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COMPETENCE ORIENTED STUDY IN ENGINEERING EDUCATION – EXAMPLES FROM THE PRACTICING PROGRAMME

Sabine Fincke, Ralph Maschotta, Yi-Chun Hsu, Thomas Röckl, Clara-Sophie Roßbach, Lydia-Dorothea Augustin, Lukas Daubner, Jan Deupmann, Marius Lehmann, Anna Maria Treffurth

TU Ilmenau (Germany)

ABSTRACT

The interdisciplinary and agile processing of projects in teams increasingly characterizes the engineer's work. Problem-solving skills, creativity, entrepreneurship, and initiative, as well as the ability to engage in dialog and conflict resolution, are relevant competencies for this.
All engineering students at TU Ilmenau can work on complex interdisciplinary projects in teams (practicING projects) right from the start of their studies. Participants in these practicING projects can also experience significant steps, aspects, and system engineering methods for demand-oriented products. The paper describes the motivation, the learning goals and methodology of practicING projects from the perspective of the supervising teachers and the participating students.

Two examples illustrate the potential of the practicING concept: the projects "Wind turbine model with digital twin" and "CrossLab/ experimental ball drop test environment".
Experiences in implementing the practicING projects to date are presented, as well as limitations and possibilities for further development.

Index Terms - Engineering education, project-oriented learning (POL), digital twins, experimental environments, TU Ilmenau, system engineering, product development

1. INTRODUCTION

The way engineers work is increasingly characterized by the interdisciplinary, and agile processing of projects in teams. Problem-solving skills, creativity, entrepreneurship and initiative as well as the ability to engage in dialog and conflict resolution, are relevant competencies for this [1]. One challenge is integrating suitable action-oriented learning opportunities into engineering education so that training and the development of essential interdisciplinary qualifications, and the application of basic technical knowledge are made possible and can be experienced from the beginning of the study program.

Within the BASIC project, instruments were developed and tested to support engineering students' development, especially in the introductory phase of studies and in the basic studies. An essential component of this BASIC teaching concept is specially designed interdisciplinary projects that are worked on by student groups in the introductory study phase for 1-2 semesters. These are suitably accompanied and supported by additional practical and motivating learning opportunities. In our experience, these are effective measures to promote the understanding of subject content, the motivation to study, and the establishment of learning groups among the participants, which supports the academic success of engineering students [2].

Based on instruments from this BASIC teaching concept, the practicING program has been established at the TU Ilmenau for several years, which bundles additional action-oriented, practical learning opportunities for engineering students across fields of study. All engineering students at TU Ilmenau can carry out exciting experiments, participate in practical seminars and workshops and work on complex interdisciplinary projects in teams (practicING projects) right from the start of their studies.

This paper describes the motivation, learning goals, and methodology of practicING projects from the perspective of the supervising teachers and the participating students. Section 2 depicts the general methods of practicING projects. The outcomes of two selected projects are presented in Sections 3 and 4. Where the objective of these projects, the requirements, the methodology, as well as selected results of the projects are presented. The practicING projects are evaluated using standard evaluation sheets. The results of this evaluation will be presented in Section 5. The last section summarizes the work and gives a short outlook on further work.

2. METHODOLOGY IN PRACTICING PROJECTS

In these practicING projects, student teams develop exhibits and prototypes used in various teaching and research areas. Teachers and experts from different subject areas, workshops, and labs supervise the project work across fields. A team of student assistants provides additional support with tutorials, workshops, and the provision of materials and prototypes for experimental set-ups. The motivation of the supervising teachers is:

- To support interested students individually as early as possible and to involve them in the work of their subject areas.
- To provide them with individual learning paths and practical experience complementary to the curriculum.
- Encourage the application and understanding of the subject fundamentals taught, including motivating students to engage with them in depth.
- To give students the opportunity to gain experience in working on complex and interdisciplinary projects in teams as early as possible.
- To support the networking and formation of learning groups.
- To work on exciting and interesting projects together with the student teams. The intensive involvement of the student groups is very helpful, especially in the development of experimental set-ups for use in teaching (student-centered teaching).

Interested students of the TU Ilmenau - including first-year students - can apply to work on these practicING projects. In a personal interview with the coordinator of the practicING offers, personal motivation, interests and learning goals as well as general conditions, are discussed at the beginning. From a catalog of available project offers, suitable projects and supporting learning offers are jointly selected from the practicING project catalog. Typically, participating students work on these projects over a period of 1-2 semesters in addition to their curricular courses. Figure 1 visualizes the process and procedure for carrying out these practicING projects. Characteristics of these practicING projects are:

- The project topics are interesting and challenging for the students in terms of content. The project results are used, for example as experimental setups and exhibits for practical courses in teaching and research.
- First-year students can also work on a large part of the topics.

- The practicING projects are integrated into different subject areas and are supervised by professors or staff there. In addition, there is coordinating support of the project teams and the involved actors. Depending on the specifics of the projects and the individual needs of the project teams, this acts as a resource agent, coach, and organizational support. Professional supervisors and experts from different disciplines are involved according to the quality standards and needs. Student tutors especially support the practical tutorials and the development and support for using units and exponents for this.
- The processing of the tasks requires the application of knowledge and skills from different disciplines (for example mechanical engineering and design, electrical engineering, programming, and possibly others).
- The work is carried out in interdisciplinary teams with 3-5 students from different courses of study.

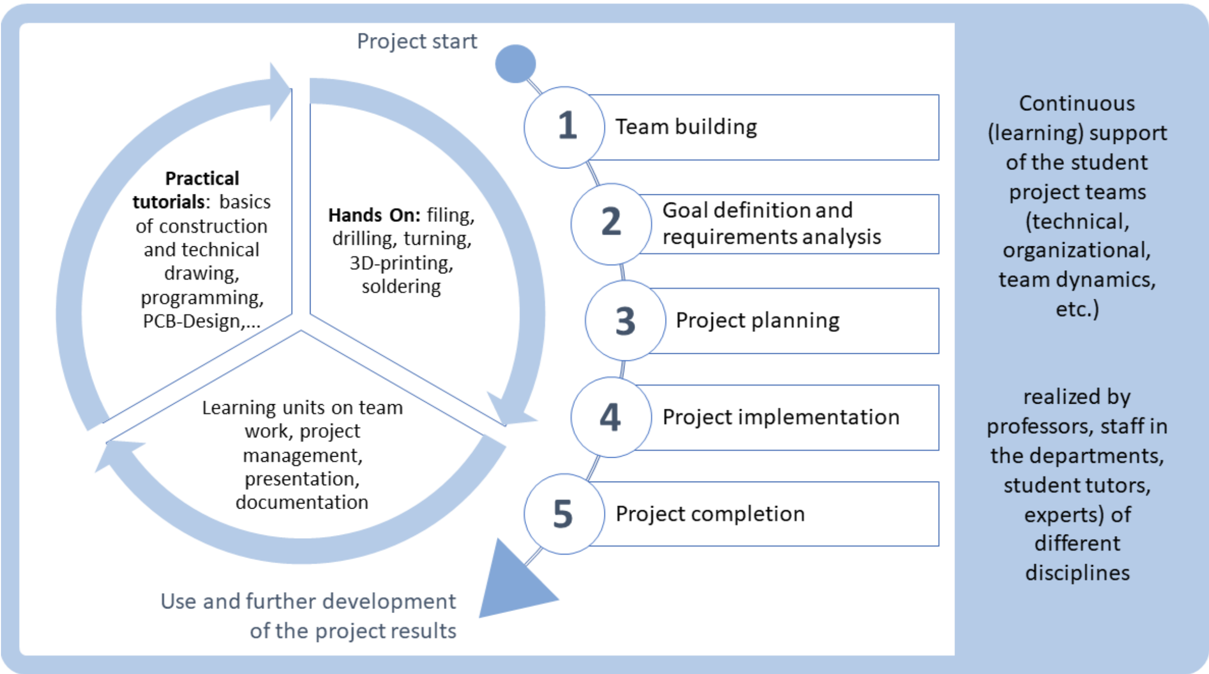

Figure 1: Implementation of a concrete practicING project from the project catalog

According to our observations, particular challenges for the project groups are often the complexity of the projects, the requirements analysis and specification of project goals, the project management processes in the team (project planning, project coordination and communication, realistic estimation of the effort for individual subtasks) and the documentation of project results and processes.

Project implementation usually involves modeling, system and component design tasks. These designed products are then to be implemented in accordance with the project objectives, i.e. developed, manufactured, assembled and tested. If necessary, test setups and prototypes for individual modules with different implementation variants are to be developed, tested and the results evaluated with regard to the project objectives. The identified project tasks are processed in parallel and partly specialized by the team members.

Participants in these practicING projects can also experience significant steps, aspects, and system engineering methods for demand-oriented products [3]. This intensive involvement of student groups in developing prototypes and experimental set-ups for teaching also supports the student-centered design of teaching and learning opportunities, positively affecting demand-oriented products in this area.

In doing so, the interdisciplinary approach requires you to familiarize yourself with methods and models from different disciplinary cultures.

Depending on the progress of the project and the time available, the project team members use introductory small learning opportunities (2-8 hours) to acquire practical skills, for example in mechanical manufacturing, 3D printing, soldering, and the design and programming of controls using different methods. The tasks of project planning, teamwork, presentation and documentation are also supported by handy learning opportunities and, if required, seminars and consultations.

Regular consultations with the technical supervisors/clients support the project teams in the processing of their projects and enable a flexible reaction to the current work status and team dynamics. Basically, the independent and autonomous work and problem solving of the project teams is encouraged. There is as much support as necessary. Appropriate digital tools (moodle course rooms, GitLab areas, etc.) are used to support the project work. The results of the projects are presented in an appreciative and public setting.

Two examples of such projects are presented in the following sections from the perspective of participating students. These are the projects "Wind turbine model with digital twin" and the project "CrossLab/ experimental ball drop test environment", which are being supervised by scientific employees of the Faculty of Mechanical Engineering and the Faculty of Computer Science and Automation.

3. EXAMPLE “FURTHER DEVELOPMENT OF A WIND TURBINE MODEL WITH DIGITAL TWIN”

3.1 Objective of the project

The objectives of the project "Further development of a functioning wind turbine model with digital twin" is to develop a functional wind turbine model with a digital twin that illustrates a concrete use case for this concept in product and system development.

3.2 Solution requirements

The solution should be robust enough to be used in teaching and at information events at the university. By further developing existing solution approaches and wind turbine models, the spectrum of use as an experimental environment for students for the teaching area of product and system development is to be expanded. Further requirements are:

- Robust construction to allow for day-to-day handling,
- Easy access and visibility of the implemented components,
- Collecting various data about the current state of the wind turbine,
- Visualization of the data as an example for a digital twin.

Only a few weeks were available for the realization of the task. The functioning exhibit was to be demonstrated at the "TU Ilmenau Study Information Day" in April 2023. We carried out the project in parallel and in addition to the regular courses during the semester. Therefore, the team was advised to take an existing model from the pool of existing exhibits as a basis to optimize it and to extend it with the components needed for the current task.

The implementation of this practicING project required the application of knowledge in the areas of mechanics, electrical engineering, computer science and product and system development.

3.3. Methodology in project processing

Three students of the Bachelor's degree program in Mechanical Engineering and Mechatronics from the 3rd and 4th semesters worked on this project, which was supervised by scientific employees of the Faculty of Mechanical Engineering. Since none of the participants had previously worked in a team over a prolonged period, we had to first establish a collaboration model on the different steps of the project. We decided for a meeting with our supervisors every fortnight, in which we presented the results of our work as well as new ideas.

In the familiarization phase, we dealt with ideas and concepts on the topic of "digital twins" and discussed them in a consultation with our supervising professor. We reviewed which application scenarios on the topic can be demonstrated with our planned model and which (sensor) data we could use for a reasonable implementation. Figure 2 visualizes our concept for the implementation.

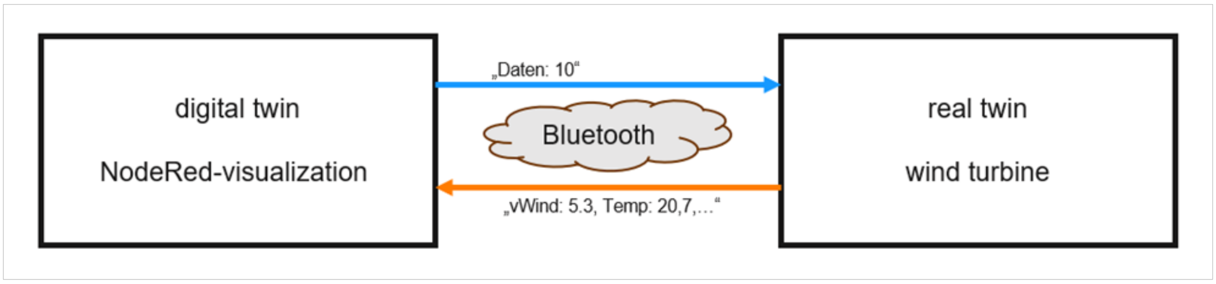

Figure 2: Visualization of our concept for the implementation, source: T. Röckl

As for the team itself it was quite difficult to establish a frequent timeslot to work on the project in presence, which meant that we had to specify individual tasks for every member based on their strengths in such a way as to achieve a later merging of anyone's contributions. We choose the three following main categories: mechanical construction, electronic work and programming which were divided into smaller subtasks.

A concept to expand an existing wind turbine model with a possibility to measure the wind speed and to provide all other measured values for further use was developed. The work on this project motivated us to deal intensively with physical relationships on the topic of wind energy, measurement methods and instrumentation for this. Since we had only little experience in dealing with the different components, we tested most of the components in smaller subassemblies to root out any problems as fast as possible without endangering the whole model.

3.4. Description of implemented solutions

The following chapter will only address some selected solutions, which represent different milestones in the realization of the project, as well as the steps leading up to them. To create the model completely from scratch would have been a time-consuming task. Therefore, as recommended to our supervisors, we chose an existing wind turbine model from the pool of existing exhibits as the basis for our work.

We tested the selected model in terms of available functionalities and limitations, as well as extension possibilities. Figure 3 (left picture) shows the selected model "Airforce 3.0", produced of the project group "Airfolg" (BASIC-model group 2020/21). This exhibit we have chosen for the extension within the framework of our project. The selected model was extended with sensors for measuring state variables such as air pressure, temperature, and wind speed. A data processing unit was implemented as well. Figure 3 shows the selected model "Airfolg" before and after the modification within the scope of our project. For a more in depth look into the implemented features, please refer to the documentation of the project

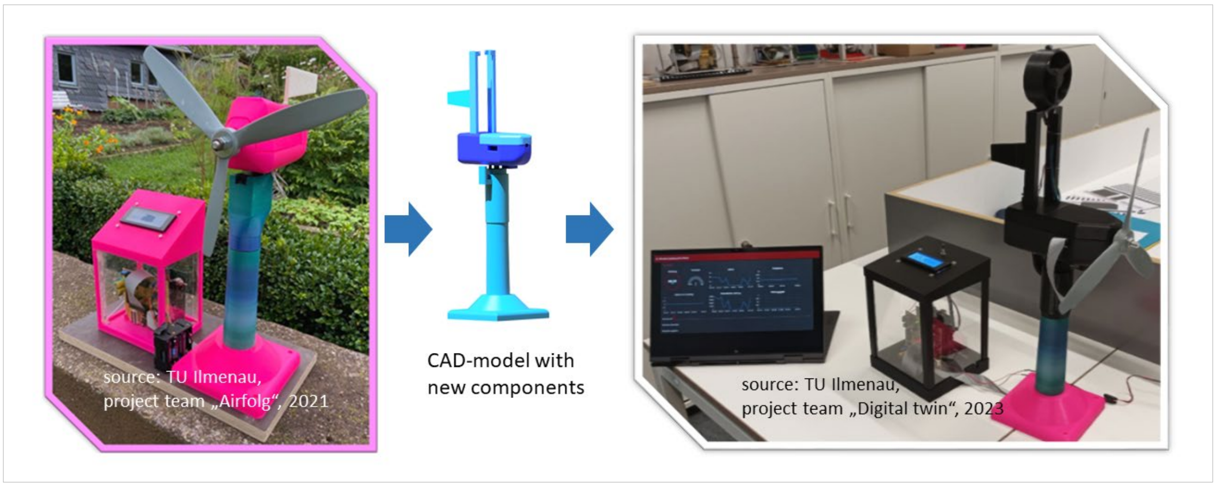

Figure 3: Selected model "Airfolg" before (left) and after the modification (right)

3.4.1. Sensors for data collection

To collect data from the wind turbine, sensors were built in the wind turbine system, including wind speed sensor, compass, real time clock, temperature and pressure sensor. These components will provide data for an analysis of the wind turbines efficiency for different conditions. Most of these sensors make use of the I2C protocol, however for the wind speed sensor we decided for a different solution.

Rather than taking a preexisting Arduino compatible anemometer, we decided to create our own solution, which is based on a cheap anemometer built for commercial use. Before disassembling the anemometer, we had to follow the technical functionality of the product, which to our understanding works as follows:

The center piece of the anemometer consists of a paddle wheel, which has 8 holes placed close to its bearing. On the opposing sides of the holes are a light emitting diode and a photodiode. These line of sight between these two diodes is therefore periodically blocked by the paddle wheel. Because a higher wind speed results in a higher rotating speed of the paddle wheel which in turn results in a faster change between blocked and unblocked states of the two diodes, there is a clear correlation between the frequency of these state changes and the current wind speed. To determine this correlation we measured the change frequency for different wind speeds. This resulted in an approximately linear correlation as seen in figure 4.

To read the light-changes we attached the photodiode in a voltage divider and read the voltage change to an analog port of the Arduino, as the photodiode is repeatedly changing from its conducting state to its non-conducting state. Since we only need the diodes, paddlewheel and bearing and didn't want to place the whole anemometer including its battery, display, and hull on the wind turbine we 3D printed some parts to attach only the paddle wheel and diodes to the gondola.

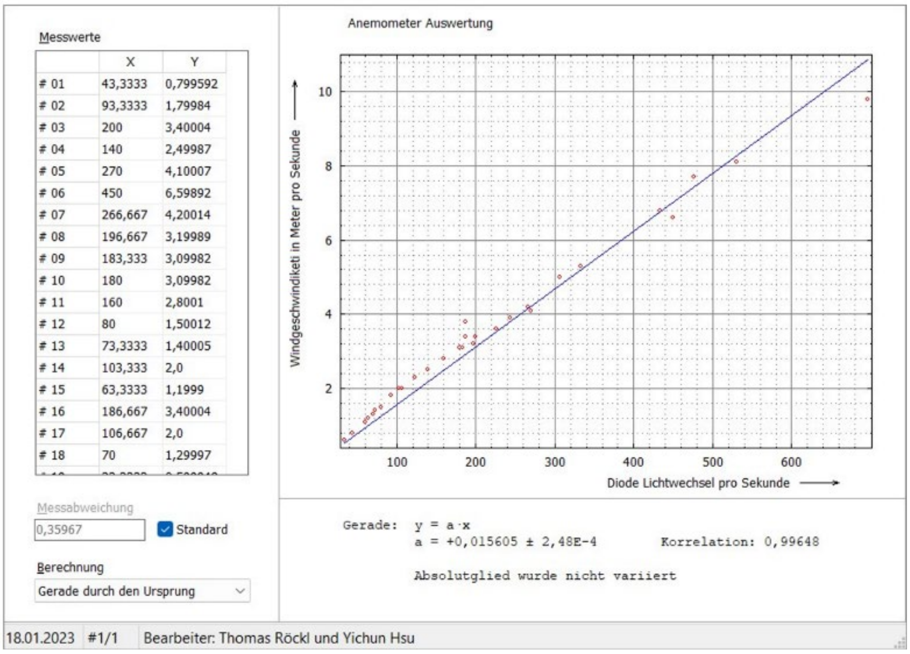

Figure 4: Measurement protocol of the performed tests with the anemometer,

3.4.2. Constructional elements

We used 3D printing processes to manufacture the individual parts. This manufacturing process requires special attention during construction. Since this manufacturing process requires special attention during construction, attention had to be paid to general design instructions such as applying chamfers and avoiding steep transitions. In addition, care had to be taken to use as little printing support structure as possible, as removing this after the print leads to a poor surface and dimensional inaccuracies. Furthermore, attention must be paid to the tolerance of the printing, which was relevant for plug-in connections, for example between the guide rods and the base plate of the housing. During the work on the project, we have designed many test parts in order to detect errors at an early stage and to work in a way that saves time and resources.

The redesign of the chassis, engine pod and the stand has not just increased the convenience of future repairs, but also provided a robust structure for educational purposes. The new engine pod implements a cover being held in place by magnets. This allows for fast opening of the engine pod and a good view and access to demonstrate the different sensors or for possible repairs in the future.

As another big step we redesigned the connection between the gondola and the rest of the turbine as follows. The first version of the wind turbine used a 180-degree Servo to rotate the engine pod. Although this makes for an easy implementation and control, this reduces the range of movement for the engine pod to only 180°. This is why we decided to build a new system using a stepper motor. The stepper motor provides a rather low resolution of 1.8° but a reasonable torque. To increase the resolution and torque even further we decided to implement a transmission consisting of two gears. The smaller gear was placed onto the engine shaft, the teeth of the larger gear were built in the wall of the wind turbine pillar. The pod is then being rotated around a small axel made from aluminum, riding on a brass bearing.

Figure 5: Insight into the redesigned gondola (left), CAD-view (middle), underside gondola with limit switches (right)

This implementation of a stepper motor would in theory provide the possibility to rotate the pod in any direction for any amount. But thereby the cables used to connect the engine pod to the rest of the wind turbine could be twisted and destroyed. To prevent such a problem, we placed limit switches on the pod's underside, which are triggered by a plastic part connected to the pillar. This reduces the range of movement to maybe 320° but constitutes a big improvement to the initial design.

3.4.3. Data presentation and digital twin

The previously mentioned collected data is stored on a micro-SD card which enables a later examination of the system. While this allows for a remote operation, only implementing this data representation would make the demonstration of the system in an educational environment cumbersome. Therefore, we implemented a digital twin of the turbine to achieve an appealing live presentation of the data, collected by the wind turbine. To establish a connection between the system and an external computer, a Bluetooth module was connected to the system plate.
The program used for our implementation of a digital twin is Node-RED[1] a software, running a server on a computer, allowing for a simple, browser-based implementation of preexisting features such as diagrams and buttons while giving the possibility to host a website to a local network. The programming is thereby achieved on a visual level by connecting different nodes, which in turn provide different functions like manipulating and sorting messages.

In the following figure 6 you can see the "flow" used in our project to visualize the live data provided by the wind turbine. The first node to the left reads the incoming messages from the com port. This messages consists of different key words and values such as "vWind: 'value'"… This message is then split into keyword-value pairs that are then being sorted by the switch node to different paths. The next "layer" consists of split nodes, these nodes reduce the incoming keyword-value pair to just the value and send the value to a diagram node. The diagram node then takes care of the data visualization.

In the bottom part of the node there are a few nodes that enable the user to write some commands to the Arduino. Since this feature is in a quite early stage this only provides a slider to change the frequency of the data being collected. This final implementation can now serve as a simple example of a digital twin as shown in figure 3 (right picture).

[1] Details you can found at https://nodered.org

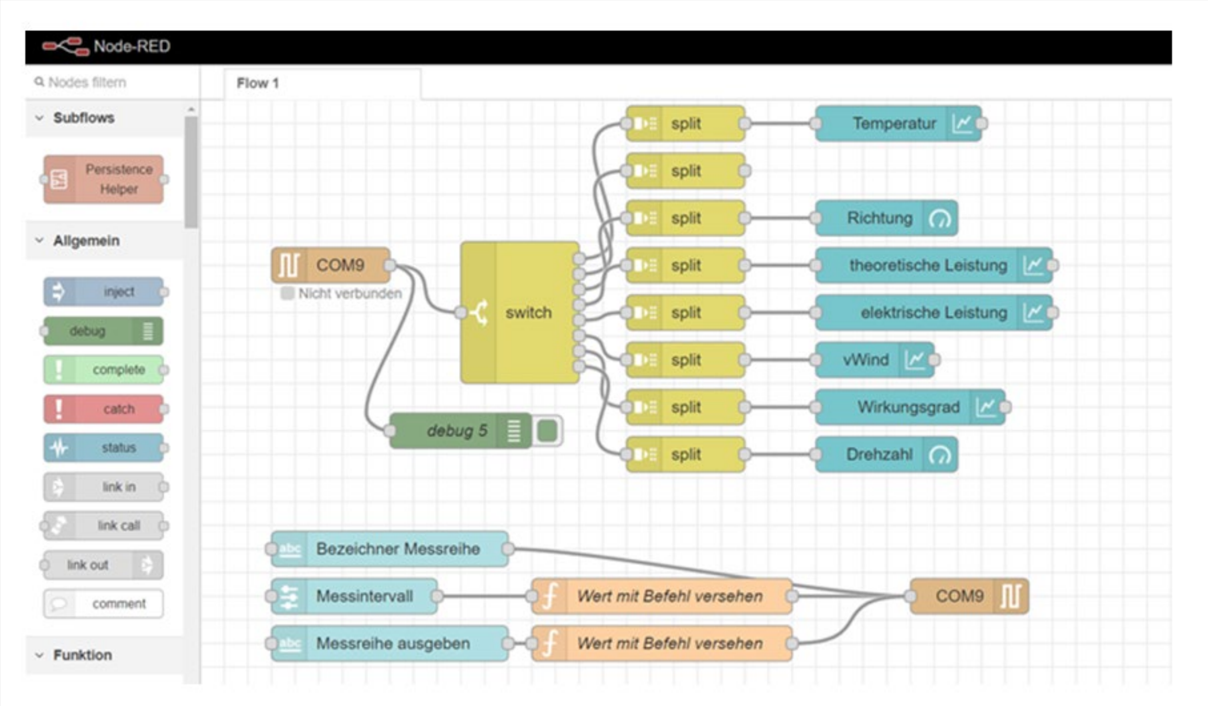

Figure 6: Node RED-Flow used to visualize the live data

3.5. Summary and outlook

After some very intensive months we as a group managed to implement many of the desired functions into the wind turbine. By doing so, we learned about the little problems that sometimes can jeopardize the success of the project. Apart from this we recognized the importance of a clear division of labor between the team members. In addition to this, we of course gathered knowledge about the respective topics we worked in, such as 3D-printing, programming, soldering and about the individual challenges and capabilities that come with the usage of these procedures and technologies. But by far the most the valuable experience we gained by presenting our interim results on a regular basis.

In retrospect there are some things we could have done differently, such as comparing different solutions and analyzing them on a deeper level before deciding for one solution and making necessary changes “on the way”. This became obvious in one of our following courses „Development methodology“ that focuses on training a more targeted approach for developing a product. During the course of this lecture, we recognized different stages in our development process in which the usage of the newly learned lessons could have helped us finding better solutions. Reviewing the project from this new perspective gave us insights and a connection to why the different approaches for finding a technical solution are of such a relevance. This is not the completion of the project, but a step on which to build upon even further.

4. EXAMPLE “CROSSLAB/ EXPERIMENTAL BALL DROP TEST ENVIRONMENT”

4.1 Objective of the project

The project "CrossLab[2]/ Experimental ball drop test environment" is based on an existing lab of a master's degree course where a ball should fall through a hole in a rotating disk using an embedded microcontroller and several sensors and actuators. This project should replace an

[2] More about CrossLabs you can found at https://cross-lab.org

existing experimental setup used for systems and software engineering education. Moreover, it aims to make further developments and to make it accessible remotely. The experimental setup "ball drop test" is used to train the systematic approach to analyzing, designing, and implementing an embedded hardware-software system

4.2. Methodology in project processing

Five students of the bachelor's degree courses in mechanical engineering and engineering informatics who are studying in the 3rd and 5th semesters are working on the first part of this project. Scientific employees supervise them. The time estimation for the whole project until a possible use in teaching was estimated at two years. Therefore, within the framework of the practicING project, only the first subproject was processed. The implementation of this practicING project requires the application of knowledge in the fields of physics, mechanics, electrical engineering, computer science, and product and system development.

For this purpose, there were continuous consultations and coordination with the specialist and organizational supervisors on the project's progress. They provided technical input. Solution proposals and requirement details were discussed. The additional necessity of contact with experts on certain topics was considered. The access to required laboratory equipment and material was discussed. The project group members had flexible access to laboratory rooms in the department. Digital tools were used to manage work results (e.g. Gitlab, Moodle course room specifically for the project group) as well as specific development tools (e.g. CAD, IDE for programming).

4.3. Solution requirements

The requirements for the solution to be developed include that it is robust enough to be used in the department's practical courses and at information events of the university. Known problems with the previous experimental setup should be solved. Another essential aspect is modularization because of the need to change the exercises every year. The controllability via the Internet (remote experiments) and the possibility of practical maintenance work are further requirements. The following major and critical components were identified:

- Base structure and framework,
- Construction of the turntable and drive thereof,
- The ball transports,
- The catching mechanism for the balls,
- The electrical system,
- The release mechanism and the ball drop mechanism,
- Separation of the balls after release,
- The modularization of the overall setup.

Therefore, the experimental setup's development and testing focuses on these components. For each of these components, the implementation in the previous experimental setup and the experience gained with it were analyzed, and requirements for the new solution were developed, discussed, and documented in discussion with the supervising department.

4.4. Description of implemented solutions

Figure 7 shows the structure used so far compared to the new setup developed in the described practicING project.

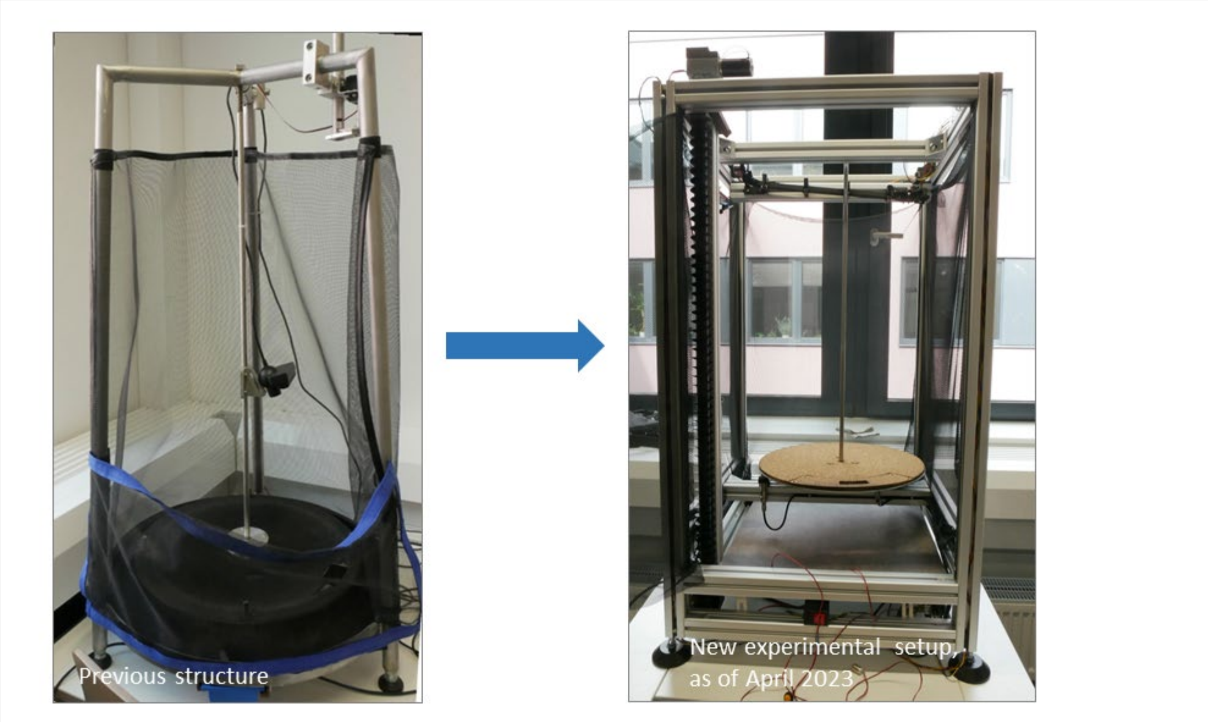

Figure 7: Experiment setup “Ball drop test environment”

The height of the new test setup is based on the previous solution (total height approximately 120 cm). The concept of the new experimental setup includes prototypes for several developed components and assemblies, e.g., for the transport of the balls, the separation of the balls, the release mechanism, and the vertical transport based on the technical principle "Archimedean screw". Moreover, the concepts of applying the developed ball drop test in the intended lectures are discussed, including the different possibilities to vary the problem definition. In the following subchapters, individual aspects of the resulting solution are explained.

4.4.1. Base structure

For the base structure of the prototype aluminum profiles are used. The profiles are in rectangular frames with multiple horizontal bracings arranged. Bolts and t-slot nuts connect the individual aluminum extrusions. This structure makes it easy to expand, stable, and simple to build. The form of these profiles allows easy attachment of other components.

4.4.2. Vertical transport (Archimedian screw)

The principle of a vertical Archimedean screw is used for the vertical transport of the balls. This module has a vertical aluminum profile and a rotating screw that lifts the balls. The cutout in the profile is used as an abutment for the balls. For stability reasons, the center of the rotating screw contains a square steel core. The screw is 3d-printed with resin in multiple sections, allowing tight tolerances. The sections slot into the steel core and are aligned by their square shape. In first tests, a much thinner round core was used which resulted in much more flexibility of the whole screw assembly to a grade where it was unusable for lifting the balls for the entire height of roughly 90 centimeters. The basic model of the screw was taken from [4] and modified to fit the application better. Therefore, the center hole of the screw that fits into the metal core was reshaped from circular to square. Figure 8 shows the creation of the prototypes for the assembly for the vertical transport of the balls.

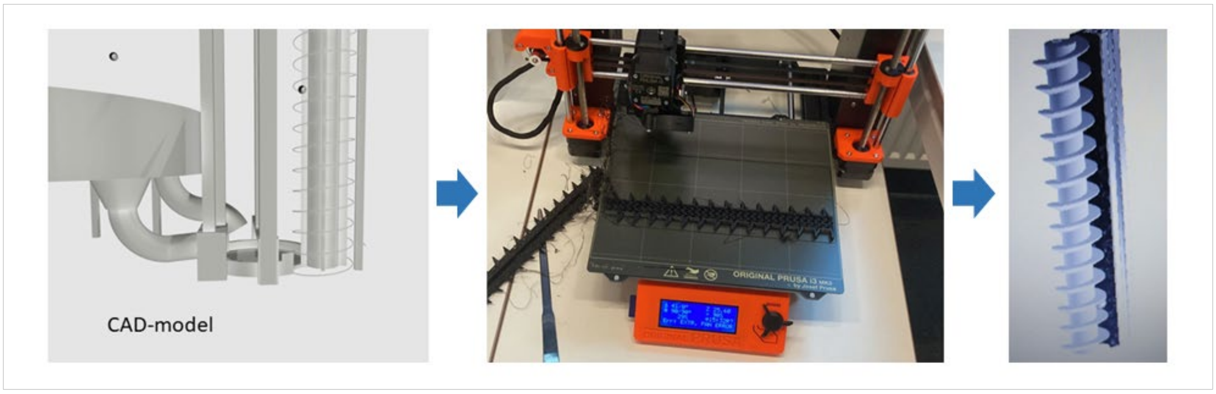

Figure 8: Creation of the prototypes for the assembly for the vertical transport of the balls

The built-in screw conveyor for the vertical transport is visible in Figure 9. The development of this assembly group was an iterative process. Construction and conception of the assembly were improved in multiple steps and prototypes. The wide variety of 3D printed prototypes was necessary to achieve planned results. Nonfunctional or no longer needed prototypes were put to professional recycling of 3D printing filament.

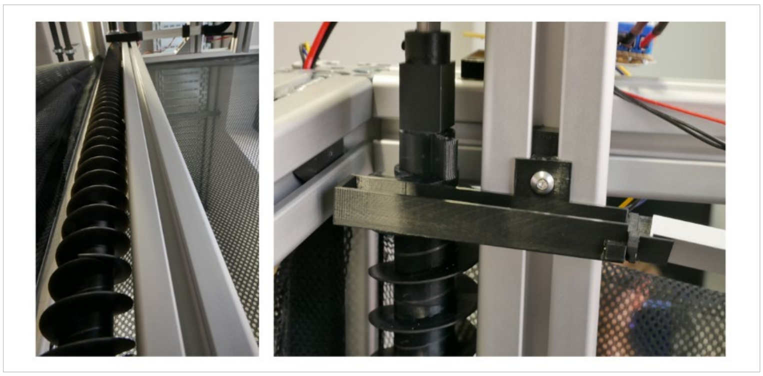

Figure 9: Built in screw conveyor (Archimedes screw principle) for the vertical transport

4.4.3. Horizontal transport

For horizontal transport of the balls, two different systems are used.

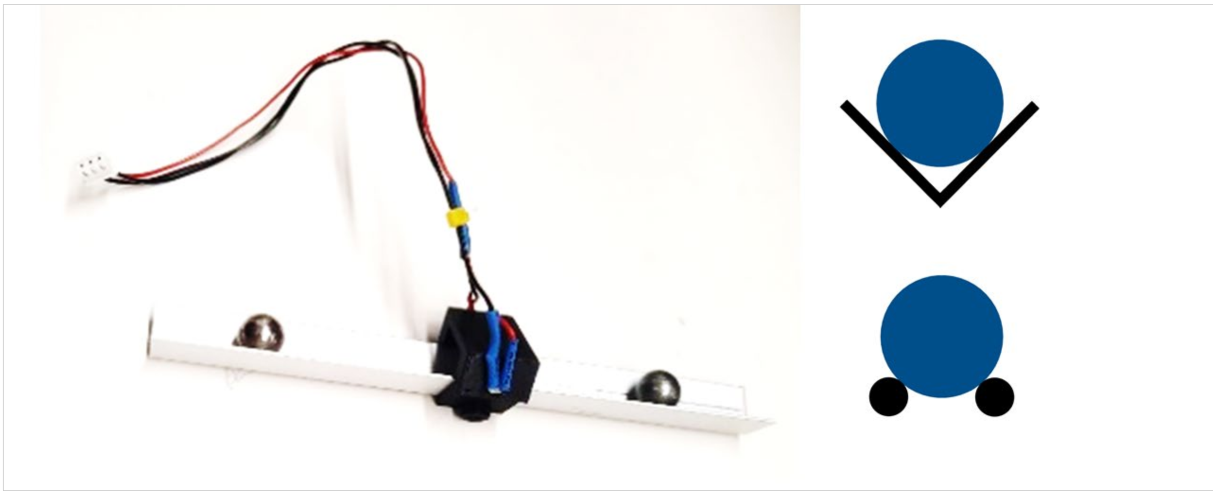

Figure 10: Developed solution for the horizontal ball transport

Figure 10 (left picture) shows the developed solution for horizontal ball transport. The transport line is made from aluminum L-profiles between different modules and other 3D-printed parts. They ensure safe transport without unwanted dropping balls for balls of various sizes. The profiles also allow the stepless addition of further attachments, e.g. light barriers. In the modules in other areas, the balls are transported on two parallel and cylindrical bars. Those bars are easier to print than the L-profiles and allow access to the balls from nearly every side. This principle is shown in Figure 10 (bottom right image).

4.4.4. Separation mechanism

For the separation of single balls out of a row, a 3D-printed disk is used. The disk is mounted on a servo motor and has a circular cutout with a radius slightly bigger than the radius of the ball. When the disk rotates, it grabs a ball with its cutout and pushes it forward on the transport lane while keeping the following balls in position.

4.4.5. Release mechanism

For the releasing mechanism of the prototype, an electrical magnet was chosen. The magnet is placed above a hole in the transportation lane and fitted with a centering cap. When the magnet is turned on, it pulls up a ball and stops it. Later when the magnet is turned off again, the ball can fall freely and without swirling. The releasing mechanism also has a rotatable arm beneath the magnet, on which the balls can rest if they roll in when the magnet is turned off. The arm ensures safe pick up of the ball. This release mechanism ensures the ball drops on a straight path downwards in the specified moment. Figure 11 shows the 3D-printed release mechanism together with the separation mechanism.

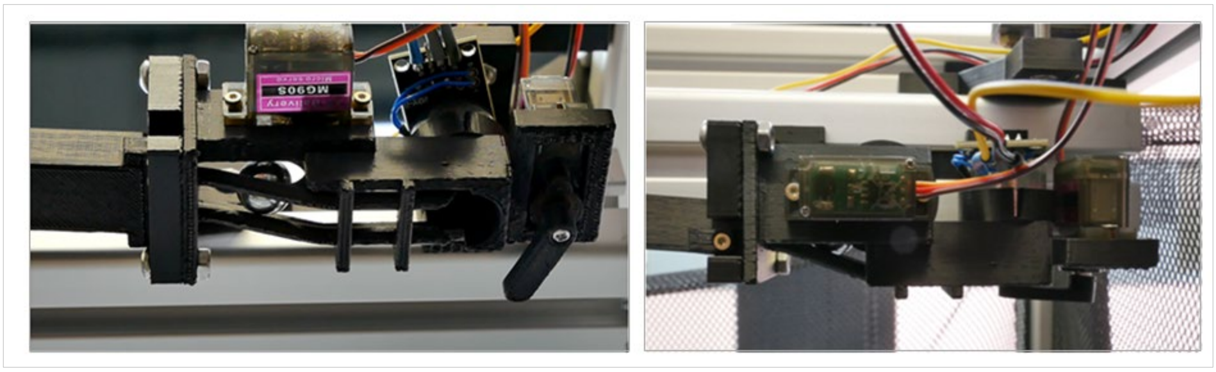

Figure 11: components for separation and release of balls

4.4.6. Modules

Right in front of the release mechanism on the ball’s way are 3 nine centimeters long modules placed, which are fully interchangeable. In the future, they can be replaced by other modules of the same size with additional sensors and actuators. With this possibility, the exercise can be altered every year.

4.4.7. *Rotary disc*

The rotary disc is an aluminum plate with a cutout through which the balls can fall freely. On top of the plate is a layer of cork that dampens the sound of the balls hitting the disc. The disk is mounted to a rotatable axis. The student must determine the disk's position and rotational speed with the help of two sensors underneath the turntable. In the turntable, two small magnets are embedded together with a Hall effect sensor that can be used to determine the position of the disk. The underside of the disk shows a pattern of 12 black and white sections. A sensor that gives an output of high reflectivity is used to determine the time between two sections passing to calculate the speed of the disk. Figure 12 shows the top and bottom of the rotary disc (middle and right picture).

Figure 12: Electrical components (left picture), top and bottom of the rotary disc (middle and right picture),

4.4.8. Electrical system

The electrical System consists of a power supply and two stepdown converters to provide three different voltages to power different components. This electrical system can provide more than enough power on the current prototype and will likely get replaced with less capable systems for more production assemblies.

4.5. Summary and outlook

This project gave us a good insight into planning and working on bigger projects. We students also learned how to plan and implement bigger projects with longer timelines, which requires thorough monitoring of time passed and progress to ensure being within schedule. Another big learning point was working in a group of 5 and with multiple external people, which required communicating about every failed or successful test with the other group members so that they all knew the current state. In the meantime, we had to realize there were problems in many places that no one had expected. For example, the motor triggers electrical interference in our signal cables. We also gained good experience in digital modeling e.g. CAD and circuit design.

In the future, the prototype will be improved, and the last errors will be corrected. Also, we will work on making the prototype accessible remotely. After that, the prototype will be duplicated for use in education. Later we or another group can develop new modules and other additions to the setup to change the exercises.

5. RESULTS AND EVALUATION

The examples of implemented projects described above illustrate the concrete processing of interdisciplinary practicING projects. It becomes clear in the description of the project work and results achieved what experiences the participating students have gained in the process. It is part of the practicING concept that students are also involved in the supervision and support of the practicING offers. They regularly have the opportunity to present their project work at events of various kinds and to pass on the knowledge they have acquired to young people and students. An online survey of students was conducted to evaluate the practicING offerings. This was directed at students of the TU Ilmenau who have used practicING offers in recent years and support the implementation. Results of this survey are presented in this section.

5.1 Design of the survey and cohort of participants

The entire survey contains 39 items in the categories "Personal information", "Used practicING offers", "Participation in the implementation of practiNG offers", "Working methods and feedback", and "Evaluation and feedback". The objective of the survey was to obtain information about the extent to which the practicING offerings and methods have contributed to supporting the objectives described in Chapters 1 and 2. In addition, feedback is expected on the quality of the offers used, particularly successful activities and possibilities for improvement[3].

30% of the students contacted who are still studying at the TU Ilmenau took part in the online survey. The question „In which degree program are you studying/studied during your practicING participation or involvement?" was answered with Mechanical Engineering (B.Sc.), Mechatronics (B.Sc.), Computer Engineering (B.Sc.), Electrical Engineering and Information Technology (B.Sc./Diploma), Biomedical Engineering (B.Sc.), Applied Media and Communication Studies (B.A.) and Industrial Engineering (B.Sc.). The majority of practicing users were in their 1st, 2nd or 3rd semester of university when they started using the practicing services. Most of the participation of the practicING offerings took place in the last one or two years, some even before. In the following sections, selected results of the survey are presented.

5.2. Used practicING offers

Figure 13 shows the answers to the question "What was/is your motivation for participating in the practicING offers?". The primary motivation for the students was the basic internship or course credit points but also the gain of experience in practical activities. Moreover, learning new things, practical application of theoretical knowledge, and general work on exciting projects were reasons to enroll in practicING.

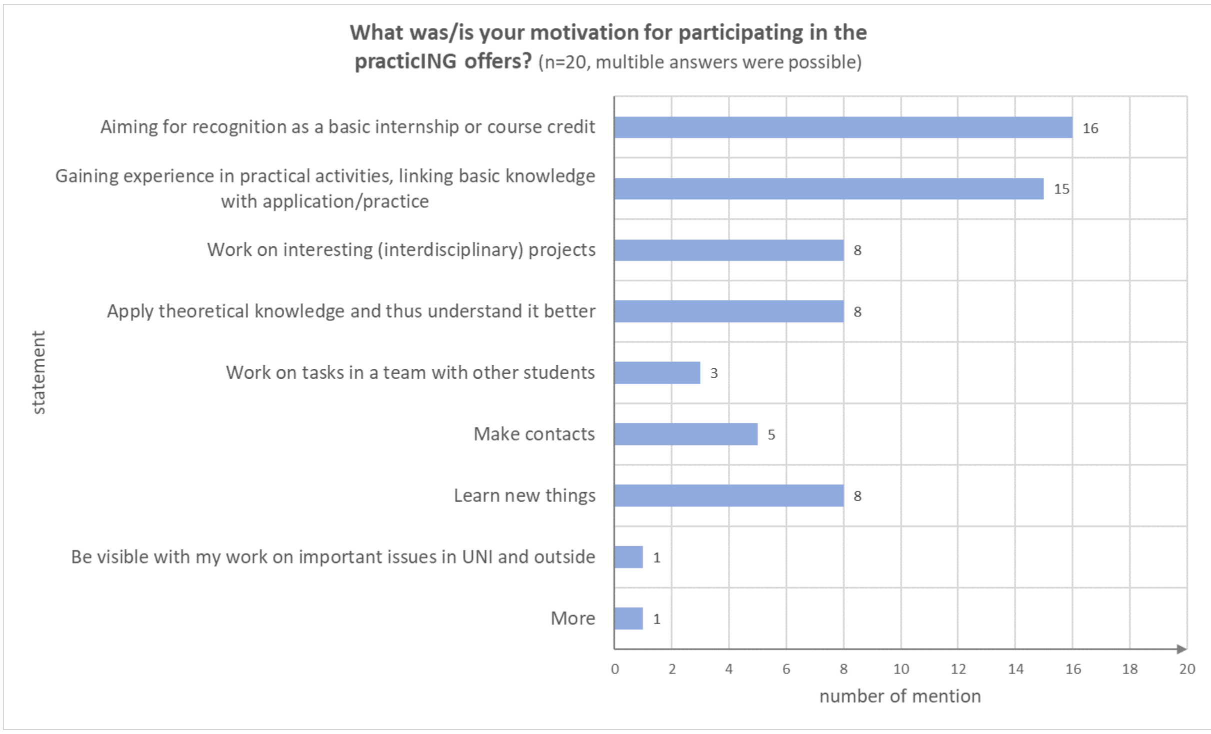

Figure 13: Motivation for participation in the practicing offers

Most respondents (88%) indicated that they had worked or were working on interdisciplinary projects. 12% used only small, hands-on, supplemental learning opportunities. Figure 14 illustrates which hands-on learning opportunities were and are used particularly frequently to

[3] Details on the survey can be found at www.tu-ilmenau.de/practicing .

support project work. A large percentage of respondents (82%) reported having worked on "Fit for Performance" learning units (team building, project planning, presentation, documentation), while 18% had not.

Figure 14: Used practicing offers

5.3. Participation in the implementation of the practicING offers

Figure 15 impressively shows the variety of activities in which students are involved in the implementation of the practicING offerings. In our experience, these activities, combined with professional support, offer enormous potential for the further individually tailored advancement of the students involved.

In these tasks, the students involved are challenged with their subject knowledge and in methodological-didactical form. In this context, the students consciously change their perspective, i.e. learners become teachers and colleagues. These tasks require competencies that were previously unknown to the students. In particular, this change of perspective, combined with the task of knowledge transfer, offers students of engineering courses an increase in competence, for example in the pedagogical field and target group- oriented public relations, which are not part of a traditional engineering course. Furthermore, students deepen their own expertise by preparing and sharing knowledge with fellow students and interested young people. Students experience direct feedback and appreciation of their achievements, which is not expressed in ECTS, but above all strengthens personal recognition. These aspects support motivation for the profession and for the successful complete a course of study.

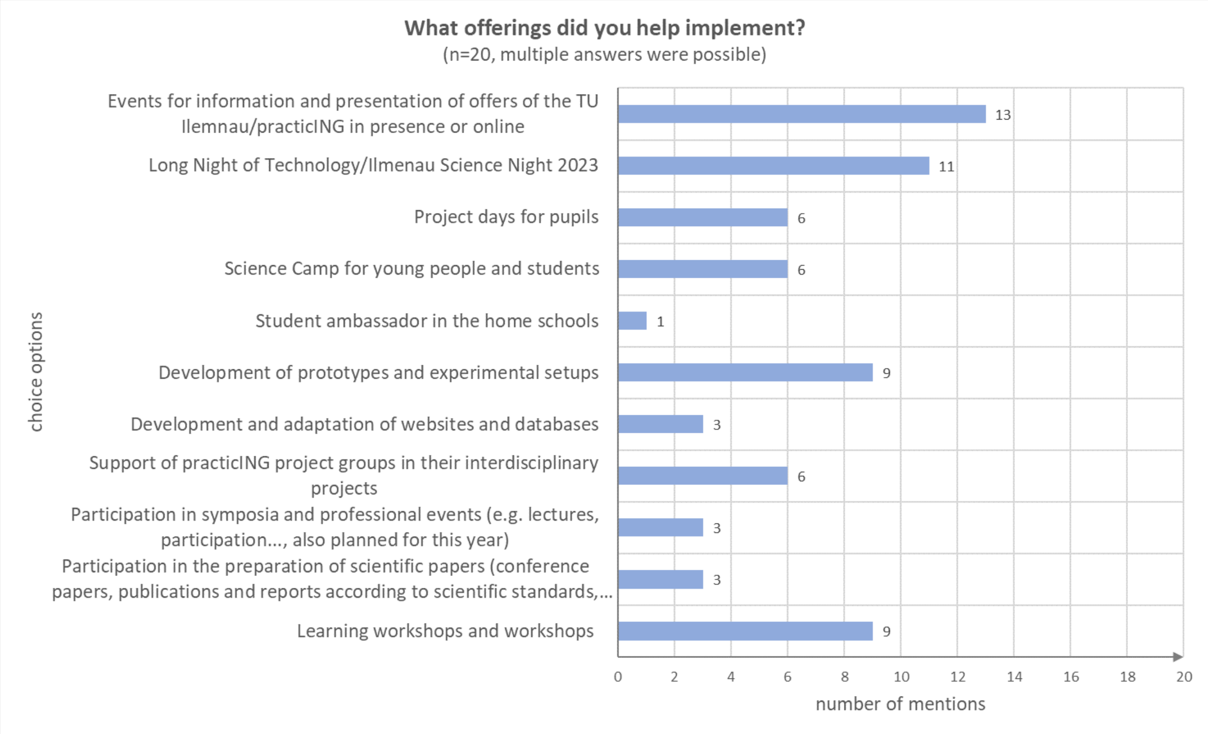

Figure 15: Offerings in which the students have collaborated

5.4. Working methodology and feedback

Student feedback on the questions related to teamwork and knowledge transfer can be found in figure 16. The answers make it clear that the practicING offerings are very well suited for gaining experience in team and project work.

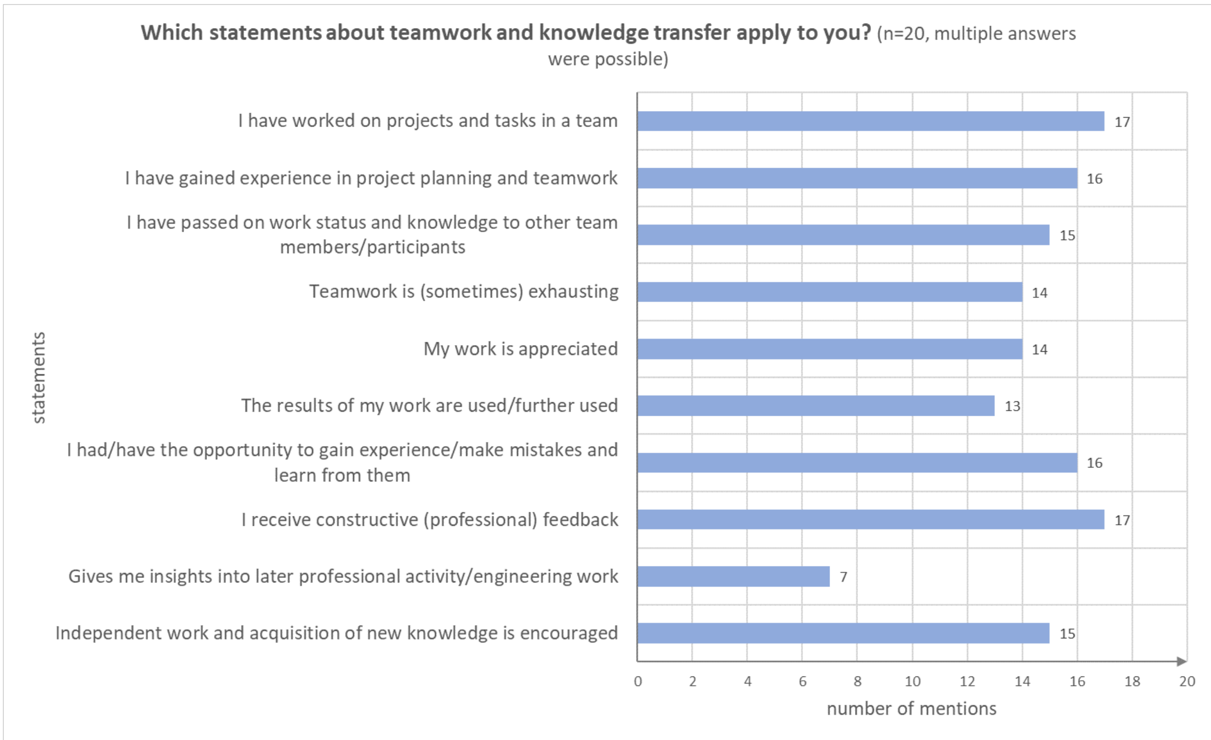

Figure 16: Answers about teamwork and knowledge transfer

The answers show that important practicING approaches (constructive feedback, the possibility to make mistakes and learn from them, results of the work are needed and used) are also perceived by the participants according to the concept.

Figure 17 shows the answers to the question “Which experiences did you find particularly exciting? Which ones did you benefit from? Which experiences led to a better understanding of learning content in later courses?”.

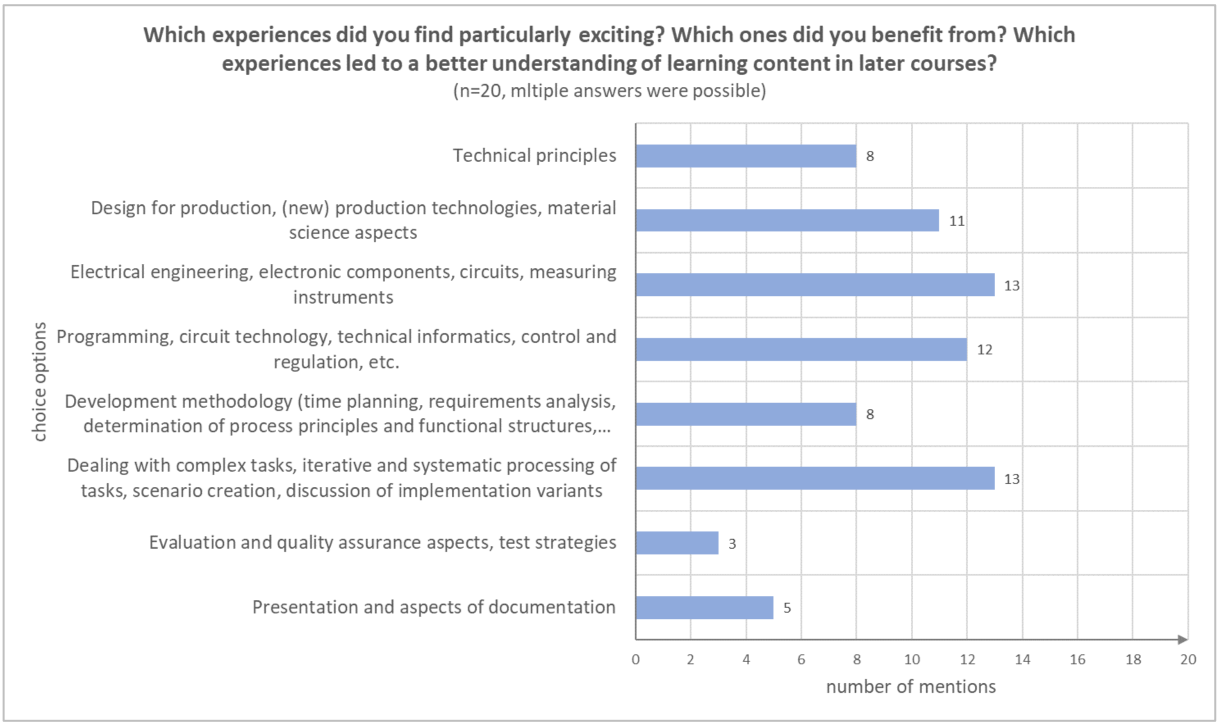

Figure 17: Responses regarding particularly useful experiences

Particularly frequently mentioned are: Dealing with complex tasks, practical experience in electrical engineering, with electronic components and circuits and measuring devices, programming, production-oriented design and new manufacturing technologies. To the question "Have you found that your knowledge and methods are not yet sufficient in some areas and are you motivated to acquire them-if necessary later? 9 students answer with "yes" and 9 students with „part/part“.Figures 18 and 19 illustrate opinions regarding collaboration with students from different fields of study as well as staffs.

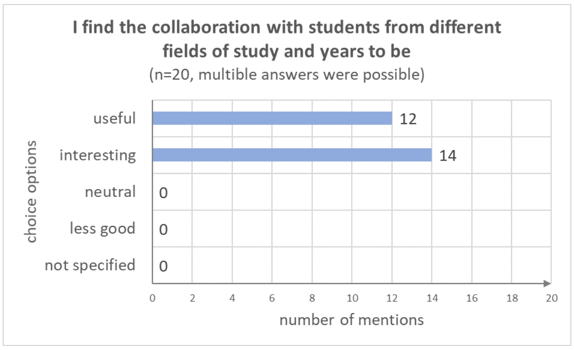

Figure 18: Collaboration with students from different fields of study

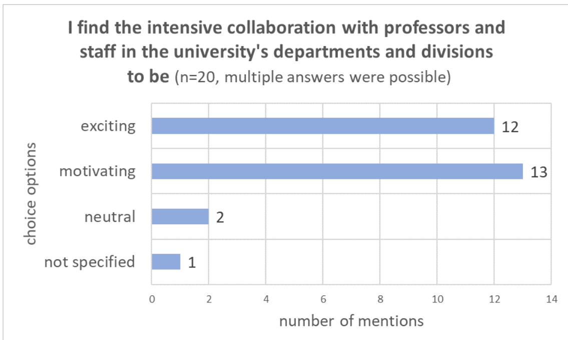

Figure 19: Collaboration with professors and staffs

Respondents indicated that they found the collaboration with students from other programs useful (12 mentions) and interesting (14 mentions). They also stated that they found the intensive collaboration with professors and staffs exciting (12 mentions) and motivating (13 mentions).

5.5. Evaluation and feedback

The respondents rated the professional and organizational support of the practicING offerings exclusively as good and very good. Most participants answered "often" to the question "I received guidance, help, and feedback when needed" (17 mentions). To the question "What was the best thing about the practicING offers came answers like:

- Insights into various topics,
- Direct close cooperation also with professors,
- Good practical supplement to theoretical basics from the early semesters,
- Essential skills for engineers are tackled right at the beginning: CAD, manual work (soldering, turning, milling, filing, drilling, etc.), programming (microcontroller),
- Start right away with your own design work as part of the practical project: Learning by doing,
- Getting a good feel for what it means to be an engineer and what requirements you should be able to handle,
- Receiving constructive criticism from people with special expertise (e.g. in the creation of operating instructions), The opportunity to go into workshops and manufacture the components yourself, Gaining experience around 3D printing,
- Insight into different areas (programming, coordination of people, electrical engineering, interaction of components, 3D printing, work in the specialized areas, professional writing....),
- I really liked the practical work or the practical reference,
- The workshops and additional offers were particularly successful.

The opinions of the students listed here illustrate the diversity of individual impressions and experiences when using the practicING offerings. The answers show that the offers correspond to the current needs of the participating students with regard to gaining practical experience and promote curiosity and motivation to learn and try out new and engineering-specific things.

6. RESULTS AND OUTLOOK

The paper describes, how the practicING program bundles action-oriented, practical learning opportunities for engineering students from various disciplines. All interested engineering students can carry out exciting experiments, participate in practical seminars and workshops and work on complex interdisciplinary projects right from the start of their studies. This paper presents the motivation, learning goals, and methodology of the practicING projects in general and illustrates the concept's potential by describing the outcome of two example projects.

The results of the evaluation indicate that the practicING offers are suitable throughout the course of study to support the development of engineering-specific competencies and individual learning paths. However, the conditions for success are available time slots that can be used by students for such and other supplementary learning opportunities. In addition, individually oriented supervision of students and project teams by staff and supportive student tutors are important conditions for the success of these offerings.

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CONTACTS

Sabine Fincke	email: sabine.fincke@tu-ilmenau.de
Dr.-Ing. Ralph Maschotta	email: ralph.maschotta@tu-ilmenau.de ORCID: https://orcid.org/0000-0001-8447-3996
Yi-Chun Hsu	email: yi-chun.hsu@tu-ilmenau.de
Thomas Röckl	email: thomas-christoph-ludwig.roeckl@tu-ilmenau.de
Clara Sophie Roßbach	email: clara-sophie.rossbach@tu-ilmenau.de
Lydia Dorothea Augustin	email: lydia-dorothea.augustin@tu-ilmenau.de
Lukas Daubner	email: lukas.daubner@tu-ilmenau.de
Jan Deupmann	email: jan.deupmann@tu-ilmenau.de
Marius Lehmann	email: marius.lehmann@tu-ilmenau.de
Anna Maria Treffurth	email: anna-maria.treffurth@tu-ilmenau.de

