". When asked about the tasks of their robots, often in the beginning the answer is "it does everything a human does". Working with the definition of robots, showing pictures or videos of existing robots, and demonstrating robot prototypes in a university lab, all help counteracting this influence.

5.5.2.3 Summary

The second research question RQ2 is concerned with the different influences on young people in the context of educational robotics activities that interfere with the objectives of the Crazy Robots concept. Our findings suggest that young people are influenced by other educational robotics activities (Q2.1) and environmental factors (Q2.2) like parents, peers, teachers, their schools, and media and science-fiction. Consequently, the Crazy Robots concept needs to encounter these influences as described in the sections above in order to address all children and introduce them to real-life problem solving in multi-disciplinary teams. In some cases, the Crazy Robots concept addresses these, e.g. with a robot demo in a university lab. In other cases, e.g. involving parents or having deeper collaborations with teachers, there is room for improvements.

5.5.3 Research Question RQ3

The third research question is concerned about how the Crazy Robots concept will introduce young people to real-life problem solving and multi-disciplinary teamwork. Are the offered structures and tools sufficient? What are the drawbacks of such an approach? How will the workshop series influence young people's interests, beliefs and expectations? Why should young people learn multi-disciplinary teamwork and real-life problem solving? How can these two be implemented in an educational robotics activity? All these questions support the second claim (C2) that postulates that the Crazy Robots approach introduces young people to real-life problem solving and multi-disciplinary teamwork. Consequently, the discussion in this section evolves around findings suggesting that the approach offers sufficient structure and tools for an introduction to real-life problem solving in multi-disciplinary teams.

5.5.3.1 Crazy Robots Concept's Structure and Influence (Q3.1)

The Crazy Robots approach has a short-time influence on young people. It is built on the elements robots and robotics, as well as product development, and it offers real-life problem solving in multi-disciplinary teams. However, there are also other elements that leave an impression on young people, e.g. the visit to the V4R lab with real robots and real experts.

Since there are no follow-up studies that examine how lasting this experience is on the young people, we avoid the term learning and prefer to use introducing. Our findings suggest that young people were successfully introduced to robotic product development with the instruments 5-step plan, multi-disciplinary teamwork with Mattie robot, and the workshop series structure based on design phases.

First, the 5-step plan is successfully applied by the majority of the participants and all robot ideas offer solutions to real-life problems. Compared to the storyboard, the 5-step plan is more extensive and easier to use by young people trained in the Austrian school system (i.e. they are used to answering questions in a numerical order).

Second, the Mattie robot teams show young people the different aspects of robotic product development: sales & marketing, engineering, design, research & development, and human-robot interaction. Teamwork on a complex technology like a robot where different parts (complex on their own) have to work together (integration) is very difficult. Even in the simplified version of the Mattie robot, students have to go through different phases of frustration and discussions. However, the activity is designed in a way that in the end, the whole team has a robot that drives around and makes previously recorded sounds. Consequently, the sense of achievement as a team is very empowering.

And third, the workshop series structure goes through three incisive phases of product design and demonstrates that robotics product development is more than engineering. This structure leans on constructionist and design-based learning approaches, and supports the creative process by infusing the values of being human-centred, collaborative, optimistic, and experimental.

5.5.3.2 Multi-Disciplinary Teamwork (Q3.2)

Although collaborative learning is sometimes used in classrooms and other educational robotics activities, the multi-disciplinary aspect that connects to real-life experts and respects individual talents and interests is rare. Our findings suggest that real-life problem solving in multi-disciplinary teams is possible with a concept that evolves around robotic product development. In the case of young people, it is deemed important that they receive more chances to try out different aspects and different team roles. This helps them understand what they like most and also gives them the opportunity to develop empathy for “the other side”. Working on a common goal with class mates on their own, without the teacher’s help, is very rewarding and an unforgettable experience.

5.5.3.3 Real-Life Problem Solving (Q3.3)

Real-life problem solving is part of learning theories that are relatively new and has not found its way into all educational robotics activities or classrooms, probably also because real solutions are hard to realise. In the case of “white-box” approaches, young learners quickly seem to reach a plateau where the robots they make are limited in what they can do (Kynigos, 2008). Eguchi (2014b) also reports about the difficulties and frustration of her students in a robotics class. She suggests that the challenge is on the educators to find the best ways to create fun learning experiences for students.

The Mattie robot supports the concept of linking user needs to requirement specifications. The pre-defined elements are helpful in enabling the students to build a robot in a short time frame. At the same time, they put constraints on the creative concepts and require a certain amount of adaptation, e.g. the robot’s locomotion with two wheels, limited simple sensors or three hours’ time force the students to adapt their initial ideas and be more creative. These limitations are very frustrating for the students. However, as soon as the prototype drives around and makes self- recorded sounds - in the specific context the children have created, e.g. a robot to cheer up sick children - the sense of achievement is very powerful.

5.5.3.4 Summary

The third research question RQ3 is concerned with the applicability of robotics product development together with real-life problem solving and multi-disciplinary teamwork in educational settings. Our findings suggest that young people were successfully introduced to robotic product development with the instruments 5-step plan, multi-disciplinary teamwork with Mattie robot, and the workshop series structure based on design phases. Consequently, the Crazy Robots concept offers sufficient structure for the creative process of developing robotic products without overwhelming the students with feasibility problems. The multi-disciplinary teamwork experience is very powerful when the initial chaos and frustration ends with a functioning prototype which connects to a real-life problem and which the students believe they have done all by themselves.

5.7 Summary

In this chapter, we elaborated on why the two claims hold by presenting findings during the case study backed by theoretical research. In order to do this, the findings were presented cycle by cycle and case by case.

In the first cycle, findings from the first three pilot studies PS1-PS3 and related work indicate that many educational robotics activities fail to address all young learners because focusing on specific tasks like navigation, manipulation, and human-robot interaction with bottom-up task solving in competitive environments attracts certain type of young people, but not all.

The second cycle findings are concerned with the pilot studies PS4-PS6 suggesting that educational robotics workshops with product or design focus attract young people who are global thinkers, like creative tasks as designing or tinkering with art materials, and probably would not participate in workshops with specific technical problem solving.

In the third cycle, findings from the main study first part MS1 suggest that the Crazy Robots concept aligns top-down with bottom-up thinking while incorporating different robotic fields with product development, thus addresses all young learners. While global thinkers identify themselves with conceptualising and coordinating, local thinkers concentrate on specific tasks that they are interested in, some in technical problem solving, others in tinkering with art materials.

The findings of the forth and last cycle are concerned with the pilot study PS7 and the main study second part MS2, as well as the complete data from all nine cases. They suggest that young people are successfully introduced to robotic product development with the instruments 5-step plan, multi-disciplinary teamwork with Mattie robot, and the workshop series structure based on design phases.

Finally, after the findings are presented, they are discussed under the three research questions that were designed to support the claims. The first research question RQ1 asks if an approach combining robotics and product development covers a sufficient range of fields, so that young people can find their interests in the activities. In the case studies involving young people with different interests and talents, this is shown clearly. The second research question RQ2 is concerned with the different influences on young people in the context of educational robotics activities that interfere with the objectives of the Crazy Robots concept. The Crazy Robots concept encounters these influences in some cases. In other cases, there is room for improvements. The third research question RQ3 is concerned with the applicability of robotics product development together with real-life problem solving and multi-disciplinary teamwork in educational settings. Our findings suggest that the Crazy Robots concept offers sufficient structure for the creative process of developing robotic products without overwhelming the students with feasibility problems. The multi-disciplinary teamwork experience is very powerful with a functioning prototype that connects to a real-life problem.

Chapter 6

Conclusions and Outlook

Crazy Robots is a concept based on product development with the use case robotics to introduce young people to real-life problem solving in multi-disciplinary teams. The focus is on finding creative solutions to real needs and presenting these to others with tangible artefacts. At the same time, the importance of each individual talent and the immanent need for collaboration is lived by being responsible for a certain most compelling aspect of the product in a team with the common goal to "help someone with a problem".

The research is based on qualitative data analysis methodology and follows a rigorous design which is structured through a conceptual framework. The research design is the link between the Crazy Robots concept and the two claims of the research:

1. Addressing all young learners (C1), and
2. Introducing young people to real-life problem solving and multi-disciplinary teamwork (C2)

The concept or its elements were tested in different settings with different groups of young people between ages 7 to 16 from 2013 to 2015 in Vienna, Austria. These groups are summarised in a multiple case study (seven pilots and a main study in two parts). Since the primary goal was science communication, it was preferred to have no control on behavioural events but rather to work with a full variety of evidence: documents, artefacts, interviews, questionnaires, and observations as well as theoretical frameworks and related work research. The data was sequentially analysed in four cycles while using codes which evolved over time into the conceptual framework structure. The first two cycles were concerned with six pilot studies, while the second two cycles were concerned with the two parts of the main study, a pilot with a different age group, and an experiment.

In this Chapter, we conclude on our findings on the Crazy Robots concept (section 6.1) and reflect on possible future work (section 6.2).

6.1 Crazy Robots Concept

Many educational robotics activities focus on specific tasks like navigation, manipulation, and human-robot interaction with bottom-up task solving, very frequently in competitive environments. These activities attract certain types of young people, but not all. In contrast, educational robotics workshops with product or design focus attract young people who are global thinkers, like creative tasks as designing or tinkering with art materials, and probably would not participate in workshops with specific technical problem solving. The Crazy

Robots concept aligns top-down with bottom-up thinking while incorporating different robotic fields with product development, thus **addresses all young learners**. While global thinkers identify themselves with conceptualising and coordinating, local thinkers concentrate on specific tasks that they are interested in, some in technical problem solving, others in tinkering with art materials.

Through its three instruments, the Crazy Robots concept introduces young people to robotic product development. First, the 5-step plan gives the students a structure to address customer needs and work through important aspects of their robotic product to **solve a real-life problem.** Second, the Mattie robot and its **multi-disciplinary teamwork** encouraging structure intensify this by showing young people the different aspects of robotic product development hands-on in five different teams: sales & marketing, engineering, design, research & development, and human-robot interaction. And third, the workshop series structure that goes through three incisive phases of product design demonstrates that robotics product development is more than engineering, robot prototypes are built in iterations, and it's possible to create a robot prototype connected to a real-life need as a class in a short time by being human-centred, collaborative, optimistic, and experimental.

Finally, a 13-year old girl from the MS1 workshops concludes the contribution of this work perfectly: "*I don't want to do anything with robotics when I'm older, but I'd like to do more robotics workshops.*"

6.2 Outlook

The Crazy Robots workshop series is an introduction to robotic product development but also to real-life problem solving and teamwork. Due to its limitation in time and resources, it only scratches the surface of robotics and product development. It is important that after the first introduction young people can pursue different areas of robotics and robotic product development that interest them most.

Future work will incorporate the Crazy Robots concept in a curriculum that addresses young people early on and continues to provide them activities during their development and secondary education until they decide to pursue further studies or start working.

Finally, for the best effect in schools, the collaboration with teachers will be deepened. This collaboration will not only involve robot experts coming to school and explaining robots to students but there will be a common concept together with the teacher, where the teacher feels valued and involved.

Bibliography

Ackermann, E. 2014. Amusement, Delight, Whimsy, and Wit, the Place of Humor in Human Creativity. In Constructionism 2014 International Conference, Vienna, Austria.

Alimisis, D. 2013. Educational robotics: Open questions and new challenges. Themes in Science and Technology Education, 6(1), 63-71.

Alimisis, D. (Ed.). 2009. *Teacher Education in Robotics-Enhanced Constructivist Pedagogical Methods.* ASPETE, Athens.

Asimov, I. 1950. *I, Robot*. Gnome Press.

Barker, B. S. (Ed.). 2012. Robots in K-12 Education: A New Technology for Learning: A New Technology for Learning. IGI Global.

Barreto, F. and Benitti, V. 2012. Exploring the educational potential of robotics in schools: A systematic review. Computer Education, 58, 3 (April 2012), 978-988.

BDC. British Design Council. Design Process in Eleven Succesful Companies. http://www.designcouncil.org.uk/sites/default/files/asset/document/ElevenLessons_Design_Council (2).pdf. Retrieved June 2016.

Beer, J. M., Prakash, A., Mitzner, T. L., and Rogers, W. A. 2011. Understanding robot acceptance. Georgia Institute of Technology, 1-45.

Benford, S., Bederson, B. B., Åkesson, K. P., Bayon, V., Druin, A., Hansson, P., and Simsarian, K. T. 2000. Designing storytelling technologies to encouraging collaboration between young children. In Proceedings of the SIGCHI conference on Human Factors in Computing Systems (pp. 556-563). ACM.

Bers, M. U. 2008. Using robotic manipulatives to develop technological fluency in early childhood. Cont P on Sci Technol Early Child Educ, 105-225.

Bers, M., Ponte, I., Juelich, K., Viera, A., and Schenker, J. 2002. Teachers as designers: Integrating robotics in early childhood education. Information Technology in childhood education, 1, 123-145.

Bers, M. U., and Urrea, C. 2000. Technological prayers: parents and children exploring robotics and values. Robots for kids: exploring new technologies for learning. Morgan Kaufmann Publishers Inc., San Francisco, CA, 2000.

Bertel, L.B., Rasmussen, D.M. and Christiansen, E. 2013. Robots for Real: Developing a Participatory Design Framework for Implementing Educational Robots in Real-World Learning Environments. HCI – INTERACT 2013. Lecture Notes in Computer Science Vol. 8118, 437-444.

Bhamjee, S., Griffiths, F., and Palmer, J. 2010. Children’s perception and interpretation of robots and robot behaviour. *In International Conference on Human-Robot Personal Relationship*, 42-48, Springer Berlin Heidelberg.

Blikstein, P. 2013. Gears of our childhood: constructionist toolkits, robotics, and physical computing, past and future. In Proceedings of the 12th International Conference on Interaction Design and Children (pp. 173-182). ACM.

Bloom, B.S. 1985. *Developing Talent in Young People*. Ballantine Books, NY.

Blumenfeld, P. C., Soloway, E., Marx, R. W., Krajcik, J. S., Guzdial, M., and Palincsar, A. 1991. Motivating project-based learning: Sustaining the doing, supporting the learning. *Educational psychologist*, 26(3-4), 369-398.

Borrego, M., Douglas, E. P., and Amelink, C. T. 2009. Quantitative, qualitative, and mixed research methods in engineering education. *Journal of Engineering education*, 98(1), 53.

Bowen, G. A. 2009. Document analysis as a qualitative research method. Qualitative research journal, 9(2), 27-40.

Bredenfeld, A. and Leimbach, T. 2010. The Roberta Initiative. *In Proceedings of the 1st International conference on Robotics in Education, RiE2010. September 2010*. (pp. 1-2). FEI STU, Bratislava, Slovakia.

Brown, T. 2009. Design thinking. Harvard B. Review, June.

Bruner, J. S. 2009. The process of education. Harvard University Press.

Buechley, L., Eisenberg, M., Catchen, J., and Crockett, A. 2008. The LilyPad Arduino: using computational textiles to investigate engagement, aesthetics, and diversity in computer science education. In Proceedings of the SIGCHI conference on Human factors in computing systems (pp. 423-432). ACM.

Cacco, L., and Moro, M. The hedgehog: how to integrate robotics in natural science scenarios. *International Conference of Robotics in Education RIE’15*, “Which approaches do actually work when introducing children to robotics?” Workshop Position Paper, Yverdon-les-Bains, Switzerland

Callister, W. D., and Rethwisch, D. G. 2013. Fundamentals of materials science and engineering (Vol. 21). New York: Wiley.

Catlin, D., and Woollard, J. 2014. Educational robots and computational thinking. In Proceedings of 4th International Workshop Teaching Robotics, Teaching with Robotics & 5th International Conference Robotics in Education (pp. 144-151).

Chambers, J. M., Carbonaro, M., and Murray, H. 2008. Developing conceptual understanding of mechanical advantage through the use of Lego robotic technology. Australasian Journal of Educational Technology, 24(4).

Correll, N., Wailes, C., and Slaby, S. 2014. A One-hour Curriculum to Engage Middle School Students in Robotics and Computer Science using Cubelets. In Distributed Autonomous Robotic Systems (pp. 165-176). Springer Berlin Heidelberg.

Condliffe, B., Visher, M. G., Bangser, M. R., Drohojowska, S., and Saco, L. 2016. Project-Based Learning: A Literature Review. MDRC.

Crespi, V., Galstyan, A., and Lerman, K. 2008. Top-down vs bottom-up methodologies in multi-agent system design. Autonomous Robots, 24(3), 303-313.

Demo, G. B., Moro, M., Pina, A., and Arlegui, A. 2012. In and out of the school activities implementing IBSE and constructionist learning methodologies by means of robotics. *Robots in K-12 education: A new technology for learning*, 66-92.

Denis, B., and Hubert, S. 2001. Collaborative learning in an educational robotics environment. Computers in Human Behavior, 17(5), 465-480.

DeTombe, D. 2015. *Handling Societal Complexity*. Springer Berlin Heidelberg.

Doppelt, Y., Mehalik, M. M., Schunn, C. D., Silk, E., and Krysinski, D. 2008. Engagement and achievements: A case study of design-based learning in a science context. *Journal of Technology Education*, Volume 19, Number 2.

Druin, A. 2002. The role of children in the design of new technology, Behaviour and information technology, 21, 1, 1-25, Taylor & Francis.

Eck, J., Hirschmugl-Gaisch, S., Hofmann, A., Kandlhofer, M., Rubenzer, S., and Steinbauer, G. 2013. Innovative concepts in educational robotics: Robotics projects for kindergartens in Austria. In Austrian Robotics Workshop 2013 (Vol. 14, p. 12).

Eguchi, A. 2014a. Educational robotics for promoting 21st century skills. Journal of Automation Mobile Robotics and Intelligent Systems, 8(1), 5-11.

Eguchi, A. 2014b. Robotics as a learning tool for educational transformation. In Proceeding of 4th International Workshop Teaching Robotics, Teaching with Robotics & 5th International Conference Robotics in Education Padova (Italy).

Eisenberg, M. 2004. Tangible ideas for children: materials sciences as the future of educational technology. *In Proceedings of the 2004 conference on Interaction design and children: building a community.* 19-26. ACM.

Fails, J.A., Guha, M.L., Druin A. 2012. Methods and Techniques for Involving Children in the Design of New Technology for Children. Foundations and Trends in Human–Computer Interaction. Vol. 6, Issue 2, 85-166.

Faste, R. A. 1994. Ambidextrous thinking. Innovations in Mechanical Engineering Curricula for the 1990s.

Feil-Seifer, D. and Matarić, M. J. 2009. Human–robot interaction (HRI). In Encyclopedia of Complexity and Systems Science (pp. 4643-4659). Springer New York.

Fisher, S. G., Hunter, T. A., and Macrosson, W. D. K. 1998. The structure of Belbin's team roles. *Journal of occupational and organizational psychology, 71*(3), 283-288.

Flannery, L. P., and Bers, M. U. 2013. Let’s dance the “robot hokey-pokey!” children’s programming approaches and achievement throughout early cognitive development. Journal of research on technology in education, 46(1), 81-101.

Fong, T., Nourbakhsh, I., and Dautenhahn, K. 2003. A survey of socially interactive robots. Robotics and autonomous systems, 42(3), 143-166.

Frangou, S., Papanikolaou, K., Aravecchia, L., Montel, L., Ionita, S., Arlegui, J., and Monfalcon, S. 2008. Representative examples of implementing educational robotics in school based on the constructivist approach. In SIMPAR Workshop on Teaching with robotics: didactic approaches and experiences, Venice, Italy.

Gardner, H. 2011. Frames of Mind: Theory of Multiple Intelligences. Basic Books.

Garzotto, F. 2008. Broadening children's involvement as design partners: from technology to. In Proceedings of the 7th international conference on Interaction design and children (pp. 186-193). ACM.

Gause, D.C. and Weinberg, G.M. 1989. *Exploring Requirements - Quality Before Design*, New York: Dorset House Publishing.

Gerber, E. M., Marie Olson, J., and Komarek, R. L. 2012. Extracurricular design-based learning: Preparing students for careers in innovation. International Journal of Engineering Education, 28(2), 317.

Gillham, Bill. 2000. Case study research methods. London: Continuum.

Grammenos, D. 2015. Future designers: a rollercoaster for the mind. In *Interactions*, 23(1), 58-63.

Gülke, T., Rumpe, B., Jansen, M., & Axmann, J. 2012. High-Level requirements management and complexity costs in automotive development projects: a problem statement. *In International Working Conference on Requirements Engineering: Foundation for Software Quality* (pp. 94-100). Springer Berlin Heidelberg.

Hamidi, F., Saenz, K., and Baljko, M. 2014. Sparkles of brilliance: incorporating cultural and social context in codesign of digital artworks. *In Proceedings of Interaction design and children* (pp. 77-84).

Hamner, E., Lauwers, T., and Bernstein, D. 2010. The Debugging Task: Evaluating a Robotics Design Workshop. *In AAAI Spring Symposium: Educational Robotics and Beyond*.

Hamner, E., Lauwers, T., Bernstein, D., Stubbs, K., Crowley, K., and Nourbakhsh, I. 2008. Robot Diaries Interim Project Report: Development of a Technology Program for Middle School Girls.

Haring, K.S., Watanabe, K. and Mougenot, C. 2013. The influence of robot appearance on assessment. In *Proceedings of the 8th ACM/IEEE international conference on Human-robot interaction* (HRI '13). IEEE Press, Piscataway, NJ, USA, 131-132.

Hendler, J. 2000. Robots for the rest of us: designing systems “out of the box”, Robots for Kids: Exploring new technologies for learning. The Morgan Kaufmann Publishers.

Hernandez-Barrera, A. 2014. Teaching introduction to robotics: Using a blend of problem-and project-based learning approaches. In IEEE SOUTHEASTCON 2014 (pp. 1-5). IEEE.

Hirsch, L., Carpinelli, J., Kimmel, H., Rockland, R., and Burr-Alexander, L. 2009. The impact of introducing robotics in middle and high school science and mathematics classrooms. In American Society for Engineering Education. American Society for Engineering Education.

Hirschmanner, M., Lammer L., and Vincze, M. 2015. Mattie - a simple educational platform for children to realize their first robot prototype. Poster and short paper at the Interaction Design and Children Conference 2015. Boston, USA.

Huber, A., Lammer, L., Weiss, A., and Vincze, M. 2014. Designing Adaptive Roles for Socially Assistive Robots: A New Method to Reduce Technological Determinism and Role Stereotypes. Journal of HRI, 3(2), 100-115.

Hynes, M., and Swenson, J. 2013. The humanistic side of engineering: considering social science and humanities dimensions of engineering in education and research. *Journal of Pre-College Engineering Education Research (J-PEER), 3*(2), 4.

IEEE Transactions on Education. 2013. 56(1), *Special Issue on Robotics in Education*

Ismail, L. I., Shamsudin, S., Yussof, H., Hanapiah, F. A., and Zahari, N. I. 2012. Robot-based intervention program for autistic children with humanoid robot NAO: initial response in stereotyped behavior. Procedia Engineering, 41, 1441-1447.

Jacobsson, M., Fernaeus, Y., Cramer, H., and Ljungblad, S. 2013. Crafting against robotic fakelore: on the critical practice of artbot artists. In CHI'13 Extended Abstracts on Human Factors in Computing Systems (pp. 2019-2028). ACM.

Johnson, J. 2003. Children, robotics, and education. In *Artificial Life and Robotics*, 7(1-2), 16-21.

Johnson, D. W., and Johnson, R. T. 1995. Social interdependence: Cooperative learning in education. Conflict, cooperation, and justice: Essays inspired by the work of Morton Deutsch, 205-251.

Johnson, D. W., & Johnson, R. T. 1987. Learning together and alone: Cooperative, competitive, and individualistic learning. Prentice-Hall, Inc.

Kabátová, M., and Pekárová, J. 2010. Lessons learned with LEGO Mindstorms: from beginner to teaching robotics. Group, 10, 12.

Kafai, Y. B. and Resnick, M. (Eds.). 1996. Constructionism in practice: Designing, thinking, and learning in a digital world. Hillsdale, NJ: Erlbaum.

Kahan, S. 2006. The power of storytelling to jumpstart collaboration. The Journal for Quality and Participation, 29(1), 23.

Kahn, K.B. 2013. *The PDMA handbook of new product development* (Third ed.). Hoboken, New Jersey: John Wiley & Sons Inc.

Kandlhofer, M., and Steinbauer, G. 2016. Evaluating the impact of educational robotics on pupils' technical- and social-skills and science related attitudes. *Robotics and Autonomous Systems*, 75, 679-685.

Kandlhofer, M., Steinbauer, G., Hirschmugl-Gaisch, S., and Eck, J. 2013. A cross-generational robotics project day: Pre-school children, pupils and grandparents learn together. J. Autom. Mob. Robot. Intell. Syst, 8, 12-19.

Karim, M. E., and Mondada, F. 2015. A review: Can robots reshape K-12 STEM education?. In 2015 IEEE International Workshop on Advanced Robotics and its Social Impacts (ARSO) (pp. 1-8). IEEE.

Katuscáková, M. 2015. Sharing Scientific Knowledge Through Telling Stories and Digital Storytelling. In European Conference on Knowledge Management (p. 408). Academic Conferences International Limited.

Kawulich, B.B. 2005. Participant observation as a data collection method. In Forum Qualitative Sozialforschung/Forum: Qualitative Social Research (Vol. 6, No. 2).

Kearney, C. 2016. Efforts to Increase Students' Interest in Pursuing Mathematics, Science and Technology Studies and Careers. National Measures taken by 30 Countries – 2015 Report, European Schoolnet, Brussels.

Kolberg, E., and Orlev, N. 2001. Robotics learning as a tool for integrating science technology curriculum in K-12 schools. In Frontiers in Education Conference, 2001. 31st Annual (Vol. 1, pp. T2E-12). IEEE.

Kokosy, A., Micea, M. V., & Saey, P. 2014. A professional project based learning method in mobile robotics. In 2014 IEEE Frontiers in Education Conference (FIE) Proceedings (pp. 1-7). IEEE.

Kolodner, J.L., Crismond, D., Gray, J., Holbrook, J., and Puntambekar, S. 1998. Learning by Design from Theory into Practice, in *Proceedings of ICLS 98*, Atlanta, GA, pp. 230– 236.

Koppensteiner, G., Vittori, L., Miller, D. P., and Goodgame, S. 2015. Teaching programming on the Elementary Level. *International Conference of Robotics in Education RIE'15*, "Which approaches do actually work when introducing children to robotics?" Workshop Position Paper, Yverdon-les-Bains, Switzerland

Krajcik, J. S., and Shin, N. 2014. Project-based learning. In The Cambridge Handbook of the Learning Sciences, Second Edition. (pp. 275-297).

Krishnan, V., and Ulrich, K. T. 2001. Product development decisions: A review of the literature. *Management science*, *47*(1), 1-21.

Kriz, S., Ferro, T. D., Damera, P., and Porter, J. R. 2010. Fictional robots as a data source in hri research: Exploring the link between science fiction and interactional expectations. In 19th International Symposium in Robot and Human Interactive Communication (pp. 458-463). IEEE.

Kuhn, S. 1998. The software design studio: An exploration. IEEE Software, 15(2), 65-71.

Kuwamura, H., Yamamoto, T., and Hashimoto, T. 2014. What is Animacy in Dynamical Movement?. *In Proceedings of the 5th international workshops on Epigenetic Robotics: Modeling Cognitive Development in Robotic Systems*.

Kynigos, C. 2008. Black-and-white-box perspectives to distributed control and constructionism in learning with robotics. In Proceedings of SIMPAR workshops (pp. 1-9).

Lammer, L., Lepuschitz, W., Kynigos, Ch., Giuliano, A., and Girvan, C. 2016. ER4STEM - Educational Robotics for Science, Technology, Engineering and Mathematics. International Conference of Robotics in Education RIE'16, Short Paper and Poster, Vienna, Austria

Lammer, L., Hirschmanner, M., Weiss, A., and Vincze, M. 2015a. Crazy Robots – An Introduction to Robotics from the Product Developer's Perspective with the 5-Step Plan and the Mattie Robot Project Assignment. In *Proceedings of International Conference of Robotics in Education RIE'15*, Yverdon-les-Bains, Switzerland

Lammer, L., Weiss, A., Vincze, M. 2015b. The 5-Step Plan: Empowered Children's Robotic Product Ideas. Short paper in Interact2015. Bamberg, Germany.

Langley, D., and Zadok, Y. 2009. Instructional Technology Implementation and Research Scenes: The Case of a Robotics Course. *In EdMedia: World Conference on Educational Media and Technology* (Vol. 2013, No. 1, pp. 564-572).

Large, A., Nesset, V., Tabatabaei, N., and Beheshti, J. 2008. Bonded Design revisited: Involving children in information visualization design. The Canadian Journal of Information and Library Science. 32(3/4): 107-139.

Leiffer, P.R., Graff, R.W., and Gonzales, R.V. 2005. Five Curriculum Tools to Enhance Interdisciplinary Teamwork. *Proceedings of the 2005 American Society for Engineering Education Annual Conference & Exposition*.

Levy, S. T., and Mioduser, D. 2008. Does it "want" or "was it programmed to..."? Kindergarten children's explanations of an autonomous robot's adaptive functioning. *International Journal of Technology and Design Education*, 18(4), 337-359.

Lutters, W. G. 2002. Storytelling in Collaborative Work: Design Challenges for Capturing and Representing Sensitive Interactions. In Proceedings of the 2002 ACM conference on Computer supported cooperative New Orleans, Louisiana, USA (pp. 266-275).

Magnenat, S., Ben-Ari, M., Klinger, S., and Sumner, R. W. 2015. Enhancing Robot Programming with Visual Feedback and Augmented Reality. In Proceedings of the 2015 ACM Conference on Innovation and Technology in Computer Science Education (pp. 153-158). ACM.

Martin, F. G., Butler, D., and Gleason, W. M. 2000. Design, story-telling, and robots in Irish primary education. In IEEE INTERNATIONAL CONFERENCE ON SYSTEMS MAN AND CYBERNETICS (Vol. 1, pp. 730-735).

Matarić. M. J. 2007. The Robotics Primer (Intelligent Robotics and Autonomous Agents). The MIT Press, Cambridge, MA.

Matarić, M. J. 2004. "Robotics education for all ages." *Proc. AAAI Spring Symposium on Accessible, Hands-on AI and Robotics Education*.

McClure, R. D. 2002. Common data collection strategies effective in qualitative studies using action research in technical/operational training programs. *The Learning Corner*.

McNamara, S., Cyr, M., Bratzel, B., and Rogers, C. 1999. Lego Brick Sculptures and Robotics In Education Paper presented at 1999 Annual Conference of ASEE, Charlotte, North Carolina.

Mead, R. A., Thomas, S. L., and Weinberg, J. B. 2012. From grade school to grad school: An integrated stem pipeline model through robotics. Information Science Reference.

Meerbeek, B., Saerbeck, M., and Bartneck, C. 2009. Iterative design process for robots with personality. In *Proceedings of the AISB Symposium on New Frontiers in Human-Robot Interaction*. Edinburgh, Scotland.

Melchior, A., Cutter, T., and Cohen, F. 2004. Evaluation of FIRST LEGO league. Waltham, MA: Center for Youth and Communities, Heller Graduate School, Brandeis University.

Miles, M. B., Huberman, A. M., and Saldana, J. 2013. Qualitative data analysis: A methods sourcebook. SAGE Publications, Incorporated.

Milto, E., Rogers, C., and Portsmore, M. 2002. Gender differences in confidence levels, group interactions, and feelings about competition in an introductory robotics course. *In Frontiers in Education*, 2002. FIE 2002. 32nd Annual (Vol. 2, pp. F4C-7). IEEE.

Mishra, P., and Girod, M. 2006. Designing learning through learning to design. *The High School Journal*, 90(1), 44-51.

Montessori, 1964. The Montessori method. (George, A.E., trans.). New York: Schocken.

Mori, M., MacDorman, K. F., and Kageki, N. (2012). The uncanny valley [from the field]. IEEE Robotics & Automation Magazine, 19(2), 98-100.

Mubin, O., Stevens, C. J., Shahid, S., Al Mahmud, A., and Dong, J. J. 2013. A review of the applicability of robots in education. Journal of Technology in Education and Learning, 1, 209-0015.

Myers, I.B. and Myers, P.B. 1995. Gifts differing: Understanding Personality Type. Davies-Black Publishing.

Norton, S. J. 2004. Using Lego construction to develop ratio understanding. Mathematics education for the third millennium: Towards, 2010, 414-421.

Nourbakhsh, I., Hamner, B. Dunlavey, D. Bernstein, and K. Crowley. 2005. Educational Results of the Personal Exploration Rover Museum Exhibit. *Proceedings of the IEEE International Conference on Robotics and Automation (ICRA-2005).*

Nourbakhsh, I. R., Crowley, K., Bhave, A., Hamner, E., Hsiu, T., Perez-Bergquist, A., and Wilkinson, K. 2005. The robotic autonomy mobile robotics course: Robot design, curriculum design and educational assessment. Autonomous Robots, 18(1), 103-127.

Nugent, G., Barker, B., Grandgenett, N., and Welch, G. 2016. Robotics camps, clubs, and competitions: Results from a US robotics project. Robotics and Autonomous Systems, 75, 686-691.

Oh, C. G., and Park, J. 2014. From Mechanical Metamorphosis to Empathic Interaction: A Historical Overview of Robotic Creatures. Journal of Human-Robot Interaction, 3(1), 4-19.

Okita, S. Y., and Schwartz, D. L. 2006. Young children's understanding of animacy and entertainment robots. International Journal of Humanoid Robotics, 3(03), 393-412.

Papert, S. and Harel, I. 1991. *The Constructionism*. Ablex Publishing Corporation.

Pellegrino, J. W. and Hilton, M. L. (Eds.). (2012). Education for life and work: Developing transferable knowledge and skills in the 21st century. Washington, DC: National Academies Press.

Piaget, J. & Inhelder, B. 1969. *The Psychology of the child*.

Plsek, P. E., and Wilson, T. 2001. Complexity, leadership, and management in healthcare organisations. British medical journal, 323(7315), 746.

Prassler, E., Bischoff, R., Burgard, W., Haschke, R., Hägele, M., Lawitzky, G., and Zöllner, M. 2012. Towards Service Robots for Everyday Environments. *Springer Tracts in Advanced Robotics*, Volume 76.

Renzulli, J. S., and Reis, S. M. 1997. *The schoolwide enrichment model: A how-to guide for educational excellence*. Creative Learning Press, Inc., PO Box 320, Mansfield, CT 06250.

Resnick, M. 2014. Give P’s a chance: Projects, Peers, Passion, Play. In Proceedings of Constructionism and Creativity Conference, Vienna, Austria.

Resnick, M. and Silverman, B. 2005. Some Reflections on Designing Construction Kits for Kids. *In Proceedings of Interaction Design and Children conference*, Boulder, CO.

Resnick, M., Berg, R., and Eisenberg, M. 2000. Beyond black boxes: Bringing transparency and aesthetics back to scientific investigation. The Journal of the Learning Sciences, 9(1), 7-30.

Rogers, C. 2012. Engineering in Kindergarten: How Schools Are Changing. *Journal of STEM Education: Innovations and Research*, 13(4), 4.

Romero, E., Lopez, A., and Hernandez, O. 2012. A pilot study of robotics in elementary education. *In 10th Latin American and Caribbean Conference for Engineering and Technology*, Panama City, Panama.

Rusk, N., Resnick, M., Berg, R., and Pezalla-Granlund, M. 2008. New pathways into robotics: strategies for broadening participation. Journal of Science Education and Technology, 17 (1), 59–69.

Sanders, M. E. 2008. Stem, stem education, stemmania. Technology Teacher, 20–26.

Schrage, M. 2000. Serious Play: How the World's Best Companies Simulate to Innovate. Boston, MA: Harvard Business School Press.

Schramm, W. 1971. Notes on Case Studies of Instructional Media Projects. Working Paper for the Academy of Educational Development, Washington DC.

Shahid, S., Krahmer, E., and Swerts, M. 2014. Child–robot interaction across cultures: How does playing a game with a social robot compare to playing a game alone or with a friend? Computers in Human Behavior, 40, 86-100.

Silverman D. 2000. Doing qualitative research. London: Sage Publications.

Sklar, E. I., Johnson, J. H., and Lund, H. H. 2000. Children learning from team robotics: Robocup junior 2000. Educational Research Report, Department of Design and Innovation, Faculty of Technology, The Open University, Milton Keynes, UK.

Soloway, E., Guzdial,M. and Hay, K.E. 1994. Learner-centered design: the challenge for HCI in the 21st century. *Interactions* 1, 2, 36-48.

Sundström, P., Taylor, A., Grufberg, K., Wirström, N., Solsona Belenguer, J., and Lundén, M. 2011. Inspirational bits: towards a shared understanding of the digital material. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, 1561-1570. ACM.

Stager, G. 2010. A Constructionist Approach to Teaching with Robotics. In Proceedings of Constructionism and Creativity Conference, Paris.

Steil, B., Victor, D. G., and Nelson, R. R. 2002. *Technological Innovation and Economics Performance. A Council of Foreign Relations Book.* Princeton University Press.

Sternberg, R. J. 1999. *Thinking styles*. Cambridge University Press.

Stevens, R., and Brook, P. 1998. Systems engineering: coping with complexity. Pearson Education.

Sullivan, A., and Bers, M. U. 2016. Robotics in the early childhood classroom: learning outcomes from an 8-week robotics curriculum in pre-kindergarten through second grade. International Journal of Technology and Design Education, 26(1), 3-20.

Sung, J. H., Sung, Y. H., and Moon, W. S. 2013. A Design and Development of Robotics Integrated Curriculum Based on Storytelling for Elementary School Student. *In International Conference on Intelligent Robotics and Applications* (pp. 580-591). Springer Berlin Heidelberg.

Tellis, W. 1997. Introduction to case study. The Qualitative Report [On-line serial], 3(2).

Thamhain, H. J., and Wilemon, D. L. 1987. Building high performing engineering project teams. IEEE Transactions on Engineering Management, (3), 130-137.

Urrea, C. 2001. Designing robotic artifacts: rural school-community collaboration for learning. *In Thinkcycle workshop*. Boston.

Val, S., and Pastor, J. 2012. Robotics in education. Proceedings in ARSA-Advanced Research in Scientific Areas, (1).

Vandevelde, C., Wyffels, F., Ciocci, M. C., Vanderborght, B., and Saldien, J. 2015. Design and evaluation of a DIY construction system for educational robot kits. *International Journal of Technology and Design Education*, 1-20.

VDI-Richtlinien. VDI 3780: Technikbewertung. Begriffe und Grundlagen, September 2000, Seite 2.

Veselovská, M., and Mayerová, K. 2014. Pilot study: educational robotics at lower secondary school. In Constructionism and Creativity Conference, Vienna, Austria.

Vygotsky, L.S. 1978. Mind in Society: The Development of Higher Psychological Processes. Harvard University Press.

Wagner, T. 2014. The Global Achievement Gap: Updated edition. Perseus Books Group.

Ward, T. B., Patterson, M. J., Sifonis, C. M., Dodds, R. A., and Saunders, K. N. 2002. The role of graded category structure in imaginative thought. *Memory & Cognition*, *30*(2), 199-216.

Weirich, A., Haumann, C., Steil, J., and Schüler, S. 2011. Learning Lab - Physical Interaction with Humanoid Robots for Pupils. In Proc. Robotics in Education, 21-28.

Weirich, A., Schüler, S., Haumann, C., and Steil, J. J. 2010. teutolab-robotik-Hands-On Teaching of Human-Robot Interaction. In Proceedings of SIMPAR Workshops' Teaching robotics and teaching with robots', Darmstadt (pp. 474-483).

Welty, C. A., Livingston, K., Martin, C., Hamilton, J., and Rugger, C. 1998. Teaching Bottom-up AI from the Top Down. In FLAIRS Conference 24-28.

Wikström, A., Andersson Schaeffer, J., Öberg, Å., and Eriksson, Y. 2011. The Use of Storyboard to Capture Experiences. In *Proceedings of the 18th International Conference on Engineering Design (ICED 11)*, Impacting Society through Engineering Design, Vol. 10: Design Methods and Tools pt. 2, Lyngby/Copenhagen, Denmark.

Williams, D. C., Ma, Y., Prejean, L., Ford, M. J., and Lai, G. 2007. Acquisition of physics content knowledge and scientific inquiry skills in a robotics summer camp. Journal of Research on Technology in Education, 40(2), 201-216.

Wolz, U. 2001. Teaching design and project management with Lego RCX robots. *ACM SIGCSE Bulletin*, 33(1), 95-99.

Wood, K. L., Mohan, R. E., Kaijima, S., Dritsas, S., Frey, D. D., White, C. K., and Pey, K. L. 2012. A Symphony of Designiettes – Exploring the Boundaries of Design Thinking in Engineering Education. *In American Society for Engineering Education.* American Society for Engineering Education.

Woods, S. 2006. Exploring the design space of robots: Children's perspectives. *Interacting with Computers*, 18(6), 1390-1418.

Yanco, H. A., Kim, H. J., Martin, F. G., and Silka, L. 2007. Artbotics: Combining Art and Robotics to Broaden Participation in Computing. In AAAI Spring Symposium: Semantic Scientific Knowledge Integration (p. 192).

Yanow, D. 2006. Studying physical artifacts: An interpretive approach. Artifacts and organizations: Beyond mere symbolism, 41-60.

Yiannoutsou, N., Nikitopoulou, S., Kynigos, Ch., Gueorguiev, I., and Angel Fernandez, J. 2016. Activity Plan Template: a mediating tool for supporting learning design with robotics. *In Proceedings of International Conference of Robotics in Education RIE'16*, Vienna, Austria.

Yin, R. 2013. Case study research: Design and methods (5th ed.). Thousand Oaks, CA: Sage Publishing.

Yudin, A., Salmina, M., Sukhotskiy, V., and Dessimoz J.-D. 2016. Mechatronics Practice in Education Step by Step, Workshop on Mobile Robotics. In International Symposium of Robotics ISR 2016, Munich, Germany.

Zaga, C., Lohse, M., Truong, K. P., and Evers, V. 2015. The Effect of a Robot's Social Character on Children's Task Engagement: Peer Versus Tutor. *In International Conference on Social Robotics*. 704-713. Springer International Publishing.

Zubrycki, I., and Granosik, G. 2015. Technology and art--solving interdisciplinary problems. Proc. of 6th Robotics in Education RiE15, Yverdon-les-Bains, Switzerland.

List of Figures

List of Tables

Appendix

Following documents are listed in the Appendix:

5-step plan template A4 format

Questionnaire Genderfair Technike

Questionnaire Crazy Robots “Robot Experts”

Überlege zuerst, was du als Roboterexperte oder -expertin am liebsten machen würdest. und kreuze unten eins an.

[ ] Mit Leuten sprechen und Aufgaben oder Verhalten des Roboters festlegen
[ ] Teile des Roboters bauen und programmieren
[ ] Aussehen und Material bestimmen
[ ] Verhalten des Roboters programmieren
[ ] Dafür sorgen, dass alle im Team richtig zusammenarbeiten damit die Teile richtig zusammenkommen und die Ziele erreicht werden
[ ] Gesetze für Roboter machen
[ ] Regeln für Roboterentwickler aufstellen, damit sie bessere Roboter bauen
[ ] Roboter testen
[ ] ____

Jetzt überlege was für einen Roboter du entwerfen möchtest.
Der 5-Schritte Plan hilft dir dabei.

1 Aufgaben: Für wen ist der Roboter? Was soll der Roboter alles tun?

.... (wie heißt der von dir entworfene Roboter?)

2 Steuerung: Wie kommuniziert man mit deinem Roboter? Gibt es so etwas schon oder sollen das Wissenschaftler_innen zuerst entwickeln?

Bitte wenden

3 Morphologie: Wie sieht dein Roboter aus (wie eine Maschine, wie eine Zeichentrickfigur, wie ein Tier, ähnlich wie ein Mensch mit Kopf und Körper, oder ganz anders)? Aus welchen Materialien ist der Roboter gemacht? Wofür brauchst du welches Material? Beschreibe oder skizziere das Aussehen des Roboters und die Materialien, die du brauchst.

Aussehen	Material

4 Verhalten: Wie soll der Roboter sich verhalten? Wie ein/eine Diener_in, Lehrer_in, Freund_in, Beschützer_in, wie ein Haustier oder ganz anders? Beschreibe auch wie das Verhalten ist.

5 Entwurf: Was für Teile brauchst du unbedingt? Was brauchst du noch, damit der Roboter seine Aufgaben erfüllen kann, so aussieht wie du möchstes, und du ihn steuern kannst?

Nun kannst du deinen ersten Prototypen bauen. Zuerst fangen wir mit einem Modell aus Modelliermasse an, um zu verstehen wie alles zusammenhängt und unseren Roboter anderen besser zu erklären. Dadurch holen wir uns neue Ideen für den nächsten Prototypen.

Fragebogen zum Workshop „Wie entwerfe ich meinen Wunschroboter?“

Datum:_7.7.2015___, 10-14jährige Schülerinnen

1) Was hat Dir gut gefallen? ☺

2) Was hat Dir gar nicht gefallen? ☹

3) Was würde Dich noch genauer interessieren?

4) Wie warst Du mit der Vortragenden zufrieden? Kreuze an!

„sehr zufrieden“ ☺ ☺ 😐 ☹ ☹ „nicht zufrieden“

5) War das Tempo ok? **[ ]** zu schnell
[ ] gerade richtig
[ ] zu langsam

6) Wie warst Du mit der Qualität der Unterlagen zufrieden? Kreuze an!

„sehr gut“ ☺ ☺ 😐 ☹ ☹ „schlecht“

7) Wie würdest Du die Atmosphäre im Kurs beschreiben?

8) Zu welchen Themen/Inhalten sollen weitere techNIKE-Workshops angeboten werden?

9) Sonstiges/Anmerkungen:

Danke fürs Ausfüllen!

Name: ____ Alter: _____ Jahre

Geschlecht: ☐ weiblich ☐männlich

Welche Wissensgebiete interessieren dich? Mehrfachauswahl möglich.

☐ Maschinenbau ☐ Elektrotechnik ☐ Mechatronik ☐ Informatik ☐ Jus

☐ (Industrie-) Design ☐ Mensch-Roboter Interaktion ☐ Medizin ☐ Biologie

☐ Philosophie (Ethik) ☐ Psychologie ☐ Soziologie ☐ Projektmanagement

☐ Mathematik ☐ Physik ☐ Chemie ☐ Sprachwissenschaften

☐ __________________________

Bitte nur eins auswählen:

Wie entscheidest du?
☐ Kopf (über die Sache)
☐ Herz (mit Rücksicht auf Gefühle)
☐ Mal so, mal so

Was beschäftigt dich?
☐ Alles und wie es zusammenhängt
☐ Nur wenige Sachen, die aber dafür sehr genau

Wie holst du dir Energie?
☐ von vielen Menschen
☐ allein oder mit einer Person, die du gut kennst

Welche Fähigkeiten hast du? Mehrfachauswahl möglich.

☐ sprachlich ☐ logisch-mathematisch ☐ visuell-räumlich ☐ inter-personal
☐ musikalisch ☐ naturalistisch ☐ intra-personal ☐ körperlich-kinesthetisch

In welchem Team hast du mitgemacht?
☐ Konstruktion (Fahrwerk) ☐ F&E (Sensoren) ☐ Design (Aussehen)
☐ HRI (Persönlichkeit) ☐ Marketing und Vertrieb

Was war deine Aufgabe im Team?

Was hat dir gut gefallen?

Was könnte besser sein?