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Raising interest of pupils in Engineering Education through Problem Based Learning*

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In 2009 within the Excellence Initiative of the German federal government and the state governments a project called 'LearnING' started at the Technische Universität München. Aim of this project is to trigger the interests of pupils and students towards robotics, cognitive systems and engineering. With the approach of Problem Based Learning gender specific aspects during the implementation of courses in school should be considered and designed gender equitable to get more girls interested in this field. By now two educational modules were implemented, one in primary school and one in secondary school. Both modules were evaluated; the data for the secondary school is already available.

Keywords: Problem Based Learning; Cluster of Excellence; Engineering Education; Gender and Diversity

1. The Excellence Initiative and the Clusters of Excellence

The Excellence Initiative of the German federal government and the state governments promotes excellent research in German universities. The aim is to support top-level university research and improve its international visibility, create excellent conditions for young scientists at universities, deepen cooperation between disciplines and institutions, strengthen international research cooperation, promote equal opportunities for men and women in research and intensify scientific and academic competition and improve the general standard of science and universities in Germany. In an extensive and internationally reviewed process universities could apply for funding.

The Excellence Initiative is conducted by the German Research Foundation (DFG) and the German Council of Science and Humanities (WR). It includes three lines of funding:

1. Graduate Schools, to foster young researchers
2. Clusters of Excellence, for the promotion of top-level research
3. Institutional Strategies, to advance top-level university research.

By being successful in all three funding lines of the Excellence Initiative with a future concept that includes gender issues as main field [1], TUM may now be named 'university of excellence'. As a new strategy in Research Policy it supports innovative research projects (Cluster), qualification models (Graduate Schools) and organisational future concepts for universities:

The Cluster of Excellence 'Cognition in Technical Systems' (CoTeSys) investigates cognition for technical systems such as vehicles, robots, and factories starting from the human brain. Cognitive capabilities such as perception, reasoning, learning, and planning turn technical systems into systems that 'know what they are doing'. One project of the Cluster of Excellence is closely linked to the didactics and methods of PBL:

'LearnING—An applied engineering program' which is embedded in the research fields of Gender Studies in Science and Engineering and Human-Machine Communication. The aim of this project is to invent an engineering education program which is applicable in schools in terms of courses starting in the primary years. The goal is to trigger the interests of pupils and students towards robotics, cognitive systems and engineering and to teach them project working and holistic thinking from the very beginning—especially in a country like Germany without engineering education in most schools [2]. Several application-oriented modules are developed and integrated into different grades at local schools. Pupils and students can experience and exercise themselves in programming and additionally learn a lot of technical knowledge e.g. about drive systems, cogwheels and sensors. Furthermore they will work problem oriented and acquire essential competencies like concept development and team work, which are necessary for a successful career [3].

In this project in the first module pupils in the age of 7 years appropriate in a playful way the differences and similarities between humans and robotic systems. Hence they are faced with everyday situations like the sensorial restrictions of robots. They have hands-on experiences of what it means to 'walk like a robot', 'hear like a robot' or 'see like a robot'. Essential elements of the whole concept are to consider gender specific aspects in the planning

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and accomplishment of courses and to design the courses gender equitable to get more girls interested in this field. To promote the sustained interest of girls in technical subjects it is necessary to set up continuous and integrated offers, which consider and focus on the gender specific way of learning and problem solving [4]. Gender sensitive education requires a learning environment, which allows children to advance individually. It also means to impart especially technical subject matters in a way to make advances to the learning needs of both girls and boys. By carrying our experiments, these pupils comprehend several perspectives and peculiarities of cognitive systems. Afterwards, they may use and transfer this knowledge in dealing with robotic systems (e.g. programming a robot drive round an obstacle). Problem analysis and problem solving in pupil centered learning situations is one of the prime concerns in this module. Research has shown that pupils and students wish to find more Problem Based Learning to improve the engineering study program [5]. The idea is that pupils and students should understand technical systems through other forms of teaching than school lessons, e.g. by experiencing.

2. Methods and Design of the project 'LearnING'

The approach of Problem Based Learning (PBL) has been introduced into engineering education during the past years. It is important for students to learn skills that are necessary in the 'real world' (e.g. problem analysis and problem solving, analytical skills and critical thinking, innovation and creativity and social abilities) [6]. Reciprocal it is important for the insemination of science and engineering contents to link them with Problem based aspects. PBL as innovative method teaches self-directed, sustainable, situation-oriented and transferred learning. The prior knowledge of the learner is integrated and the students make new experiences by solving multiple case. To implement Problem Based Learning, a realistic problem has to be provided to the pupils and it should be attractive for them to imagine. PBL as a method enables the opportunity of learning technical matters in a very concrete and demonstrative way and furthermore many additional skills which are essential in the future.

In the offered modules the purchase of knowledge and competences should not be done through reception and repetition but through the approach to complex and authentic problems. The modules were accompanied by tutors and for the most part structured with team- or group work. With open problem based processes the pupils should be encouraged to create creative problem solving and so for example are not frustrated when there are difficulties in technical issues.

Research has shown a superiority of PBL in 'soft' dimensions like contentment, self-confidence and application of knowledge in concrete problems [7]. Certainly the success of PBL could not be evaluated through the simple check up of grades. Several studies show advantages of PBL in comparison to conventional teaching [8], especially on soft dimensions as self-rated development of social and key competencies [9].

The Modules in primary and secondary school were divided in three Lessons (primary school 90 min; secondary school 135 min). The idea was a division in a perception-cognition-action-loop. This loop was confirmed with the approach of PBL. The modules are, for this, specified further down.

3. Robot Junior in primary school

We decided to start with the Robot Junior project in primary school. In the last years there are plenty of calls in the professional literature which stress the importance to promote boys and girls in the early age [10]. The first step was to find a cooperating school. Therefore a project description was sent to several primary schools in and around Munich. For the implementation of the first modules we selected the Grundschule II in Ottobrunn, a suburb of Munich.

Thereafter, a letter with the project description and the dates for the lessons was distributed amongst the parents to register their children for the participation. In this description gendersensible aspects were followed (e.g. speech and motivational approaches). It was planned to conduct the project with 16 participants to have one supervisor per 4 children, but the interest in the course was much higher than expected. Therefore, 21 pupils were selected from the 4th grade with 7 female and 14 male participants and it was decided to repeat the course in a year. The project was divided into three lessons, each had 90 minutes. These lessons were held on Monday in the afternoon after the regular school lessons were finished.

The first lessons started with a presentation of the research team, our university and the project. The children were invited to bring along robots they already have at home. After the introduction, they had the chance to present these robots and their abilities to the rest of the group. Afterwards, we presented some robots for educational purpose and pictures of the robots, which are developed and worked on in CoTeSys.

Next in this lesson was a card game, in which one person is in charge to explain, draw or play a certain word in a way that the rest of the group can guess this word. In order to make it more difficult some words may not be used and these are also listed on the card. The words for our game were selected from the fields of robotics and possible areas of application. The class was divided into groups of 4-5 children together with a supervisor to act as refugee. For every word the group guessed correctly, they got points.

These points were used in the next step of the lesson, where the groups were asked to tinker a robot in one area of application they had heard of in the card game, e.g. a robot to help in the garden or in the kitchen. The points they had collected in the game were used to ‘buy’ material required to create their robot.

An example of such a robot can be seen in Fig.1. In addition to the assembly of their robot, they had to think about a name, what it can do, where and for what tasks it can be used. This had to be summarized in a small story, which they had to present together with the robot to the rest of the class.

Concluding the first lesson, some clippings from the movie ‘Wall-E’, which is very well known in Germany, were presented as a base for discussion, what this robot can do, feel or perceive and how realistic it seems to them accompanied by an explanation what is possible in robotics today.

The second lesson started again with short clippings from ‘Wall-E’ to connect to the last lesson. This time the focus was set on the movement of the robot. It was discussed what different styles of movement a robot could have.

After this discussion the pupils had to play a relay. The idea was to limit their degrees of freedom in movement. On the one hand, this allowed them to see how important this movement freedom is for such simple tasks like running and handing over of objects. On the other hand they can get an idea how it is for a robot to move or why research efforts try to give robotic manipulators the same degrees of freedom as a human has. Therefore they got splints on their legs to disable the functionality of their joints. A two finger gripper without tactile feedback was simulated using two sticks. With these sticks they had to grasp a ball run towards and around a pylon and back to the start, where they had to handover the ball to the next in line. The preparations for this relay game are depicted in Fig. 2.

After this game, they had to build a robot out of bricks using an instruction manual in one hour. They could choose the design and their preferred movement concept (e.g. wheels, legs or chains). When a group got stuck tutors helped to support them in their construction process. In the end of the second lesson, one person of the group had to present their robot to the rest of the group and tell them about its capabilities.

For the game of the third and last lesson, the class was divided in groups of two. One child was the ‘camera’ and one played the gripper. The child playing the camera could instruct the other one (which was blindfolded and thereby not being able to see the objects on the table) by voice (e.g. forward, up, down, grasp, etc.) to move their hand and arms to grasp an object and lay it down in a predefined area. After five minutes they switched position. The idea behind this game was to let them experience how important the visual channel is for the perception and localisation of objects to grasp them. At the same time this should give them a feeling of how modules communicate with each other to reach a common goal together.

After this game they had to visually program the robots they had constructed last time. The kids are acting now with robots from LEGO Mindstorms. Sample tasks were to move forward and grasp a ball or to follow a black line. Additionally, they had the chance to play around with a program allowing them to give speech instructions (similar to the ones used in the game before) to the robot. Of course this was done with the guidance and support of a tutor and they could experiment also with the other kinds

Fig. 1. Girls tinker a shopping assistant robot.

Fig. 2. Preparations for the relay game using sticks to transport the ball.

of sensors (acoustic, touch, etc.). As always, they had to present their robot and its abilities to the rest of the class and demonstrate some of its functionalities.

As this was the last lesson a discussion round was started allowing them to tell us what they liked about the conducted project and what they disliked. What they liked most was the programming of the robots and the construction of these (8 votes). Furthermore, they enjoyed the games, where they had to move like a robot (6 votes). Most of the girls liked the tinkering in the first lesson (6 votes), whereas the boys (5 votes) did not like the handcrafting so much. A lot of them found the course to short in time (11 votes). Furthermore, one mentioned the degree of help from the tutors should be more equal and another one disliked the division into groups.

After this discussion session, they got the chance to get to know our research platform for human-robot interaction, which has speech recognition, speech synthesis and a touch screen to interact with the user. Finally, they got a diploma for participating successfully in this course.

4. Robot Junior in grammar school

The next project was conducted in the 6th grade of a grammar school. Therefore the Adolf-Weber-Gymnasium was selected. It is a commercial high school and located close to the campus of our university. Based on the experience of the first module in the primary school the length of the lessons was extended from 90 minutes to 135 minutes. The course was again divided into three lessons and repeated for three classes.

The first lesson started with a presentation of our university. They had the chance to present their own robots and their capabilities to the rest of the class. After discussing weather robots can have a female or male gender, we introduced different kinds of robots ranging from robots to cuddle, manufacture in industry up to service robots assisting in the household and the robots we are working on in CoTeSys. In a further discussion, they were asked to explain how they think a robot might work and how it can perceive the environment and interact with objects.

However, for the next time slot the class was divided into groups and they had to construct a robot on their own. The lesson was concluded with an introduction to speech as a natural way of communication between humans and as a useful way of communication with the robot. It should be shown that between talker and recipient sometimes there are misunderstandings that engender non-intended results. Rules and grammar should be considered in a human-human-interaction, just the same as in human-robot-interaction. After the required hardware for speech recognition and synthesis was presented, an overview about visual programming in the obeyed software was given. Using a very simple recognition grammar they had the chance to implement a basic greeting dialog.

The second module started with the group-presentations of tasks, assigned at the lesson last time. The second module has the topic 'grasp like robots'. As introduction the boys and girls made a game in which they grasp various objects with clothespins. The idea is that they realize the differences between human and robotic senses and apply their knowledge in dealing with the technical systems. In groups they transferred their experiences and proceed with challenges like telling the robot to grasp a ball or driving round an insurmountable obstacle and finding a new path to a target. The results were presented by each group at the end of the module.

As culmination of the modules in grammar school, the TU München invited all classes to visit the CoTeSys Central Robotics Laboratory in Munich. The children had the opportunity to operate with robots which are developed intramural. The aim was to show present results of robotics development and initiate discussions about future challenges in this field. Finally it was a successful completion of the modules in grammar school and the boys and girls became an insight in the life of the Technische Universität München. In Fig. 3 you can see them acting with the robot ELIAS.

5. Results

The modules in primary and grammar school were evaluated in a pre-post-survey of the children. For now the evaluation of the modules in grammar school is finished. The results demonstrate several effects of the modules. The evaluation was conducted one week before the first implementation

Fig. 3. Pupils at the CoTeSys Central Robotics Laboratory at the Technische Universität München.

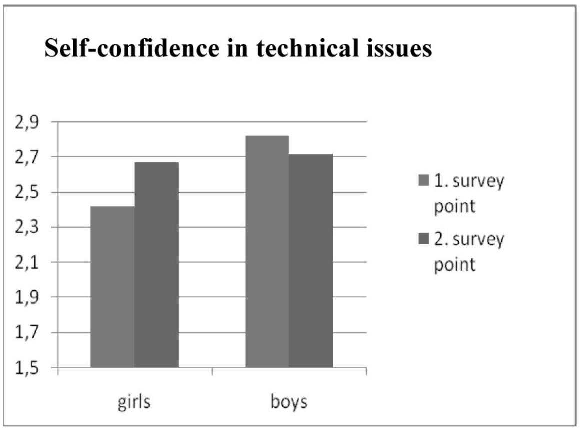

Fig. 4. 'I think I am as good as the other children in technical issues' (0 = 'I don't agree', 5 = 'I totally agree').

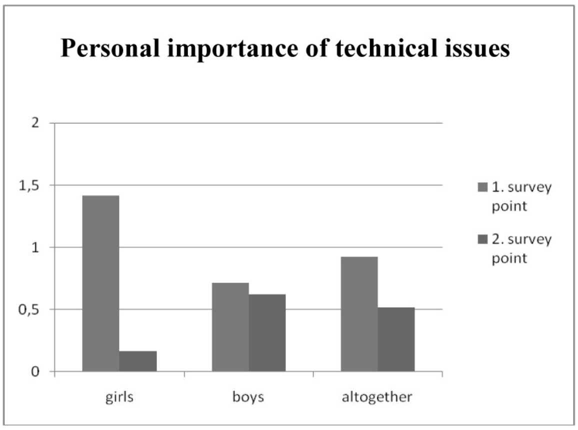

Fig. 5. 'It would be easy for me to abandon technical issues' (0 = 'I don't agree', 5 = 'I totally agree').

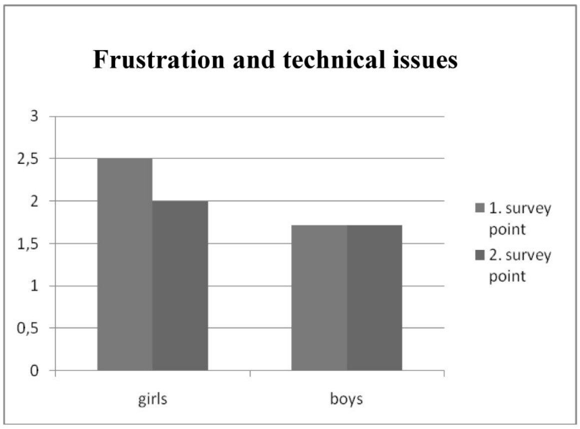

Fig. 6. 'I am immediately frustrated when there are difficulties in technical issues' (0='I don't agree', 5='I totally agree')

of the modules and one week after the last implementation. It doesn't evaluate the knowledge of the boys and girls, but for example the subjective assessment of their own capabilities. Overall we evaluated 40 children in the first survey (response rate: 83%) and 27 in the second survey (response rate: 67, 5%). At the time of the second survey a school excursion of a few boys and girls inhibited a higher rate. The possible answers have scale from zero to five, also called Likert-Skala [11].

The results show, that it was possible to achieve positive effects in the classes with the implementation of the modules. Overall the effects on girls were higher than the effects on boys. Before the implementation the average of girls thinking they are as good as others in school in technical issues was very low in contrast to the boys (2, 41 to 2, 82). After the last implementation the girls approached to the boys (2, 67 to 2, 71). Furthermore the children who have the opinion that it is no problem to abandon technical matters was minimized during the 3 weeks of implementation (girls 1, 42 to 0, 17; boys 0, 71 to 0, 62).

One goal of the modules was that boys and girls don't feel frustrated when difficulties in challenges emerge. For that reason the approach of Problem Based Learning was in the focus of the lessons. With the experiences they gain not only technical skills but also a lot of practical skills. It is most important that the pupils understand the problem and are curious to find a solution by critical thinking and self-directed learning strategies. The approach of PBL lead to better comprehension and a sustainable knowledge about topics important to their future career, because pupils and students remember the elements better when they experience them by themselves. The hands-on experiences of experiments should help to understand the applications and solution processes of the tasks. Positive effects in this case can only be seen for the girls. 'I am quickly frustrated when there are difficulties in technical issues' the average of girls who agreed was lower after the implementation of the modules (from 2, 50 to 2, 00). Among the boys, no effect could be manifested (1, 71 to 1, 71).

6. Conclusion and future work

The results of the evaluation in secondary school show, that it is possible to achieve positive effects with the approach of Problem Based Learning in schools. It seems that especially the girls are responsive to this concept and it is possible to converge them to technical and engineering issues. It would be important to build upon these experiences and results and offer gender specific accesses to technology.

The next implementation will be the 'Excellence Module' in secondary school. This Module will also be evaluated and also compared with the results of the survey in the 4th class in primary school and the 6th class at the Gymnasium. It would be interesting in which extent the effects differentiate or correspond. Additionally the Excellence Module will be evaluated with a mixed research method to provide valuable insight into educational implementations as a complement to quantitative approaches [12]. If the surveys show that it is possible to reach effects in all the different modules it would substantiate the importance to trigger the interests of pupils and students from the very beginning and that it is important to accompany the pupils along the Educational Chain ('Bildungskette') to gain consistence and sustainability in the education process of young boys and girls.

Finally it could be said that the resonance of the courses was very high. From the beginning in primary school with 21 pupils, we had to offer 3 courses with overall 48 high school students. After the first implementation in primary school the pupils and teachers asked for more modules so we decided to supply the courses a second time.

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