Crazy Robots – An Introduction to Robotics from the Product Developer's Perspective

with the 5-Step Plan and the Mattie Robot Project Assignment

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***Abstract*—Robotics is an excellent tool for teaching science and technology, so current approaches in educational robotics mostly focus on these domains. However, besides engineering we also need social sciences, design and business approaches in robotics. Crazy Robots is a top-down approach to educational robotics from the product developer's perspective. Curiosity, creativity, persistence, and teamwork are in focus. In three consecutive workshops at five high schools, children aged 11-13 work through three incisive phases of product development: "ideation", "prototyping", and "evaluation". The approach follows the educational goals of empowering children, providing a structure for creative processes, and teaching the product perspective (top-down). Feedback from teachers and students reflects the positive achievements of the concept.**

***Keywords*— robotics in school, project-based learning, constructionism**

I. Introduction

Robotics is an excellent tool for teaching science and technology [1, 2], so current approaches in educational robotics mostly focus on these domains [3]. Yet, robotics is also excellent to teach any other concept because children easily connect robots to their personal interests [4]. When educational robotics activities focus on STEM (science, technology, engineering and mathematics) or robotics itself, they naturally attract more children who are already interested in these subjects; e.g., robotics conferences such as GCER who offer a research perspective to robotics directly address children interested in STEM. Competitions (e.g. Botball, FIRST or Robocup Junior) offer a structure for problem solving in group settings by encouraging focused hands-on problem solving, team work, and innovation [5]; however, not all children are interested in STEM or motivated by competition or tasks that require a specific kind of thinking. Alimisis [6] argues that benefits of educational robotics are important for all children: robotics projects and courses should include the whole class and not only children talented in science and technology. So, what happens when we introduce robotics in the classroom to students with various interests?

Rusk and colleagues [7] offer four strategies as entry points into robotics: exhibitions rather than competitions, themes instead of challenges, art in combination with engineering, and storytelling. Furthermore, constructionism underlines the hands-on aspect and essentially states that by being externalized or given form, children's ideas become tangible and shareable, which in turn helps them to be formed and transformed [8]. Following these principles, Resnick [9] suggests that children need four things to flourish: To work on a project that is related to their life, work and share with peers, develop a passion that makes them more persistent in case of failure, and play as a means of enjoying. Resnick and Silverman [10] also draw attention to the importance of supporting different styles of playing, designing, and thinking. Finally, Garzotto [11] argues that developing technology in an educational context creates a more holistic view (product focus) underlining a number of benefits: collaboration and discussion skills, project/goal oriented attitudes, and capability of reflection and critical thinking (as well as reflecting on technology) for children.

We developed Crazy Robots to address children with various interests and talents, and introduce them to robotics from the product developer's perspective. In the following sections, we will explain the approach in detail, present our case study with five middle school classes, and share our findings and lessons learned.

II. Crazy Robots

Crazy Robots is a top-down approach to educational robotics from the product developer's perspective, i.e. first comes context and relationships, then details. Curiosity, creativity, persistence and teamwork are in focus. In three consecutive workshops children work through three incisive phases of product development: "ideation", "prototyping", and "evaluation". The approach follows the goal to introduce children with various talents to robotics from different perspectives and gives them the possibility to focus on an area of interest while solving real-life problems in collaboration with others.

There are three educational targets to achieve this goal:

1. Empowering children to address problems that influence their lives by helping them become robot experts who solve real-life problems based on their interests and talents;

2. providing a structure for this open creative process;
3. teaching the product perspective which starts from the top with context and relationships, and then moves downward into details; the product perspective includes all aspects of robotics, so that children focus on what interests them most, e.g., appearance design or sensors, or defining the tasks of the robot, its behavior or customer segment and sales strategy.

We have developed two concepts around these targets: (1) the 5-step plan [12] and (2) the project assignment with our educational robotics platform named Mattie robot. Furthermore, we have built these concepts into three consecutive workshops: In the first workshop "ideation", each student designs her or his own robot with the help of the 5-step plan and builds a non-tech model out of modelling clay. In the second workshop "prototype", students receive a project assignment to build a robot for children. They work in five teams on different parts or concepts of the Mattie robot to realize their idea (by also using the 5-step plan as a helping structure for their ideas). Finally, students assess their robot from technical and user perspectives in the third and last workshop "evaluation" and present the robot concept as well as their evaluation results.

A. 5-Step Plan

The 5-step plan (Fig. 1) is designed for children in primary and secondary school; it is based on design methods that empower children [13] by giving them a child-appropriate structure for their creative process. The plan can be integrated into different teaching or research contexts, and adapted to different age groups or even to adults who are not familiar with robotics.

Fig. 1. The 5-step plan - an overview for teachers and researchers

The 5-step plan starts with a pre-phase where the researchers introduce themselves as robot experts and ask the children for their help. As a starting point, children are introduced to technology as "human-made objects, tools, artefacts that help us". The definition of robots draws on the definition of technology. Autonomy distinguishes robots from other technology and results recurrently in unexpected or "strange" behavior. Children are shown pictures of different robotic applications from industrial to service robotics, including personal robots, exoskeletons and prostheses, primed to the notion that robots are "something that we build to make our lives easier" and guided towards the concept of autonomous behavior.

In the main phase, children are explained that real robots are highly complex, autonomously acting, programmable machines which are designed by a team of experts from different disciplines (designers, human-robot-interaction experts, programmers, engineers, etc.), and built after months (even years) of work. The researchers briefly introduce three incisive stages which are common in many different design processes:

1. Ideation: Gathering ideas, drawing sketches and storyboards, building models to share and discuss ideas
2. Prototyping: Building one or two best ideas into prototypes, choosing one idea, ameliorating the prototype
3. Evaluation: Function testing of the prototype and evaluation in user studies and surveys

The 5-step plan is offered as a tool in the "ideation" phase to design a robot from scratch as well as in the following stages of "prototyping" and "evaluation" to refine the idea. Children are guided step by step through five important topics they need to cover if they are to design a robot. Each step is explained in detail to the children with examples. In the last step, robot parts, pictures of mechanic and electronic parts are shown. At the end of each step there is a short discussion where children contribute their ideas and ask questions. The five steps are following:

- Step 1 – Robot Task ("assignment")
- Step 2 – Robot Interaction
- Step 3 – Robot Morphology ("looks and materials")
- Step 4 – Robot Behavior
- Step 5 – Robot Parts

After this brief theory children immediately start building a non-tech prototype with modelling clay which they can take home to show family and peers. In the post-phase, once through all five steps, we use iterations as common in user-centered design. More details can be found in [12].

B. Project Assignment with the Mattie Robot

Fig. 2. The Mattie Robot: Left our simple design suggestion for demonstration purposes. Right the design of a 2nd grade school class

The project assignment incorporates all three previously mentioned phases of product development with more emphasis on "prototyping" and "evaluation". The whole class receives the assignment to build a robot for children. The class decides for which children the robot is and what it should do. Because of time constraints, we offer the Mattie robot (Fig. 2), a platform where common robot functionalities like navigation or interaction are pre-defined. The limitation of the robot's abilities forces children to think out of the box, improvise and be creative. And at the end, there is a finished prototype, an important "quick-win" for motivation.

The Mattie robot is built 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 (Fig. 2). It is designed for classroom workshops in middle schools for children aged 11 to 13 to introduce them (and their teachers) to robotics and allow them to focus on aspects they find most interesting: engineering, research, design, human-robot interaction or marketing. Besides the top-down perspective, the Mattie robot has the characteristic of a "white-box" robot showing the inner workings to demonstrate that "real" technology is accessible, an important aspect in educational technology as pointed out by various researchers, e.g. [14]. 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 locomotion, user interaction is possible via buttons that can be painted on the robot using conductive paint or be 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. The design of locomotion and interaction is kept very simple to allow children the replication at home. More details on the Mattie robot can be found in [15].

For the project assignment students are split into five groups of three to five students. Each group works either on a specific part of the robot or other tasks related, described in more detail in section III. B. Then, all of the parts are combined to a functioning simple robot which can be remote controlled, follows light and reacts to touching via audio. In the evaluation phase, different teams work on different perspectives (technical or user), described in more detail in section III. C. Finally, the students present their sales idea or robot concept, the robot and its functions and the evaluation results.

In the next section we will introduce our case study with five middle school classes, describe how we incorporated the concepts "5-step plan" and "project assignment" into three consecutive workshops and provide more details on each.

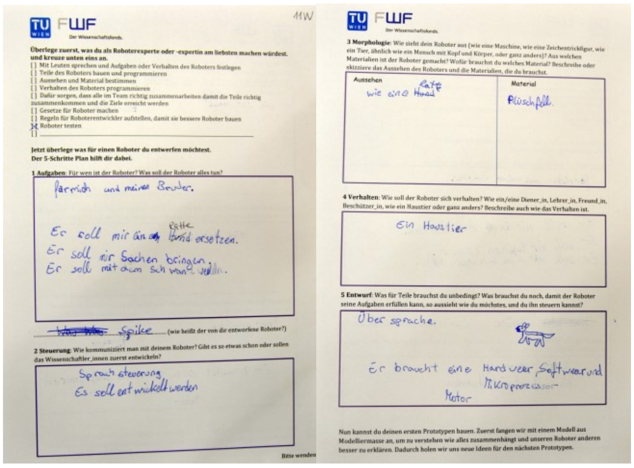
III. Case Study

Five middle school classes (age range 11 to 14) in Vienna and surroundings have participated in our case study, successfully completing three workshops: three 2nd classes and one 3rd class with their handicrafts teachers (groups of 12 to 15), and one 3rd class with two physics teachers (25 students) and two tutors (8th graders from the same school to assist and learn). In total, 70 students participated in the project. Two researchers conducted the workshops. The first and third workshops were held in the classroom or handicrafts room (two class hours, approx. 100 minutes in total), while as for the second workshop the students visited the Vision for Robotics Group at the Vienna University of Technology to see real experts at work with real robots and attend a workshop (two hours) in a lecture or seminar room (depending on group size).

Each workshop had a theory session which preceded the practical work. In the first workshop, the classes were introduced to the 5-step plan and worked on non-tech models of their own. In the second workshop, the class split into four or five groups and worked on a common goal from different perspectives (engineering, research & development, human-robot interaction, design and optionally sales & marketing). In the third and last workshop, the class integrated the robot parts, demonstrated the robot and its functions, evaluated the robot from technical and user perspectives and presented the results. Students, teachers and other stakeholders had also the possibility to visit the project homepage in German (http://schraegeroboter.wordpress.com) for information about the project, details about workshop materials, comments and questions.

A. 1st Workshop – Ideation

We started our theory session with the 5-step plan, including definitions of technology and robots as well as the description of the three distinctive product development phases of "ideation", "prototyping" and "evaluation" (PowerPoint presentation with discussion), and then distributed a two-page 5-step plan template (Fig. 3) before the break. The transition from filling the template to building the non-tech prototype went smoothly. The materials provided were modelling clay in two colors for each child and a selection of decoration materials (stones, feathers, plush wire and foam craft shapes) for all to choose from.


TU WIEN FWF Der Wissenschaftsfonds.

11W

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
[X] 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?

für mich und meinen Bruder.
Er soll mir ein Ratte ersetzen.
Er soll mir Sachen bringen.

Spike (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?

Sprachsteuerung
Es soll entwickelt werden

Bitte wenden

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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
wie eine Ratte	Plüschfell.

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 Haustier

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

Über sprache.
Er braucht eine Hardwear, Softwear und Mikroprozessor
Motor

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.

Fig. 3. Two page template for 5-step plan from 11-year-old girl describing her robot rat Spike (notice the change from dog to rat which was easier to build)

At the end of the workshop, we did not have time for a post-phase with presentations; we coded age and gender of the child on every template page and photographed it. 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 exhibition on the home page. Teachers had the possibility to let students present their prototypes and discuss the five steps with them in the following classes. Fig. 4 shows some non-tech prototype examples.

Fig. 4. Non-tech prototypes from two different classes

B. 2nd Workshop – Prototyping

Before we started the second workshop, the class visited the Vision for Robotics Lab at the Vienna University of Technology and were shown a demonstration of the Romeo robot from the company Aldebaran (http://projetromeo.com/) where we introduced them to the robot's different capabilities and sensors including 3D cameras and computer vision. In the workshop after the demonstration, we started the theory session by repeating definitions from the first workshop: 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). We also repeated the five steps and underlined that our next focus was on prototyping and getting deeper into different robot parts.

It was also an important topic of this workshop to introduce children to robot experts: "What kind of people are they? What do they know?" We explained children important areas in robotics such as mechatronics and coding but also sociology, psychology, design, or ethics. We told them about three different personality traits to consider when collaborating: thinking and feeling types [16], generalist and specialist thinkers [17], and extrovert and introvert types [16]. We also introduced them to different intelligences [18] underlining that each of them was unique with their interests and talents, and could contribute different aspects to a team. We also talked about what robotics experts all had to have in common: curiosity, creativity, persistence and the ability to collaborate.

Finally, the "CEO of Crazy Robots Company" (one researcher) charged the "Mattie robot project manager" (the other researcher) with the project assignment to build a robot for children with a budget of 300 Euros. The project manager explained the concept of the Mattie robot, and then divided the students in groups. Each group had different tasks which are described in the following:

Sales & Marketing: In this task, students 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 the tasks of the robot along with its design and behavior. 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 groups 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 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. We programmed the microcontroller beforehand because of time constraints; in an expanded workshop, students can also code. This is a classic technical assignment with a predetermined goal that has to be achieved.

Human-Robot Interaction (HRI): The children in this group need to define the types of sound files the robot will play and design an interface for the interaction. 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 which creates the buttons.

Research & Development: This group is like the research & development department of a company or researchers at a research institution who develop new sensors. For this task we let students get acquainted with real sensors and teach them what to do with sensor readings – a number which represents a voltage. In a wooden box six sensors are connected to a display which shows the current sensor readings. 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 who finish quickly there is an optional task: the students connect a tilt sensor with an LED 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 what the robot is for and for whom. 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.

C. 3rd Workshop – Evaluation

In the third workshop, all of the five classes first had tasks to complete from the second workshop, e.g. finishing buttons or design. Therefore, the theory part was kept very short, again repeating definitions and shortly explaining what evaluation is. Then, some students were given the unfinished tasks from the second workshop. The rest of the class was divided into two teams: technical evaluation and product (or user) evaluation.

The technical group evaluated the chassis, e.g. average speed of robot, maximum distance of infrared receiver, reliability of the ultrasound sensor for detecting objects, or average deviation on a straight line. The user group was again divided into user study experts and marketing experts. While the user study experts designed the study and prepared questionnaires and interview guidelines, the marketing experts designed a product poster. When design and buttons were finished, the whole robot was put together and the user study conducted either with class mates or students recruited from other classes. Then, the presentations followed: Product presentation, robot demonstration and presentation of evaluation results. Fig. 5 shows the garbage robot hull of one class and their marketing poster of the final product. Finally, we concluded the workshops with a feedback round.

Fig. 5. Garbage robot of 3rd graders, e.g. stating garbage facts when touched (left) and marketing poster with 4 Ps (right), either for the classroom or for older people at home

D. Analysis

We used five instruments for analysis: (1) documentation (templates and questionnaires); (2) feedback from teachers; (3) feedback from students; (4) physical artefacts; and (5) observations. There was static filming for audio purposes, photography of all documents and some prototypes, also group feedback and individual email feedback from teachers. Feedback from students was collected in a questionnaire after the second workshop and in the final feedback round. In our analysis, we looked into each robot idea, either from each student collected on the 5-step plan templates, or from each class as demonstration and product presentation and also observed the repetition of definitions and concepts in every subsequent workshop to see if students had learned these. We compared these findings to our participant-observations as well as student and teacher feedbacks. In our qualitative analysis we examined three educational targets:

1. Empowering children to address problems that influence their lives
2. Providing a structure for this open creative process
3. Teaching the product perspective

IV. Findings and Lessons Learned

Crazy Robots and the 5-step plan follow the goal to introduce children with various interests to robotics from different perspectives. In this paper, we present our findings and lessons learned from an educational robotics perspective.

A. Empowering children

We wanted to understand if children with different interests (not only the ones interested in robotics or STEM fields) were empowered by the 5-step plan as product designers to think about real robots for real-world problems. Our findings suggest that they were. Each student and each class had one robot idea to solve a problem from their lives, ranging from robots for parents with babies to transporter or cooking robots. Many robots (75%) 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 transporting from A to B.

Although the first workshop 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"). For some children, the differences between the Mattie robot and the Romeo robot were unacceptable (although we explained to them that all the talk and movement of the robot was pre-programmed); they rather thought that they could work on Romeo or build more advanced robots. Next time, we will try to make clearer how much robot experts have studied and worked on robotics before building Romeo and do the demonstration after the workshop to limit disappointments.

B. Structure for creative processes

We provided three distinctive structures for the children: (1) the product development stages "ideation", "prototyping", and "evaluation"; (2) the 5-step plan to build a robot from scratch; and (3) different teams working on a common goal. Teachers were very positive about all three structures and expressed their wish to continue the project on an annual basis. They underlined the importance of teamwork and their amazement about the capabilities of their students. The students did not have much experience or no experience at all in teamwork. They were not always happy about all team members, but very proud of their achievements in the end. Repetitions were also successful. At the beginning of the third workshop, the class was able to answer what technology was and define the difference between a robot and other machines. The students also remembered the product development stages "ideation" and "prototyping", and the different steps to consider when conceptualizing a robot.

C. Product Perspective

The different groups gave the students the possibility to see different aspects of robotics. 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. We had positive experiences in the classes that had a Sales & Marketing team. This team was able to coordinate the other teams to reach a common goal, i.e. robot concept, more quickly. In future, we will organize the three workshops a little bit differently, so that the class arrives at a common concept more easily and quickly. It was also 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 materials also frustrated from time to time. The top-down approach at the beginning of the second workshop (conceptualizing the robot) was frustrating to all classes, yet, in the end all could accomplish this task to their satisfaction, which then empowered them. One comment of a girl in this respect was: "Finally, we managed to do something almost on our own, without the teacher helping us that much."

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 can be 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 behavior than in building or programming details.

Unfortunately, we could not delve into more details in the different groups. Students wanted more materials and time. It would be nice to refer them to other workshops where they can deepen their knowledge in the areas that interest them most and help them more to pursue these goals in their spare time on their own or with peers.

V. Conclusions & Outlook

We have presented Crazy Robots, an introduction to robotics from the product developer's perspective, addressing children with various interests and talents. We applied our concepts "5-step plan" and "Mattie robot project assignment" in three consecutive workshops for middle school students in five schools. Our findings suggest that this top-down approach empowers students to work on technical solutions for their everyday problems (although the limitations of technology frustrate them); it provides enough structure for their open creative process (which is very valued by the teachers); and it gives them a nice overview on different robotic areas that go beyond STEM fields. Teachers also feel comfortable with this approach and confident enough to introduce their classes to robotics in this way. We have learned that follow-up workshops after the introduction are needed to refer interested students to and that we need to find a better way than a homepage to connect the students and teachers to us and each other. We think that we have come very close to the goal of picking the whole classes curiosity for robotics. A 13-year old girl summed it up better than we could: "I don't want to do anything with robotics when I'm older, but I'd like to do more robotics workshops." Our next step is to adapt the concept to older students in 5th grade where they will have one project day to work on the Mattie robot.

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