ENTHUSED FOR ENGINEERING – A ROBOT COMPETITION TO PROMOTE STEM INTERESTS IN HIGH SCHOOL STUDENTS

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Abstract

Robotics is an extremely fascinating field of engineering, relevant for a lot of different areas. Many young high school students are interested in this topic and want to realize own projects, but a lack of access to the topic, knowledge, and whom to ask, rapidly stops their development. On the other hand, STEM (Science, Technology, Engineering, and Mathematics) departments, like the Department of Electrical and Computer Engineering (ECE) at the Technical University of Munich (TUM), would like to increase the diversity of their students and staff and run a diverse number of projects to foster underrepresented groups. We present a project that tries to address both of these issues by running a robotic competition addressing high school students and working in close collaboration with their teachers.

Target group are 14 to 18 years old high school students, who have at least some interest in Engineering and want to realize a technical project in a team of classmates. The participants must design, develop and build fully autonomous robots solving a specific task — which changes from year to year. This building-process starts from the very first idea and ends in a well-designed robot, usually not only technically solving the task, but also conveying a specific team style and thus also including artistic aspects into the whole project. A key difference to similar competitions is that TUM does not provide a more or less complete set of finished modules, but instead off-the-shelf components. The skill set required to pursue personal projects is therefore an implicitly taught part of our project.

Students in the master’s program of Electrical and Computer Engineering guide the interested target group through the project-year, explain difficult correlations in simple words and guide the young teams. Both sides can profit from this construction. While the participants’ knowledge increases immediately, the tutors train their soft skills and leadership competencies.

As the advisors are only a few years older than the high school students all can talk to each other like friend, ask questions about the project and talk as well about their decision it which subject to major in. The positive feedback inspires TUM to enlarge the project in the next years.

Keywords: STEM in education, Robotics, Scientific Communication, High school student.

1 INTRODUCTION

Robotics and automation are influencing more and more parts of our everyday life each year and are part of the digitalisation process taking place for some decades. Being able to take part and shape this design process is thus an important value for society and for deciding future policies. The Department of Electrical and Computer Engineering (ECE) at the Technical University of Munich (TUM) covers a very broad range of research and study topics from power generation and storage, over high frequency communications and machine learning to medical and rehabilitation devices. Each of those topics is extremely broad itself, power storage, for example, is important for storing electricity generated by renewable sources, for making e-mobility possible, but also for our nowadays ubiquitous smart devices like phones and watches which should ideally last for days and take no time to charge.

Nevertheless, ECE faces visibility problems: robotics and automation are often thought to be topics solely governed by mechanical engineering; machine learning, computing, and communications are attributed to computer science. Additionally, in Germany, there are no courses in secondary school, which have a direct equivalence to study programmes offered by ECE. This is an additional drawback compared to disciplines like computer science or physics.

Reconsidering the argument that digitalization and automation have a large impact on societies, we want the people shaping this process to be representative of many different and diverse backgrounds as society is itself. Thus, we want students with low and high income background, students who only moved away from home for holiday as well as refugees from a different continent, students whose
grand-grandparents where born in Munich and students who moved to Germany only recently. Naturally, this is only a very idealised vision, but nevertheless useful to move a very tiny step towards the desired direction. As resources are limited, it is an efficient approach to tackle an obvious issue, where the largest effect could be accomplished, first: In the winter term of 2018/2019, 17% of the ECE's students where women (699 out of 4076 in total) [1]. To improve that number, there are two options: ensure that women will find a good study environment, which supports them in their needs, and getting more women to start studying electrical engineering. For the first option, different programs exist, but the scope of this paper is the second option: How to make studies at ECE more attractive for women?

Trying to answer that question raises a preceding question: Why are female high school graduates hesitant to start studies in engineering, even if they are very successful in STEM topics during school? There are indications that the reason for this observation is caused by the perception of engineering to be a “male” field of study [2, pp. 15-27], and that the perceived image of engineering professions overlaps very little with the desired self-image within society, friends, and family [3].

The key idea behind the presented project is that doing an engineering project with a group of classmates and friends is a very good representation of what engineers do as a profession and how many different facets are important to successfully finish this project. Multiple grading scales (there is not a single price for winning the tournament, but multiple categories) foster this multitude of facets. Another aspect are our tutors, where we take care to employ women and men to have many different role models present in the competition and the opportunity to have a high level of perceived similarity with at least one of them.

2 CONCEPT, DEVELOPMENT AND ORGANISATIONAL BACKGROUND

This section explains the concept, the intention, why the project was installed, the developing process and the practical organization. The last paragraph summarizes interesting facts about the target group.

2.1 Concept

“Schüler bauen Roboter” (German for “High school students construct robots”) is a project, which brings together schools and university. During one school year, high school students can construct a functioning robot with the help of TUM, which is supposed to solve a given task. At the end of the school year, the different groups can compete against each other.

In the project “Schüler bauen Roboter”, school groups use a supplied kit with basic modules (e.g. motor driver, central control unit) to construct their own robot. The base modules abstract complex problems (e.g. protection of the I/O channels from short circuits). That means the high school students can construct their robots without frustrations while leaving open questions such as clever mechanical design, selection of suitable sensors and actuators. A team of TUM scientists developed and assembled the kits especially for “Schüler bauen Roboter”. In order to be able to give socially disadvantaged pupils from less educated classes access to a robotics project, the complete material is provided free of charge.

During the entire project phase tutors individually supervise the participants. Regular meetings of all participants provide an opportunity to exchange experiences and establish contact with the university. The groups independently implement their concepts and compete against the other teams. There is no given complete solution, but the teams have to develop creative solutions together. The project has been running successfully since the 2016/17 school year (now three rounds). In the school year 2018/19, a total of 117 high school students from eleven groups were involved.

2.2 Development

“Schüler bauen Roboter” was heavily inspired by Student Robotics [4] originating from the University of Southampton. Their basic idea of only providing finished modules for difficult circuity and sensitive electronics but leaving mechanical and non-complicated electronics completely to the participants was detailed in the last section. TUM supported two local schools taking part in their tournament for two years (2014 & 2015), which convinced us to start a similar tournament. Two considerations played a major role in this decision: first, while Student Robotics also gives out their kits for free during the project time, travel expenses have to be payed by the schools and students. While this works well for
schools in the UK, it yields huge costs for schools from the continent and thus deters those schools from considering to take part at all. On the other hand, Student Robotics’ motivation is driven by doing cool stuff with robotics. While ECE naturally shares this enthusiasm, we considered this as an opportunity to explicitly foster diversity goals and try to ensure showing different role models to students. In no way should this imply that Student Robotics does not share this goal, it happens there out of pure coincidence by the shared joy for robots. Student Robotics is also a really huge event. Their final tournament takes two full days on a weekend with over 50 groups from different schools. When starting an own project, this size is illusionary and having tutors with different backgrounds is unlikely to happen by coincidence.

In the school year 2016/17, “Schüler bauen Roboter” finally started with 5 groups and about 50 participants. The first task was a simple line following robot where the difficulty increased by introducing turns, interruptions, hills and combinations of the aforementioned settings. The second round in the following year repeated the task and primarily helped to stabilize the project from learnings from the first year and a slight increase in the number of groups.

In the school year 2018/19, finally 11 groups with 117 participants took part in the project. The organisational team found out that about 10 groups with about 100 participants is an ideal size of the group for the project. We also changed the task to “sumo”-robots wrestling against each other (trying to move the other over the edge of a platform) to keep the competition interesting for everybody.

2.3 Differences to Similar Projects

From seemingly comparable competitions, “Schüler bauen Roboter” differs in that it does not offer a modular walk-through, such as projects based on LEGO Mindstorms. The school groups cannot proceed according to a prepared template, but have to develop their own creative solutions to make their project into reality. Technical understanding, basic knowledge from school, as well as the teamwork between each other and with the tutors are important prerequisites to solve the project together. Even the mentoring teachers do not get a “sample solution” at hand. School groups will soon realize that even their teachers cannot answer all questions on an ad-hoc basis. Instead, they must think together, plan strategically, and bring in all their knowledge. Only through lived diversity as a natural part of human interaction and through joint project work, a functional and competitive robot emerges. Likewise, the handling of suitable sources is an important key competence here. TUM offers advice and suggestions with the help of a learning counter during the events as well as in an online wiki. The wiki helps the students to help themselves and offers interesting links and questions around topics such as 3D printing, board production or Arduino programming. For further questions or assistance, the tutors are available.

Even students, whose STEM knowledge may not be sufficient to master other competitions like the Physics Olympiad without frustration, are included in the teamwork here. The most important principle in “Schüler bauen Roboter”: everyone can participate and bring in their knowledge, ideas and creativity in teamwork. We recommend the groups to define supervisors, such as a communications officer, a finance officer, or a designated team, which will later take care of the design of the robot, within the teams. Outstanding team achievements in these categories are considered separately and highlighted in the award ceremony at the closing event.

2.4 Organisation

The project is located and organized at the ECE department of TUM with two contact persons in the department. One contact person takes over the organisational level and one is the responsible technical contact person. They work closely together and always act as a team.

Small abstracts of the courses are published online in different sections of the university website (e.g. www.ei.tum.de/studienangebot/schuelerinnen-und-schueler/; www.schueler.tum.de) and in different German online magazines for study orientation (e.g. komm-mach-mint.de, mintzukunftschaffen.de). In addition, handouts are distributed to schools, teachers, alumni of the workshops and interested high school students in the region around Munich at fairs for study orientation and via mail. This flyer is updated once per semester. In addition, the new dates for workshops are sent to the interested target group via e-mail.

The participation is free of charge and open to all interested high school students. A fee should not be a barrier for participation. The protection of private data is very important. Careful use of personal data is guaranteed and limited to the necessary minimum.
2.5 Target Group

The project is aimed at high school students as well as those who want to attain their higher education entrance qualification through second chance education. The students enrol in the class or in the form of elective courses or school seminars through a supervising teacher, who takes over the internal school coordination and is the contact person for ECE. Most of the participants are between 15 and 18 years old and they are searching for a field of study, which they can start in the future. These participants already have a basic knowledge about technical subjects and are interested in new topics and the university-life. Most of the attendees live in the area of 200km around Munich.

The group of learners together is very heterogeneous with different previous knowledge and different life experience. By targeting different types of school, the age structure of the participants is very broad: In the current school year 2018/19, the youngest participant is at the age of 13 years (7th grade of a high school), while the oldest vocational student is already 29 years old. However, all of them are united by their motivation to develop and implement a functioning robot within one year in small groups, sometimes completely without previous knowledge.

3 COMPOSITION

A basic composition for all the school year has been set up, to help the participants to plan their projects better. A fixed, proved and well-thought pattern is an important requirement of a successful workshop phase. Nevertheless, on the other hand it is also important to react flexible and individually on all the requests from the attendees. First, this basic pattern is described in the following section. Afterwards the detailed parts of “Schüler bauen Roboter” are explained.

3.1 Basic Composition of the project year

After the application period, the actual “Schüler bauen Roboter”-year starts with the first welcome meeting, where everybody has the chance to get to know the project and each other. Three network meetings structure the year, where high school students and supervising teachers can get in touch with the tutors, the scientific and organisational contact persons. The concrete dates for this are communicated directly at the beginning of the project phase in order to facilitate better planning for all participants. The project is split into different phases to allow a constant high level of attention. The following figure shows the whole composition during one school year.

![Figure 1. Basic composition of one project year.](image)

The three network meetings take place at TUM in Munich and form the basis of the project. At these meetings, the participants have the opportunity to exchange ideas and discuss their experiences in the large group. They can also compare their current status with the others and thus assess themselves better. The time between the meetings at TUM can be perfectly used for building phase at schools. During this time, the high school students and their teachers must plan and implement their project.
plans themselves. During the two phases of the project, they have the opportunity to call on the support of the university. The tutors are always open for ideas or questions from the students if necessary.

This plan gives a worthy structure to the project. At the same time, it is very important to leave open space for individual ideas and wishes from the participants.

3.2 Detailed explanation of the project components

In the following section, the phases, which were described roughly in the last section, are explained more detailed.

3.2.1 Application

The students can apply for “Schüler bauen Roboter” in small groups under the supervision of a teacher. Usually the application process starts in summer and ends at the beginning of a school year in September. The groups have to write a letter of motivation via email. The ECE department checks the applications and picks groups with the best applications letters and the best motivation. The experience shows, that the ideal size of the whole group is about 10 teams with about 10 participants each. In this case, a real competition is possible, but on the other hand networking among the different groups is still possible.

3.2.2 1st Network meeting, welcome

“Schüler bauen Roboter” usually starts in October with the first network meeting. The participants get to know each other and learn about the project and the upcoming task. The project is explained with a plan for the following school year, as well as the required material spent. At the same time, trained tutors familiarize students with the topic and the challenges ahead. For most of the attendees it is the first time they visit a university.

3.2.3 Building phase at schools

After the kick-off meeting, the individual school groups work again in small groups at their schools. During the first phase of work, individual students will find their role in the collaborative learning process, depending on personal strength. They learn that it is precisely the interaction of different personalities that drives a team forward.

During the entire project period, the individual groups are closely accompanied and supervised by ECE students. These tutors assist the groups with questions and problems during the design phase and visit the individual school groups at their respective schools up to three times during the school year. Due to the low age difference between students and tutors, fears of contact between school and university should be reduced. Especially female tutors are role models for the high school students, who show that ECE is not solely a male domain, but rather a forward-looking occupational field for both gender. In addition, the student tutors can learn a lot: By guiding and supporting younger students over a school year, they can demonstrate and strengthen their empathy and leadership skills.

3.2.4 2nd Network meeting, exchange and network

In a mid-term meeting in January all teams must present their interim results in plenary and have the opportunity to interact with other groups or already test their robots under real conditions. The other groups, the tutors and a jury give feedback on their presentations and their project. The individual groups have an opportunity to compare and reflect their own actions with those of the other groups. Additionally to input from the groups, the mid-term meeting also offers a small lecture to the groups. In the winter term of 2018/2019, we used this opportunity to give a brief introduction into 3D printing with focus on how to get started with their own models and an offer to have them printed and sent before the final competition. A photo of this lecture is shown in Fig. 2.
3.2.5  **Building phase at schools**

The participants have now about two months’ time to solve any problems back at their schools. They have about six to eight weeks left to improve and fine-tune their robots. If there is enough time left, they will also improve the design of their project.

3.2.6  **3\textsuperscript{rd} Network meeting, tournament**

The final meeting of the group is held in such a way that it does not conflict with the Bavarian Baccalaureate examinations and therefore takes place approximately in April. At this final meeting, there is a competition of the individual team results. Particularly exciting in the competition are the diverse ideas of different groups with different backgrounds (see Fig. 3). The robots of the individual teams compete against each other in a tournament. This is how the overall winner of the competition is determined.

In addition, the creativity and the unique solutions of the individual groups are highlighted and also honoured at the end of the project. This emphasises that very different approaches to a problem lead to a valuable solution with their own pros and cons, but all capable of solving the initial task and a significant amount of individual taste. Every group gets a (positive) feedback at the end, because every single group does something outstanding and unique. They all created a working robot form scratch within half a year, showed their engineering capabilities, and had a lot of fun doing it.
4 EVALUATION AND IMPROVEMENT

Each meeting at TUM closes with a feedback session. Evaluation is very vital to guarantee a constant high quality of a project and to improve it regarding the target group. In this section the focus lies on the evaluation method, the results and the permanent improvement process.

4.1 Evaluation Method

During every school year the ECE department runs three phases of evaluation. After every meeting at TUM a written questionnaire is distributed to the participants and their teachers. The organizers decided to define two different versions of questionnaires for the two target groups. The survey wants to find out if the current session was satisfying for the participants:

The key questions:
- Did you like the project over all?
- What did you expect at the beginning from the workshop? Could your expectations be fulfilled?
- Could the workshop help you with your study orientation?
- Do you already know, in which subject you want to major in?
- What did you like best about the project?
- What did you like least about the project?
- How could this project be improved? Do you have suggestions?
- Would you recommend this workshop to friends and classmates?
- Would you like to take part again?
- Was the time required for the project reasonable?

In addition to the written questionnaires, the tutors talk after the personal training sessions at school with the participants. The familiar atmosphere and the talks on equal terms must be preserved. A written questionnaire fits at that point not in the pedagogical concept. It could rather scare the participants or could seem like a test at the end of the learning session. For such a small statistical population questionnaires are inappropriate. The organizers decided to use a qualitative method and installed feedback sessions at the end of the workshops. The above defined key questions are discussed with each group individually.

In addition questions were designed according to the leading questions that built the basis of the workshop intention. Those questions are supposed to check, if the workshop aims are still fulfilled:
- Do you have an idea about Electrical and Computer Engineering now?
- Could you explain to a friend the bachelor’s degree program?
- Do you have an idea, how it feels to be a student at university?

According to the different preferences of the different individual groups, the questions are formulated every time in a slightly different order and manner of speech. Most important: The participants are encouraged to talk about their experiences and feelings in an open interview situation. The tutor writes after each workshop a brain dump with the anonymous feedback of the participants. Tutors also write down their subjective impressions, if everything worked as planned.

4.2 Results of the Evaluation and Improvement process

The growing numbers of participants can be mentioned as the first success. Starting in 2016/17 with only 5 groups and about 50 participants in total, the project grew quite fast. In the school year 2018/19 finally 11 groups with 117 participants took part in the project.

Almost all respondents would recommend the event to others: high school students and teachers. Some of the teachers now even take part a second or a third time. Many of them asked already now about the upcoming school year.

This success is of course only possible, because the workshops are in a permanent Plan-Do-Check-Act-circle. The department listens to the needs of their target group. The teachers and students preferred a straighter timetable with clearly defined dates and goals because of organizational
planning at the school. Scheduling all meetings at the university before the projects begins, is very important. When registering, teachers know exactly how often they will visit the university, at which dates and how long these meetings approximately will take. In contrary, the final room or venue for the meetings is not important at all and can be scheduled only a few weeks ahead if it is within the same vicinity.

To keep deadlines visible and also help teachers explaining what they spend their time on, a poster showing some artwork/photo representative of the competition or the task and detailing all the deadlines (mid-term and tournament) is a good communication medium. A typical issue faced by participants in tournaments, similar to the one presented in this paper, is a lot of slack time in the beginning and a huge workload towards the end. To mitigate this issue, the mid-term meeting is not only meant to be an exchange between the different groups, but has certain deliverables which are also graded to allow more facets than “best performing robot” and also give feedback to the groups how well they perform. Because grading is a difficult matter and can influence the motivation of the groups a lot, it is important to accentuate the positive aspects instead of a huge grading.

Because changes are already implemented, it is difficult to mix up the feedback three years ago with today’s current feedback and put everything together into one big database. To give an impression about the current evaluation results, the feedback from the last school year 2019 is summarized as follows. 117 high school students and 11 teachers took part.

- 10 of 11 groups managed to present a functioning robot at the tournament.
- The project and the introduction to robotics at TUM were very interesting for everyone, but most of the participants are not sure about their future plans yet.
- All of them are interested in the field of robotics and many of them want to get to know TUM and the robotics topic better.
- One group would prefer a more challenging workshop in the future, one had serious problems with the task, 9 of 11 graded the difficulty appropriate.
- 11 of 11 groups would recommend “Schüler bauen Roboter” to others.
- Individual opinions and ideas cannot be published here because of data protection, but they will influence future plans of “Schüler bauen Roboter”.

The tutors were very satisfied with the groups, because all of them did a good job.

5 CONCLUSION

It is very hard to evaluate the effectiveness of the presented robotic tournament on fostering a more diverse student body. This is on one hand due to data protection considerations — we do not want to keep personal data of underage students for more time than absolutely necessary and especially not match them against applications for TUM. On the other hand, the sample size is also extremely small: we had around 120 participants this year, ranging from 13 to 29 years. Each year, around 800 students start their studies at our department. The numbers for the departments of mechanical engineering and the department for computer science, which have roughly the same target audience, are similar and there are four university like institutions in Munich where students could end up.

All in all “Schüler bauen Roboter” is a program, where students from high-schools get in touch with TUM during a longer time period, they can get to know the university, the subject robotics and the way engineers work. This helps them to make a conscious study decision and ultimately contributes to higher study satisfaction and a lower dropout rate.

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