New ways in engineering education for a sustainable and smart future

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***Abstract*—This *Innovative Practice Full Paper* presents a constructivist concept for engineering education for non-technical students. Global challenges and transformation processes 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 on transformation processes in Engineering Education: (1) by the development of a theory-based teaching and learning concept on electrical engineering for this special target group of non-technical students; and (2) by presenting the implementation of the undergraduate (bachelor) course with innovative project-based laboratory experiments.**

***Index Terms*—Student-centered course design, Engineering education for non-technical students, Transformation processes in engineering education**

I. Introduction

Global transformation processes and sustainability issues lead to a rapid increase in interdisciplinary problems, characterised by high degrees of complexity and responsibility as well as the need for a broad knowledge on topics where disciplines intersect, [1]. 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 a sustainable future [2]–[4]. On one hand, the field of engineering science is confronted with a continuous increase of the demand for knowledge and skills [5], [6]. On the other hand, there is a massive shortage of skilled professionals [7]. The shortage of young engineers presents a structural problem that deflates growth and innovation and causes high value losses for the economy. In this context, the engineering sciences have a special responsibility to offer suitable research-based courses for a broader target group and interdisciplinary education, especially in light of the current shortage of qualified specialists. This paper contributes to that research discourse by presenting an innovative theory-based teaching and learning concept for an engineering course for bachelor students of non-engineering disciplines (e.g. Environmental Sciences and Economics) and associated empirical findings of implementation. As a research goal, a specific contribution to the innovative practice of engineering education, sections II and III concern the student-centered lecture Electrical and Automation Engineering (four semester hours per week) based on constructivist and problem-based learning theories and on the model of Educational Reconstruction, as in [8], [9], as the research framework. The objectives and the didactic design of the bachelor course as well as the engineering key topics in the context of new technologies, sustainability and IoT/Industry 4.0 are presented. Undoubtedly, intuitive technical understanding of most engineering fields can be conveyed best by letting the students tinker with specific systems themselves. For this purpose a newly developed laboratory experiment is presented in section IV. Finally, in section V, the paper outlines the experience of the first implementation of the course Electrical and Automation Engineering in wintersemester 2019/20 and further discusses future perspectives within the discipline of engineering education and research.

II. Methodology and goals

First, it is necessary to clarify the connection between the research goals and the selected methodology. The research objectives in this paper are standing for both, theoretical understanding and educational practice. In order to *design and to study* within the same research process, as in [10], we have chosen design based research. Design based research is a multi-faceted approach that provides valuable results for both theoretical understanding and educational practice, [11, p. 6]. With a focus on engineering education for a sustainable and smart future, this research deals particularly with the theory-based course-design for students who do not come from a technical field. Limitations of the study are given, since the developed concept was only put into teaching practice once. Furthermore, the evaluation part is restricted due to limited resources. In further research work an extension is planned to strengthen the validation of the teaching concept.

The student-centered course design is based on Educational Reconstruction [8], [9] as the research framework. In [12], this framework is further developed towards a focus on engineering education. To take the students seriously as an active starting point for the construction of knowledge, the model of Educational Reconstruction can be a major help, see [9], [12], especially for that specific target group. 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 environments is drawn from the comparison. This is particularly important for the didactic construction of engineering courses for non-technical students. In this case, the challenge is 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 [13]. Fig. 1 shows the framework of Educational Reconstruction adapted for the field of engineering sciences and non-technical learners. To implement the model, the research steps A to F must be completed. These steps are detailed in [14].

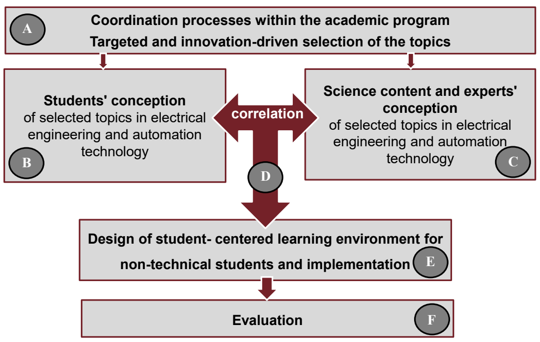

Fig. 1. Research Framework: Model of Educational Reconstruction with focus on engineering and automation technology and non-technical students, based on [12]

In the sequel, by using the framework, the paper by way of example outlines the individual research steps for designing the course "Electrical and Automation Engineering" for non-engineering students: elaboration of the relevant scientific content and experts' conception, correlation to students' conception, design and implementation of the student-centered learning environment, and, finally, evaluation. 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, to further develop Engineering education for a sustainable and smart future. The general objective of the course "Electrical and Automation Engineering" is to impart a basic understanding of technology in a context relevant for engineering and professional practice.

The newly developed course on electrical and automation engineering for non-technical bachelor students aims at the following targets:

- impart knowledge and skills of selected technical basics in electrical engineering, metrology and sensor technologies (including optics) as well as control and drive systems,
- develop close links between the basic technical knowledge and possible applications in technical innovations, use of selected examples of systems (e.g. e-mobility, smart sensors, VR and 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.

III. Novel theory-based teaching and learning concept for an engineering course for bachelor students of non-engineering disciplines

A. *Relevant scientific content*

By applying the model of Educational Reconstruction in all its sequences, research data were explored that are 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 industrial innovations and scientific key concepts have been identified and analyzed from industry applications and the literature, e.g. [15]–[20]. What are new industrial developments due to the digital transformation? How do the concepts look like in science? What scientific models exist and where can coherences and limits of the imagination be found?

Table I shows the key topics of the bachelor course on electrical and automation engineering for non-engineering technical students.

TABLE I
Topics of the course
"Electrical and Automation Engineering"

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

Students get basic knowledge of selected systems, models, and parameters in the range of automation technology (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.

The process "know-comprehend-apply" as well as a strong focus on practice enables students to transfer solitary topics into the context of complex issues analytically and systematically. This is supported by reinforcing interdisciplinary and systematic competencies of students, who are encouraged to utilize their individual academic background (e.g. business administration, 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 correspondence to the next step of the model of Educational Reconstruction (*design and implementation of the student-centered learning environment*), the didactic design of the course is presented below.

B. Didactic design of the student-centered course

The course "Electrical and Automation Engineering" is one of six courses of the minor (i.e. secondary subject of the study program) "Engineering Fundamentals", see Fig. 2. The minor "Engineering Fundamentals" provides an overview of the most important technologies and technology-oriented processes in the manufacturing industry. Beside the treatment of the technological areas of mechanical engineering, electrical and automation technology as well as information and communication technologies, an interest-based in-depth study through two elective modules is possible. This minor can be studied in combination with different majors, e.g. Economics, Environmental Sciences and Digital Media. Fig. 2 shows an overview of the minor "Engineering Fundamentals", the course "Electrical and Automation Engineering" is scheduled in the third semester.

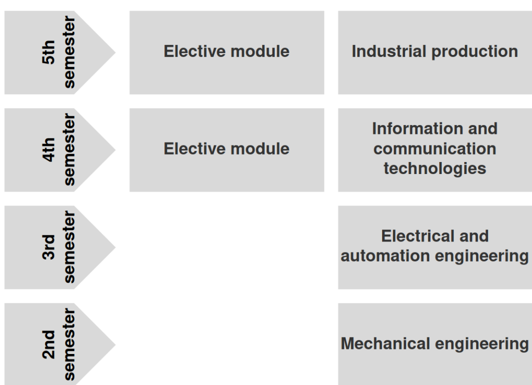

Fig. 2. Overview of the minor "Engineering Fundamentals" as a comprehensive insight into relevant engineering disciplines

The student-centered course design originates in constructivist learning theories, e.g. [21], [22], and gender-sensitive teaching concepts, as in [23]–[25]. Both theoretical approaches emphasize three essential aspects of the process of learning and the acquisition of competences as well as the conditions promotive to this process: the importance of active engagement and problem orientation, the importance of motivation and success, and the importance of scientific relevance and transfer. These theoretical principles have been incorporated into the didactic design of the "Electrical and Automation Engineering" module and implemented in teaching practice, see Fig. 3. The 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 digital transformation processes leads to new technologies and fields of work, which can be characterized by high degrees of complexity and responsibility as well as the need for a broad knowledge on topics where disciplines intersect. The teaching and learning concept actively addresses those recent trends to empower students. Based on a solid fundamental knowledge on engineering, course graduates are prepared to identify and describe problems and to develop appropriate solutions in teams in order to actively contribute to necessary change processes. Both targets require a strong content-related focus on the most important technical topics, shown in Table I. Additionally, innovative didactic concepts and digital teaching and learning approaches are needed to effectively support the competence development of students in a limited amount of time. The student-centered and innovation-driven design of the teaching and learning concept integrates "smart laboratory sessions" as digital approaches to strengthen practical relevance in class. Furthermore, the course design also takes into account the diverse backgrounds of the students in this course.

The course takes up on innovative trends, on the interaction of technical components in complex and interlinked systems as well as on a strong focus on transfer between theory and practice. The audience consists of a highly diverse group of students from different faculties, who want to acquire technical knowledge and skills in addition to their respective major (e.g. business administration, economics, environmental sciences, psychology, digital media). 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. On the other hand, 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 competencies. Therefore, course contents, learning objectives, teaching and learning methods and examination format need to be coordinated.

The change from a knowledge-based view to an innovation and competence-based view is a key element for the integration between the theoretical goals of the course and its didactic design. From a theoretical perspective, the teaching and learning concept is based on the principles of research-based teaching and learning, self-regulated learning and a space for collaborative and hands-on working and learning [21], [22]. To foster learning among diverse students and to provide a gender-sensitive teaching, the concept incorporates the structural elements as seen in Fig. 3. A main focus is the strong link of theoretical and practical experience of the students and the facilitation of hands-on experiences within the "Smart Lab Sessions". This approach is considered to be beneficial for the acquisition of competences from the point of view of teaching and learning theory as well as gender theories, as in [21]–[25]. An example of the lab is presented in detail in section IV. As depicted in Table I and Fig. 3, an innovation-based selection of *technical key topics in the context of digitalisation and Industry 4.0* is the

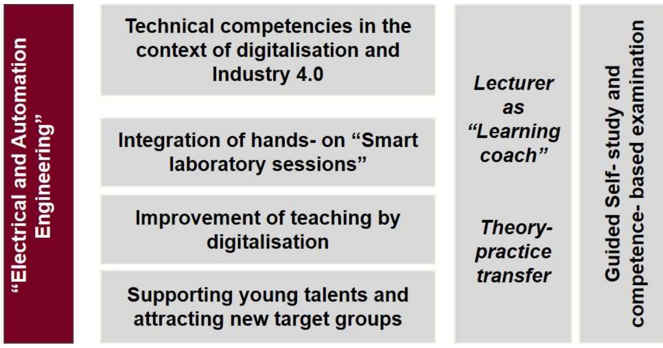

Fig. 3. The theory-based concept of the bachelor course ”Electrical and Automation Engineering” for non-engineering students

starting point. Selected topics are characterised in a way that they contain crucial professional competencies the students need in order to analyze and reflect interdependencies and develop options for action when working at the interfaces in modern production environments and in social contexts. *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 a quick access to understand complex systems. There are four modular and smart (IT-based, intelligent) laboratories, which are closely related to the concept of Industrie 4.0 [20], [26]. Topics include technical fundamentals, metrology/measuring technology and smart sensors, control engineering and image processing (e.g. Augmented and Virtual Reality, RFID). 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. 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.

IV. Innovative project-based laboratory experiments

As an example, a laboratory experiment from the broad field of electrical powertrain technology is presented. The indicated lab fits in the third topic, ”Control and acuator technology” and ”E-Mobility”, as seen in Table I. (Another lab experiment platform that fits the second topic in the table can be found in [27].) The attendance in the lab is necessary for a succesful examination. 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.

Remark 1: AC motors, while constructionally much simpler than DC motors, are notoriously hard to control since the rotating three-phase field has to be actively generated and supplied externally, which requires knowledge of the absolute rotor angle at all times and, ideally, an expensive four-quadrant DC power supply or transformer.

In this experiment, a small DC motor is to be controlled using a modern digital embedded platform. The most important design goal of this experiment is the sustainability aspect, which is achieved by

- using exclusively low-cost hardware that is 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 and pointers in C-code.

A. Technological foundations of the experiment

For graphical embedded software development, MathWorks provides expansion packs, 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 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. the ARM processor architectures) on the 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., e.g. Hardware-in-the-Loop (HIL) or 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. Possible hardware targets for which this criterion is met can be divided into general purpose boards and specialized education-oriented systems. General purpose boards include

- Raspberry Pi (SOC-based full Linux computer, but only with a digital GPIO interface)
- BeagleBone Blue (SOC-based full Linux computer with many specialized on-board peripherals, including H bridge, ADCs and sensors)
- **STMicroelectronics Nucleo** (industry-focussed ARM microcontroller development/prototyping boards with many peripherals)
  - F103RB
  - F302R8
  - F401RE
  - **F411RE**
  - F746ZG

- **F767ZI**
  - L053R8
  - L476RG
- **Arduino Due** (education-focussed ARM microcontroller boards with basic peripherals)
- NXP FRDM-KL25Z (small ARM board with on-board accelerometer and capacitive touch sensor)
- **NXP FRDM-K64F** (faster ARM board with more interfaces and sensors)

We recommend using Arduino Due (84 MHz Cortex-M3, about 40 EUR), ST Nucleo F411RE (100 MHz Cortex-M4, about 20 EUR), ST Nucleo F767ZI (216 MHz Cortex-M7, about 25 EUR) or NXP FRDM-K64F (120 MHz Cortex-M4, about 50 EUR). The Arduino has a pronounced focus on education, while Nucleo boards and the NXP FRDM-K64F are rather targeted to industrial R&D departments. Arduino Due and NXP FRDM-K64F have all relevant interfaces, including analog outputs (DAC). Arduino is better documented than the other boards, while the others are faster and have an integrated floating point unit (FPU) for accelerated math operations in IEEE 754, which is the standard number format used in Simulink. Arduino does all that in software and, hence, needs more CPU cycles to achieve the same.

Remark 2: The FPU hardware acceleration feature of the Nucleo and NXP boards allows for much faster execution of numerical algorithms, which can be important if very small sampling times are required, e.g. for stiff differential equations, for example for model-based control of hydraulic systems.

The Nucleo F411RE has a small form factor, lacks analog outputs (DAC) and can only accelerate single precision (32 bit) floating point math operations, while the larger F767ZI is faster, supports double precision (64 bit) FPU, has more interfaces, and a DAC. In most cases, all four options are viable for a teaching environment.

Remark 3: The FRDM-K64F remains the most versatile option since it features several on-board sensors, Ethernet, a slot for microSD cards for storage and good Simulink support of DACs and the hardware quadrature decoder. In this contribution, for cost reasons, a Nucleo F411RE is used.

For the experiment, an ST Nucleo F411RE is combined with a motor driver shield ST X-NUCLEO-IHM04A1 [28], which is based on the dual H bridge IC L6230, also by ST. It can work in the range of 8 V to 48 V with nominal currents up to 1.4 A (2.8 A peak), rendering it useful for safe experiments that can be done by an unskilled person.

Remark 4: This shield is pin-compatible with Nucleo and Arduino boards, the pin and port assignment is given in Table III. There, the port in parentheses is the Arduino port name (which will also be recognized by Simulink for Nucleo), while the other is the specific port name of the Nucleo F411RE.

The shield can be stacked on the respective microcontroller board, see Fig. 5. Then, the board is connected to a PC using Micro-USB or Mini-USB, depending on the board. The schematics is given in Fig. 4 (left). Nucleo boards can present themself to the PC in two modes: As USB mass storage device, used by Simulink for flashing the compiled software, or as a virtual serial (USART) interface, used for Hardware-In-The-Loop (HIL) or rather Processor-In-The-Loop (PIL) capabilities like real-time monitoring of signals or tuning of controllers.

The software is built entirely within Simulink. Once the Nucleo driver *STSW-LINK009* [29] and the *Simulink Coder Support Package for STMicroelectronics Nucleo Boards* [30] from the Add-Ons menu in Matlab are correctly installed, a new Simulink model file is created. In the model settings, it is necessary to select the right hardware target and configure the correct COM port, as detected by Windows, according to the documentation [31], [32]. Next, specific blocks for the Nucleo can be dragged & dropped from the Simulink library, in particular the *Digital Write* and *PWM Output* block, displayed in Fig. 6 (right). In the block settings, the respective pin is declared, e.g. `PF15`, see Table III. A *Digital Write* block is used to write the value 1 to EN-A to enable one of the two H bridges available on the shield. For the inputs IN1A and IN2A, however, *PWM Output* blocks should be used, so the motor can be driven with variable power instead of just turning it on or off. These blocks have additional setting, in particular the PWM frequency, which can be set up to 100 kHz.

Remark 5: Lower frequencies (in the range of a few kHz) can reduce electrical switching losses, but at the cost of more noise, both acoustic and electromagnetic. 20 kHz is a common choice to avoid audible disturbances. If the elctrical current is to be measured, e.g. for advanced control strategies or observer design, higher PWM frequencies combined with an analog low-pass filter (LPF) is advisable, because it somewhat alleviates the necessary compromise between noise reduction and phase delay of the LPF.

The input port of these blocks is not a logical 0 or 1, as with the *Digital Write*, but a value between 0 and 100, specifying the duty cycle of the PWM signal that will be automatically generated in hardware. For simplicity, only one input (IN1A or IN2A) should be used at a time, and the other set to zero, respectively, to drive the motor either forwards or backwards. The output behavior can be seen in Table II, where these two modes are highlighted. Manual control of the motor can be implemented using interactive elements like switches and sliders, see Fig. 6 (right).

The motor connected to the driver shield can be any DC motor with nominal voltages up to 48 V. If the motor's start-up current is over 2.8 A, it is advisable to implement a current limit for the power supply. Futhermore, it is possible to combine the two H bridges of the driver shield to drive one bidirectional motor with up to 5.6 A, or one unidirectional motor with up to 11.2 A [28].

The motor used for this experiment is the one presented in [33], EMG30 by Robot Electronics [34]. It is a 12 V DC motor with a rated current of 530 mA and a stall current of 2.5 A. Thanks to a 30:1 reduction gearbox, a safe rated speed of 170 RPM at a rated torque of about 0.15 Nm is achieved. While rather slow and inefficient, this motor is sufficient for educational robotics applications. At about 35 EUR, the motor is not particularly cheap but still reasonably priced. Simpler models can be found e.g. on eBay below 2 EUR per piece.

Remark 6: The EMG30 also features an integrated quadrature encoder with 360 ticks per revolution, based on Hall sensors. The supply voltage for the sensors should between 3.5 V and 20 V. Since the outputs are open-collector, they require pull-up resistors (e.g. between 3.3 kΩ or 4.7 kΩ to pull up to 3.3 V). Using these signals, it is possible to measure the speed and implement speed control in Simulink, e.g. with a simple PID controller, which is available as a single block with online tunable gains.

For advanced control strategies and model-based state observers, it is necessary to measure the motor current. This can also be achieved with the existing hardware. The IHM04A1 motor driver shield has mounting locations for current measurement shunts on the top side of the board, one for each H bridge, visible in Fig. 5. By default, they are not populated and occupied with conductor bridges (the white elements labelled ”0”), which can be soldered off and replaced with custom high precision resistors. After this, it is sufficient to evaluate the measured voltage over this resistor to deduce the current. No further wiring is required since the reading point is already connected to an ADC, see Table III.

Remark 7: In order to reduce the noise in the current measurement, which mainly originates from the PWM control of the transistors, it is sensible to use an LPF, as indicated in Remark 5. For this purposes, there are unpopulated SMD mounting points for an RC-based LPF located on the driver shield next to the shunt resistor, so no additional wiring is required for this purpose, either. The cut-off frequency of this first order RC filter should be chosen as high as possible for minimum delay and as low as necessary for attenuation of higher-frequency noise. Selecting very high PWM frequencies for the H bridge can help to shift the bulk of the noise to very high frequencies which are stronger attenuated. The electrical dynamics of the motor itself helps, too, as it also represent an LPF (of the RL variety).

TABLE II
LOGIC TABLE

EN	IN1	IN2	S1	S2	S3	S4	O1	O2
0	*	*	0	0	0	0	High Z	High Z
1	0	0	0	1	0	1	GND	GND
1	**1 or PWM**	0	1	0	0	1	**Vin × dc (RMS)**	GND
1	0	**1 or PWM**	0	1	1	0	GND	**Vin × dc (RMS)**
1	1	1	1	0	1	0	Vin	Vin

TABLE III
PINS AND PORTS

IHM04A1 pin	F411RE port	Description
EN-A	PF15 (D2)	Enable H bridge A
IN1A	PE11 (D5)	Digital signal for H bridge, positive motor terminal (O1)
IN2A	PF14 (D4)	Digital signal for H bridge, negative motor terminal (O2)
ADC6 (SENSE-A)	PA6 (D12)	Current measurement shunt (optional, not populated by default)

B. Procedure of the experiment

The described experimental setup can serve as a foundation for many variations of lab experiments related to electrical drives, for example the following:

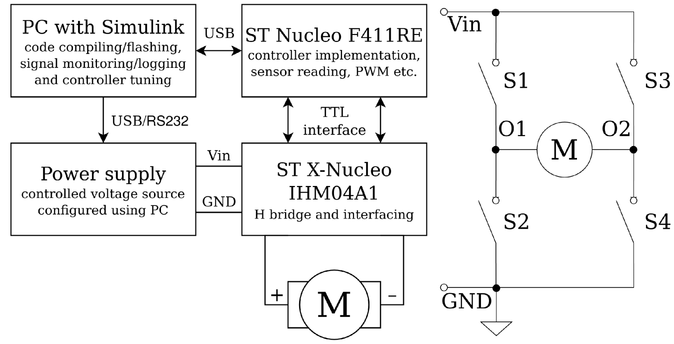

Fig. 4. Components of the experimental setup (without encoder interfacing, left) and H bridge schematics (right)

1) The students are supplied with the material and a laptop PC running Windows 10 and Matlab Simulink.
2) They test the online PIL communication between PC and Simulink by flashing the example model shipped with the Support Package (making an on-board LED light up when the on-board user button is pressed).
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) If necessary, a supervisor will configure the fixed voltage and the current limit of the power supply
5) Students are now asked to implement a manual control scheme to drive the motor, using the supplied documentation, e.g. as in Fig. 6 (right).
6) (optional) If oscilloscopes are available in the lab, the students visualize the PWM signal generated by the motor driver.

The experiment can of course be extended by multiple aspects, e.g. closed-loop speed control (by creating a program to estimate the speed from the digital incremental encoder signals, based on time measurement between rising and falling edges), or torque/current control (using current measurement shunts).

V. FIRST EXPERIENCES AND REFLECTION

A. Trial run with the experimental platform

The experiment detailed in section IV was performed interactively in a regular classroom, equipped only with a digital projector, within a total time of two teaching units (2 × 90 minutes). Due to the portability of the DC drive experimental setup, which fits completely in a small box, it can be carried out virtually anywhere, given electrical outlets.

1) Technical specifics: Programming and flashing the microcontroller using Simulink can be done with any standard laptop PC that is recent enough to run Microsoft Windows 10. Alternatively, it is possible to run Windows 10 and Simulink within a virtual machine (tested with the free Oracle VirtualBox system). This allows usage of Linux or Mac computers, based on passthrough of the USB interface to the virtual machine.

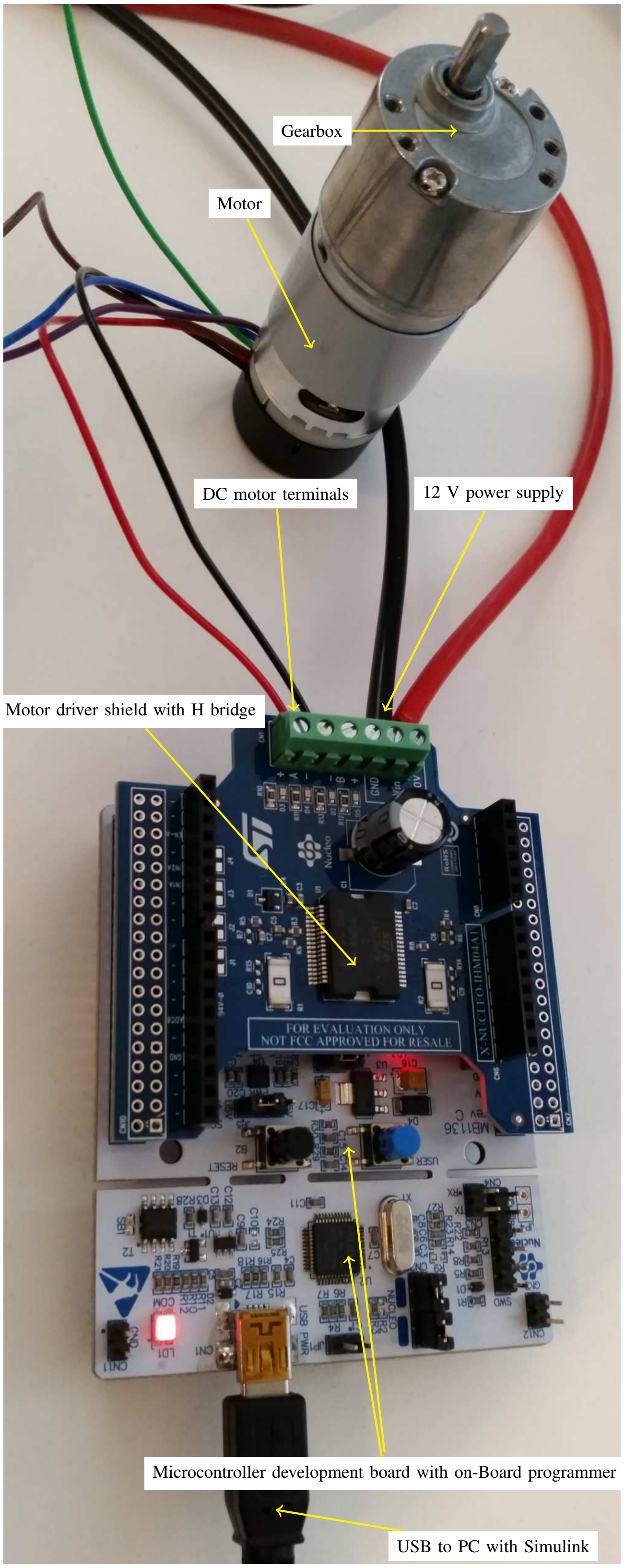

Fig. 5. Experimental setup

2) Fundamentals crash course: Right before the experiment was conducted, a tutorial seminar of 90 minutes was dedicated to briefly introduce key fundamentals necessary for a basic understanding of electric motors:

- magnetic fields of permanent magnets; magnetic poles; field lines; zero divergence (no sources/sinks)
- cause of magnetic fields (electrical current), examples: Earth (molten iron convection currents) and permanent magnets (Weiss domains)
- field shape of current-carrying conductors; right-hand rule; superposition (solenoids)
- flux and flux density; Lorentz force
- phenomenological derivation of electromagnetic induction (Faraday's law) using a Web Applet [35]
- visualization of a rotating conductor loop in a constant magnetic field using a Web Applet [36]
- self-induction and self-inductivity
- schematics of a DC motor, especially the commutator
- derivation of the electromotoric torque using Lorentz force; proportionalities between current $\leftrightarrow$ torque and voltage $\leftrightarrow$ speed
- derivation of the two coupled differential equations that describe the dynamics of DC motors

$$\frac{\mathrm{d}i(t)}{\mathrm{d}t} = \frac{1}{L}\left[u(t) - Ri(t) - K\omega(t)\right] \tag{1}$$

$$\frac{\mathrm{d}\omega(t)}{\mathrm{d}t} = \frac{1}{J}\left[Ki(t) - b\omega(t) - \tau_{load}\right] \tag{2}$$

- transition to Simulink by implementing the differential equations, see Fig. 6 (left), using fictional parameters given in Table IV, and
- introduction of the principle of the feedback control loop and step responses.

TABLE IV
SIMULATION PARAMETERS

Symbol	Value
T_s	0.1 ms
K	0.01 Nm/A (Vs/rad)
R	1 Ω
L	0.5 H
J	0.01 kg m^2
b	0.1 Nms/rad

3) Execution and reception: A prototype form of the experiment was demonstrated in the classroom, with a seamless transition from the mathematical model in Simulink to the DC motor control in Simulink. The students that were present were well-motivated and eager to learn, which is reflected in the phenomenon that there were many interposed questions about side aspects during the progression of the experiment, i.e. about

- the basic working priciple of digital simulation software like Simulink, which is to discretize the system's differential equations (e.g.$\dot{x}(t) = f(x(t))$) in time and use this to predict the state in the next time step (e.g. $x(k+1) = x(k) + T_s f(x(k))$),
- architecture of microcontrollers in comparison with PCs (absence of an operating system),

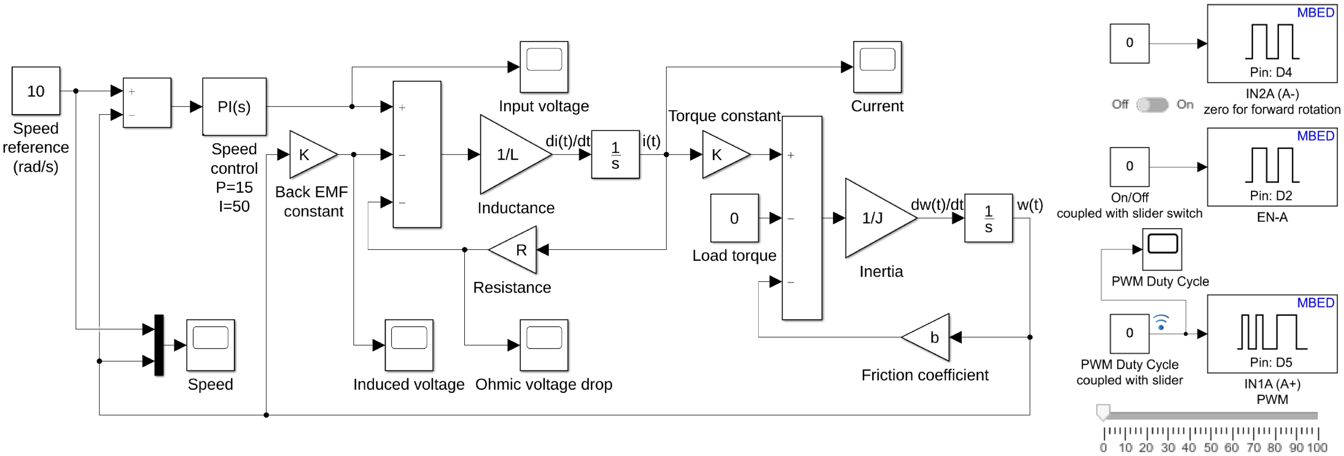

Fig. 6. DC motor and PI controller implemented in Simulink (left) and manual motor control using interactive elements in Simulink (right)

- modelling the dynamics of electrical circuits using Kirchhoff's laws, self-induction, and Faraday's law,
- modelling the dynamics of rotational and translational mechanical systems using Newton's laws of motion,
- some fundamental aspects of system theory: system states and their dynamics (time behavior), system boundaries, and the fact that the only interaction with the environment has to be mapped into the input and output signals,
- basics of control theory, the standard feedback control loop, and proportional-integral (PI) controllers, and
- PWM control and why the underlying time-averaging principle works, that is, the low-pass-filter nature of most physical and physiological system (PT2-like behavior), which was elaborated on with the example of human vision (LCD backlight brightness control is usually done with PWM since the brain averages out the brightness).

B. First experiences and reflections of the new course design

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 programs business administration, economics, environmental sciences and business informatics have participated. For the forthcoming round of the minor program "Engineering Sciences Fundamentals", 35 students have registered.

In a survey at the end of the semester, students have given positive feedback on the course. Students referred in particular to the possibility of combining the engineering fundamentals with their non-technical main subjects. Especially the close connection of the theoretical contents to the offered laboratory experiments was seen as helpful for the learning process. For others, working with the example systems turned out as a first close contact with technology and a journey with a steep learning curve.

As instructors' reflection, 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 lectures and from the teaching concept. 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 interdisciplinarily 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 a profound preparation of students for their future career in interdisciplinary and diverse teams.

VI. Conclusion

An innovative concept to teach fundamentals of engineering to non-engineering students was derived and implemented. 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. After successful realization of the concept, activities to further establish and extend it to other courses (e.g. within the first semesters of the master degree programme) are planned. First experiences and evaluation results from the winter semester will be presented at the FIE 2020 conference. The aim is to share the idea of the teaching and learning concept and first implementation experiences within the discipline of engineering education and research.

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