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Published in:
Engaging Engineering Education

Publication date:
2020

Document Version
Publisher's PDF, also known as Version of record

Citation for pulished version (APA):
Block, B-M., Haus, B., Stenken, A., & von Geyso, T. (2020). Interdisciplinary engineering education in the context of digitalization and global transformation prozesses. In J. V. D. Veen, N. V. Hattum-Janssen, H-M. Järvinen, T. D. Leat, & I. T. Dam (Eds.), *Engaging Engineering Education : Books of Abstracts - SEFI 48th Annual Conference Proceedings* (pp. 617-627). European Society for Engineering Education. https://www.sefi.be/wp-content/uploads/2020/11/Proceedings-2020-web.pdf

INTERDISCIPLINARY ENGINEERING EDUCATION IN THE CONTEXT OF DIGITALIZATION AND GLOBAL TRANSFORMATION PROCESSES

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Conference Key Areas: *Interdisciplinary engineering education, Sustainability*
Keywords: *theory-based engineering course design for non-engineering students, educational reconstruction, practice-based learning concepts, rapid prototyping, maker culture*

ABSTRACT

Global transformation processes and sustainability issues lead to a rapid increase in problems at the boundary between technical and non-technical disciplines in higher education. Furthermore, new fields of work emerge due to the digital transformation. Graduates need to be prepared to identify and describe problems and to develop appropriate solutions in teams in order to contribute to change processes related to the future in a smart world. Engineering sciences have to take up the challenge to provide suitable educational programs for a broader target group, i.e. non-technical students, especially in light of the current shortage of qualified specialists. This paper contributes twofold to that discourse; (1) by a novel theory-based teaching and learning concept for an engineering course for bachelor students of non-engineering disciplines (e.g. sustainability sciences) and associated empirical findings of implementation, and (2) by innovative project-based laboratory experiments that encourage interdisciplinary approaches. As a specific contribution to the innovative practice of engineering education, part (1) outlines the student-centered lecture scheme "Electrical and Automation Engineering" (four semester hours per week). The framework-based development, the objectives and the didactic design of the bachelor course as well as the engineering key topics in the context of smart technologies and sustainability are presented. Part (2) details novel practices in the area of engineering education by two specially designed lab experiments. Starting from the theory framework, the paper contributes to a theoretical understanding and educational practice of engineering courses designed for a specific group of students at the crossroads of engineering and other disciplines.

1 INTRODUCTION

In today's world, which is characterized by global transformation processes and sustainability issues, engineering sciences continue to be an important shaper of these change processes. In addition to digitalization as a major influencing factor, further changes lead to challenges and modified framework conditions that the engineering sciences have to face [1–5], including:

- changing requirements for the professional field, the subject content and the competence development of students,
- increase in complex global problems, dealing with constant change,
- changes in the institutional framework and in the roles of universities and teaching staff,

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- dealing with diversity, heterogeneous target groups, opening up new target groups to secure young talent and developing interdisciplinary solutions,
- need for new teaching and learning arrangements (including digital, individualized, collaborative).

Furthermore, new fields of work emerge due to the digital transformation. Those novel fields of work can be characterized by high degrees of complexity and responsibility as well as the need for a broad knowledge on topics where disciplines intersect. Graduates need to be prepared to identify and describe problems and to develop appropriate solutions in teams in order to contribute to change processes related to the future in a smart world, cf. [1, 3, 6].

Engineering sciences have to take up these challenges to provide suitable educational programmes for a broader target group (e.g. non-technical students); especially in light of the current shortage of qualified specialists. In this context there is a constant demand for research on theory-based development of targeted didactic concepts for this specific target group and associated empirical findings of implementation.

This paper contributes to that research discourse on transformation processes in engineering education. In section 2, the model of Educational Reconstruction as a theoretical framework for a student-centered conception and implementation of engineering lectures for non-technical students is presented. Based on the framework, section 3 introduces the theory-based lecture scheme ”Electrical and Automation Engineering” as a contribution to the translation of educational research to practice. The objectives and didactic design of the bachelor course are shown as well as the curricular implementation. Section 4 presents two innovative project-based laboratory experiments that focus on interdisciplinary teaching in the engineering sciences in the context of digitalization. Finally, the paper outlines the experience of the first implementation of the course in wintersemester 2019/20 and further discusses future perspectives within the discipline of engineering education and research.

2 THEORY-BASED FRAMEWORK AND GOALS

The research objectives in this paper are standing for both theoretical understanding and educational practice. With a focus on the engineering sciences, it deals particularly with the theory-based course-design for students who do not come from a technical field. Furthermore, the presented framework for student-centered course design in engineering is adjusted to constant change (e.g. changes in occupational fields and subject contents, changes in institutional frameworks, increasing complexity and globalization), and to heterogeneous groups of students. The framework is based on Educational Reconstruction, see [10]. The model of Educational Reconstruction is a research framework that is used in scientific education, as in [7, 8]. It is still common in engineering sciences to base the teaching on technical matters. Other aspects like the teaching objective or the perspective of the learners are often considered secondary. To counter this imbalance in the didactic work and to take the students seriously as an active starting point for the construction of knowledge, the model of Educational Reconstruction could be a major help, see [9, 10], especially for that specific target group.

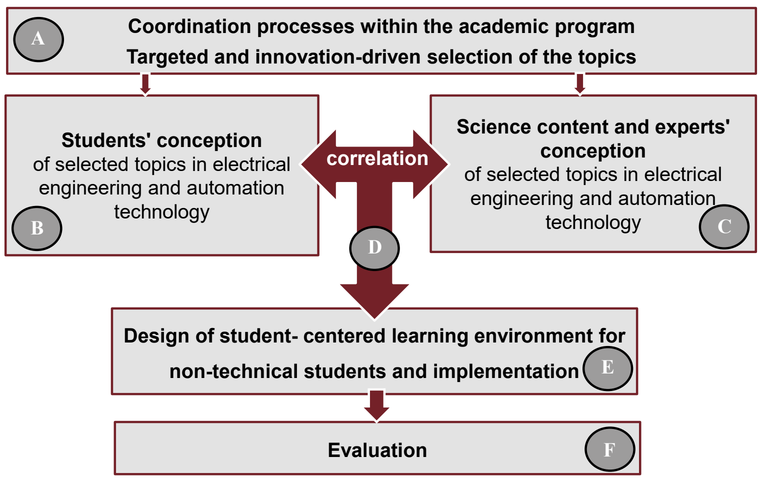

Fig. 1. Model of Educational Reconstruction with focus on engineering and automation technology and non-technical students, based on [7–9]

In the model of Educational Reconstruction, scientific concepts and the perspective of the learners are related to each other. A conclusion about the design of student-centered learning environment is drawn from the comparison. This is particularly important for the didactic construction of engineering courses for non-technical students. In this case, it is a challenge that the majority of students are new to the field and not familiar with it. Therefore, it can be concluded that teaching contents may not simply be dictated in a scientific manner but have to be ”created” in a pedagogically useful manner through the conception of the learners themselves, as in [11].

By constructing teaching contents in this way, there are three elements that interact as teaching methodology triplet, [10, p. 4]: the students' perspectives, the clarification of experts' conceptions, and the didactical structuring. As result, a theoretical guided course concept is derived. Fig. 1 shows the generic model adapted for the field of engineering sciences and non-technical learners. To implement the model, the research steps A to F must be completed. The model in all its sequences provides research data that is used for the consistent implementation of study-centered education for non-technical students in engineering education. In the following, these will be described in detail.

At first, the course contents must be coordinated within the curriculum. The goal is *a coordinated and innovation-driven selection of content* that fits the challenges of digitalization and Industry 4.0 (step **A** in Fig. 1). Then, the experiences and the students' conceptions about electrotechnical concepts, particularly in context of Industry 4.0, have to be collected (step **B** in Fig. 1). What view do they have about these concepts and where do they make connections between the theoretical foundations and the practical implementation? The learners' conception is collected by students' self-reports. Besides background on technical subjects, socio-demographic data, and motivation to study a technical minor, the report contains questions for the non-technical students about possible career perspectives. At the same time, the scientific clarification is being prepared (scientific content/experts' conception and correlation, step **C** in Fig. 1). The industrial innovations and scientific key concepts have been identified and analyzed from industry applications and the literature, e.g. [12–17]. What are new industrial developments due to the digital transformation? What do the concepts look like in science? What scientific models exist and where can coherences and limits of the imagination be found? The technical clarification identifies the similarities and the differences of the experts' conceptions and determines which theories they are based on. In step **D**, the learners' understanding about the technical theory is reflected. That way differences between scientific perspectives and the perspectives of the learners are disclosed. Are there existing correspondences to the scientific model? At which point can you build on the learners' conceptions? As a result of this correlation, research-based findings exist that prescribe what has to be regarded while introducing terms, concepts, and models to the special target group of non-technical students. Furthermore, with the goal of fostering students' learning process, the result of the correlation proposes the appropriate course design that is most likely to be successful. The findings of the analysis phase (**A** to **D**) lead to the theory-based development of the design of student-centered learning environment (step **E** in Fig. 1). This design phase of an engineering course for non-technical students is presented in section 3. Further influences are theoretical frameworks like constructivist learning theories, e.g. [18, 19], and gender theories focusing on STEM education, e.g. [20–22]. As a final evaluation (step **F** in Fig. 1), in the first implementation phase we gathered student feedback on the course. The feedback from the students will be incorporated into the process of improvement of the course design. In the next development stages, an evaluation in mixed-method design is planned to get empirical evidence about the effectiveness of the course.

Based on the presented phases of the model, the theory-based development of the teaching and learning concept ”Electrical and automation engineering” for non-engineering bachelor students is now illustrated. This bachelor course (4 semester hours per week) is one of six courses of the minor (i.e. secondary subject of the study program) ”Engineering Fundamentals”, among others Mechanical Engineering, Information and Communication Technologies. The minor ”Engineering Fundamentals” provides an overview of the most important technologies and technology-oriented processes in the manufacturing industry. This minor can be studied in combination with different majors, e.g. Economics, Environmental Sciences and Digital Media.

In times of continuous mechanization and digitalization, a basic understanding of technology is becoming increasingly important in order to actively shape transformation processes at the interface of society, economy, technology and the environment. As described in the introduction, interested non-engineering students have to be empowered to deal with the most important technical disciplines in context of industrial systems, too. The general objective of the new course is to impart a basic understanding of technology in a context relevant for engineering and professional practice. Furthermore, it aims at the following targets:

- imparting knowledge and skills of selected technical basics in electrical engineering, metrology and sensor technologies (including optics) as well as control and drive systems,
- developing close links between basic technical knowledge and possible applications in technical innovations, use of selected examples of systems (e.g. e-mobility, smart sensors, VR/AR), and
- improving the transfer between theory and practice by implementing hands-on sessions ("smart" lab sessions) as well as use of selected digital approaches of teaching.

The strategy for pursuing these objectives is set out in the next section.

3 NOVEL THEORY-BASED TEACHING AND LEARNING CONCEPT

In correspondence to the model of Educational Reconstruction, the development and implementation of the learning environment is presented below. As mentioned before, the student-centered course design originates in constructivist learning theories, e.g. [18, 19] and gender-sensitive teaching concepts, as in [20–22]. The framework-based course design process mainly focuses on two targets. First, the didactic layout of the course should optimally foster learning processes in the highly diverse group of students and make the course attractive to students. Second, the teaching and learning concept actively addresses innovative technologies. Based on a solid fundamental knowledge of engineering, course graduates should be prepared to identify and describe problems and to develop appropriate solutions in teams in order to actively contribute to necessary change processes. These goals and the limited time resources require a focus on paradigmatic innovative technologies and technical content, shown in Table 1. Students get basic knowledge of selected systems, models, and parameters in the range of automation technology (e.g. electrical engineering and electronics, control engineering, and actuator technology) in the context of digitalization and Industry 4.0. They are proficient in methods for calculating simple electrical circuits, acquire practical skills in the analysis of selected automation systems and in measuring relevant process variables. Students acquire professional and methodical expertise that enables them to successfully develop suitable solutions for complex, and at least to some extend technical, problems.

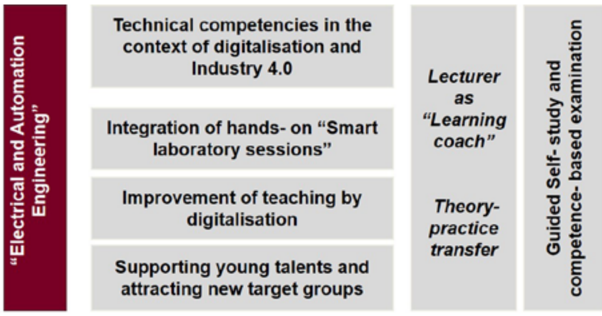

Fig. 2. The theory-based concept of the bachelor course "Electrical and Automation Engineering" for non-engineering students.

The highly diverse group of students requires an innovative teaching and learning concept to integrate different disciplinary cultures and to specifically support those "non-traditional" students in acquiring competences. The course takes up on innovative trends, interaction of technical components in complex and interlinked systems as well as on a strong

Table 1. Topics of the Course "Electrical and Automation Engineering"

Technical contents	Integration of technological innovations and industrial trends in the context of Digitalization
Electrical engineering basics (DC and AC technology)	Renewable energy, solar cell
Measurement and sensors technology	Smart Sensors, VR and AR, Auto Identification (including RFID)
Control and acuator technology	E-Mobility

focus on transfer between theory and practice. For this purpose, the concept integrates "smart laboratory sessions" as digital approaches to strengthen practical relevance in class. The experiments developed specifically for this purpose are presented in section 4. The process "know-comprehend-apply", as well as a strong focus on practice, enables students to transfer individual topics into the context of complex issues analytically and systematically. This is supported by reinforcing interdisciplinary and systematic competences of students, who are encouraged to utilize their individual academic background (e.g. business administration or environmental sciences) to work on problems and case studies. Working on interdisciplinary problems, and getting to know new technical fields independently, prepares students for their future professional life in industry with interdisciplinary and diverse teams. In summary, the concept incorporates the structural elements as seen in Fig. 2. As depicted there and in in Table 1, innovation-based key topics in the context of digitalization, Industry 4.0 and smart laboratory sessions are the centerpiece of the teaching and learning concept. They are expected to allow immediate transfer between theory and practice as well as quick access to understanding complex systems. There are four modular and smart (IT-based, intelligent) laboratories, which are closely related to the concept of Industrie 4.0 [17]. The smart laboratories are useable for both practice sequences during lecture sessions as well as practical experiments and projects of students. In addition, concepts of digitalization are integrated to improve the teaching and learning arrangement. For example, modelling and simulation via Matlab and Simulink software by The MathWorks, Inc. pick up mathematical system models from the smart laboratories and provide an authentic computer simulation and digitally supported failure analysis, while also allowing for graphical software development for embedded systems that interact with the real systems. These approaches are explained in detail in the following section.

4 TWO INNOVATIVE PROJECT-BASED LABORATORY EXPERIMENTS

4.1 AdvancedVisionCar (AVC)

The goal of the experimental framework "AdvancedVisionCar" (AVC) is to familiarize students with the use of virtual reality (VR), augmented reality (AR) and mixed reality (MR). For this purpose, a platform was created with which not only the handling of the different "Realities" could be trained, but also the students had the opportunity to test their previous knowledge in the field of sensors.

This platform was implemented in the form of the AVC, see Fig. 3. The AVC is an RF remote-controlled vehicle with several sensors and camera systems. This vehicle is supposed to bridge the gap between Industry 4.0, the different "Realities" and a sensible application in the industrial/corporate context. This is achieved by using the prototype vehicle to practice preventive and acute maintenance work in hard-to-reach places. The driver has the option of controlling the AVC via radio-transmitted video outside of their sight. They receive this video stream from the WiFi camera at the rear of the vehicle. It is transferred to a monitor, which also displays the sensor data. In addition, they have the option of recording a 360° video which can then be examined for evaluation purposes after the journey. The sensors on board the vehicle also offer the possibility of detecting temperatures. This significantly improves error analysis. The recorded video can be examined retrospectively with the help of VR glasses and thus give the user the feeling of having been the passenger themself, which improves the

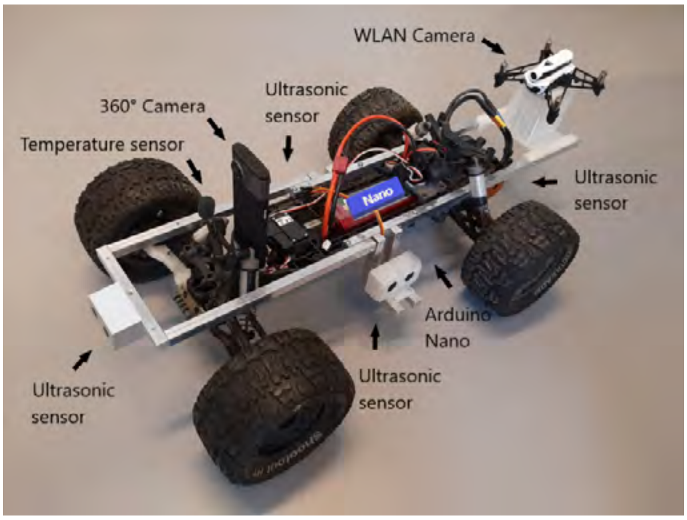

Fig. 3. AVC vehicle with components

chance of error detection. Microsoft HoloLens is also used to enable the combination with mixed reality. This is used to set waypoints on the course that should be checked regularly. In addition, the HoloLens offers the option of binding error reports to parts of the examination object so that they are available digitally and on site. This means that a user wearing a HoloLens can access these reports as soon as they approach the object under investigation. The complete architecture of the experimental framework can be seen in Fig. 4, more details are given in [23].

The implementation in the teaching context was realized with the help of a trail that the vehicle has to follow. In Mixed Reality, relevant points were also marked out on the route at which measurements were to be carried out. While the driver navigates this course, they must pass obstacles. At the points where there is a marking in the MR, they stop for a measurement. Variables to be measured include temperature and labels that must be recognized by using the video of the 360° camera.

The AVC is equipped with four ultrasonic distance sensors (UDS) and one temperature sensor. The sensors used are four HC-SR04 (ultrasonic sensors) and one TMP36 (temperature sensor). The control and monitoring of the sensors was carried out with the help of an Arduino Nano, which is operated on a 9 volt block and was programmed with the standard Arduino IDE.

Regarding optics, the AVC has a WiFi camera and a 360° camera. The WiFi camera is used for live image transmission to a computer, which the driver uses to orient themself, while the 360° camera records a video of the entire environment. The distance sensors are specially designed to be able to navigate the vehicle in remote-controlled mode without crash. The temperature sensor is located above the vehicle for maintenance and analysis purposes. All sensor data is transmitted live to the computer where it is displayed next to the live image. The VR video is loaded onto an Oculus Quest, which are VR glasses that allow the user to intuitively rotate and look around in the video. The MR data is transferred to a Microsoft HoloLens which another user can wear. Using the data and waypoints in the HoloLens, the other user helps the driver navigate. The waypoints are currently only displayed in the HoloLens. In the future, it is planned to transmit the live image in VR so that the driver can see the entire all-round view while driving. In addition, thanks to the sensors, there is the possibility of linking a neural network to the vehicle control which automatically approaches the marked points and enables measurements. So, the operator could concentrate solely on troubleshooting. Another improvement is the integration of a capacitive sensor for material detection. Furthermore, the sensor data could be transferred directly into virtual reality so that the operator can see live what the sensor is detecting. In addition, this data is to be transferred to the HoloLens in mixed reality, so that a second operator can carry out analyzes in parallel from the outside.

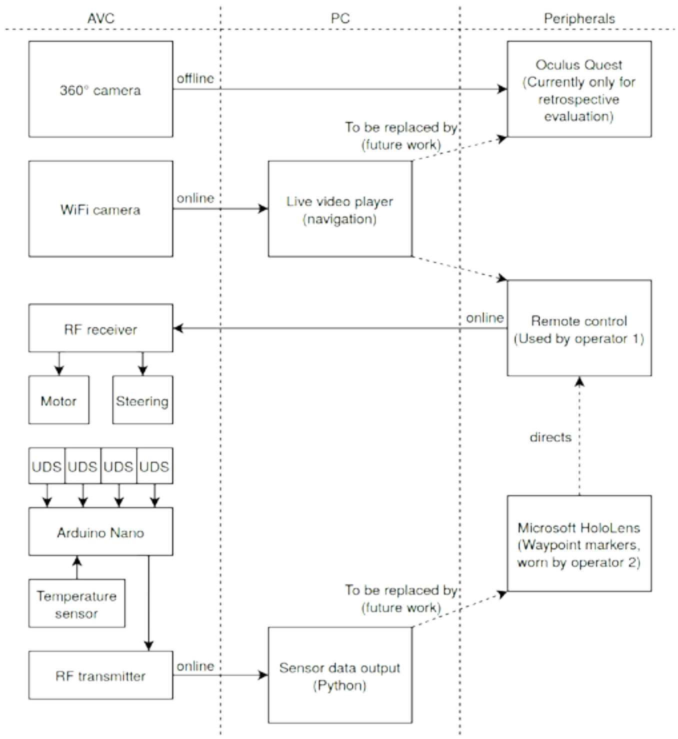

Fig. 4. Schematics, components, and dependencies of the VR/AR experiment

4.2 DC motor

As a second example, a laboratory experiment from the broad field of electrical powertrain technology is presented. (Much more details on this experimentation platform can be found in [24].) The common denominator of this discipline obviously is the electric motor. The simplest possible form (in terms of usage) is the brushed DC motor, since in its most basic function it only requires two leads and an ordinary power supply. In this experiment, a small DC motor is to be controlled using a modern digital embedded platform. An important design goal is the sustainability aspect, achieved by

- using exclusively low-cost hardware that is widely available, compact, lightweight and portable,
- basing the experiment on a standard laptop PC for maximum compatibility,
- using modular components that are as versatilely deployable as possible, and
- using graphical software creation processes, ensuring ease of use to allow for an emphasized focus on key technological aspects instead of e.g. memory management in C.

For graphical embedded software development, MathWorks provides expansion packs for Matlab, so-called Support Packages, for use with the Simulink Coder and Embedded Coder toolboxes. Some (but not all) of these Support Packages, combined with said toolboxes, facilitate four features

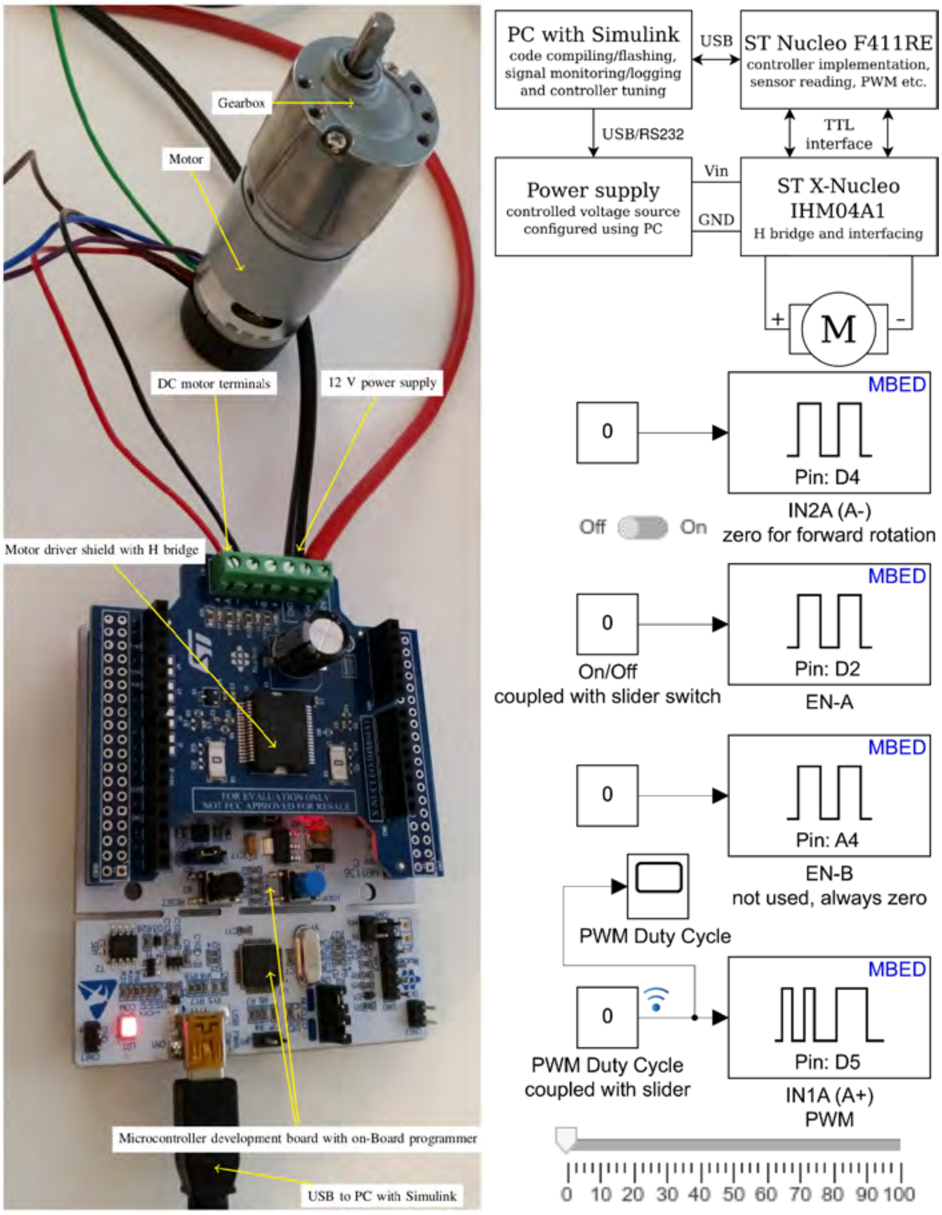

Fig. 5. Left: Experimental setup; Top right: Schematics and interfaces; Bottom right: Manual motor control using interactive elements in Simulink.

that are important for the teaching approach described in this contribution:

1. automatically generate C code from a graphical Simulink model file,
2. cross-platform-compile the code for the hardware target (e.g. ARM architecture) on PC,
3. flash the binary program into the hardware target and run it, and
4. continuously communicate with the hardware target in real time to log signals, tune parameters, switch between program logic paths, etc., i.e. Hardware-in-the-Loop (HIL) and Processor-in-the-Loop (PIL) features.

An aspect of the method that is essential for this experiment is that all four steps are executed consecutively, automatically and within a short time frame, using a single click or command. This is the case e.g. for the STMicroelectronics Nucleo F411RE microcontroller development board [25, 26], which was used in this contribution and is shown within the experimental setup in Fig. 5 (left, the white PCB). There, the other components can be seen, namely the ST X-Nucleo IHM04A1 motor driver shield [27] and an EMG30 motor by Robot Electronics [28]. The described experimental setup can serve as a foundation for many variations of lab experiments related to electrical drives, for example the following:

1. The students are supplied with the material and a laptop PC running Microsoft Windows 10 and MathWorks Matlab and Simulink.
2. They test the online HIL communication between PC and Simulink by flashing the example model shipped with the Support Package (lighting up an on-board LED on press of on-board user button).
3. They assemble power supply and motor, connecting all leads, and ask a supervisor for acceptance before they power on (however, experienced students may complete the experiment unsupervised, since only relatively safe voltage and current levels are used)
4. Students are now asked to implement a manual control scheme to drive the motor, using the supplied documentation, e.g. as in Fig. 5 (right).

5 IMPLEMENTATION AND FIRST EXPERIENCES

The course ”Electrical and Automation Engineering” was implemented for the first time in the winter term 2019/2020. 13 bachelor students (4 female, 9 male) of the major study programmes business administration, economics, environmental sciences and business informatics participated. For the following round of the Minor Program ”Engineering Sciences Fundamentals” 35 students have registered. The aforementioned variety of new fields of work and professional profiles requires high degrees of knowledge and skills from the students with regard to both their minor and their respective majors. Furthermore, the students need the particular skill to systematically form networks of the interdisciplinary knowledge. Imparting the methodological knowledge on working interdisciplinary is an essential part of the course ”Electrical and Automation Engineering”, and of the minor ”Engineering Fundamentals”. This was achieved by the inclusion of different discipline-specific perspectives of students' majors to develop solutions for scientific questions or case studies. Students and lecturers willingness and motivation to ”bring to life” the interdisciplinary discourse, and their readiness to deal with interdisciplinary problems as well as new scientific fields independently, leads to an profound preparation of students for their future career in interdisciplinary and diverse teams. The lab experiments, which were not compulsory attendence, also proved popular among the students. The small group sessions were highly interactive and agile, due to many interposed questions by students with an advanced technical background, about side aspects and other applications. For others, working with the example systems turned out as a first close contact with technology and a journey with a steep learning curve. Being able to react to such diverse educational preconditions, especially incorporating the skills and perspectives of the non-technical students in a constructive way instead of considering them as the ”weakest link”, requires a high degree of flexibility both from the lab equipment and from the teaching concept. According to the students' positive feedback on the new course, these goals were achieved. In fact, as justification, they referred in particular to the possibility of combining the engineering fundamentals with their non-technical main subjects.

6 CONCLUSIONS AND ACKNOWLEDGEMENTS

The objective of the paper is to represent an interdisciplinary engineering course concept for bachelor students who do not come from a technical field. A suitable framework for the student-centered course design in engineering education is introduced. The didactic concept actively addresses the diverse backgrounds of the students in this course. This professional diversity carries an important potential to take up an interdisciplinary point of view in class sessions in order to prepare students for globalized scientific and working environments. To facilitate a quick grasp of basic technological aspects, two laboratory experiment systems were developed. They cover AR/VR technology as well as electrical drives, sensors, intuitive programming, control engineering and other related fields. After successful implementation of the combined concept, activities to further establish and extend the concept to other courses (e.g. within the first semesters of the masters degree programme) are planned. Evaluation results will be used to improve the concept continuously and in a systematic manner. Limitations of the conducted study were the small number of students and lack of a quantitative evaluation, since this was the first implementation of the course.

As part of the research project ”Innovation Plus”, the development of the smart technology lab-sessions is funded by the Ministry for Science and Culture of the German state of Lower Saxony in 2019 and 2020.

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