A MODULAR, SCALABLE OPEN-HARDWARE PLATFORM FOR PROJECT-BASED LABORATORY COURSES IN ELECTRICAL ENGINEERING STUDIES

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ABSTRACT

Electrical engineering, as well as other technical and scientific study programs, typically include laboratory courses in which students work on practical exercises with electronic circuits. Usually, self-contained hardware for each topic being covered is applied. These pre-build electronic circuits are often complex and not easily understandable at a glance. This hinders in-depth understanding of the topics in the limited amount of course time. Moreover, each time the students are confronted with new hardware, a familiarisation process is necessary before they can start the actual experiments. Typically, each topic is dealt with on a single appointment, thus for the students there is no possibility to experiment, develop routines or to correct misconceptions. To overcome these issues, a modular, scalable open-hardware platform, comprised of small, easily combinable modules, is presented. In the design of a laboratory course for a specific topic, the required experimental setup can be assembled from these modules. Further, the platform allows for a realisation in individual steps, thus encouraging experimentation and enabling the students to gain understanding of each component, e.g. by system identification approaches.

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1 MOTIVATION

Laboratory courses are typically found in bachelor's study programs and mark the first step towards practical work in electrical engineering studies. The students are tasked to apply theoretical knowledge gained in lectures on practical examples. This implies that the course itself is intended to deepen the understanding of newly learned concepts and to learn the correct operation of measurement equipment and methods.

In many of these courses, self-contained hardware dedicated to the respective topic is applied. Students are confronted with often complex, monolithic electrical circuits, preventing an in-depth understanding of the components and their functionality. As new hardware is used for every exercise, an anew and often lengthy familiarisation period is required preceding the practical work.

2 METHODOLOGY

2.1 Goals

To overcome the drawbacks of monolithic, single-topic hardware, a new, modular hardware platform is designed. Compared to commercially available electronic modules and kits, which typically either focus on secondary school teaching or digital microcontrollers (e.g. *PHYWE* experimental kits and *Arduino* shields), the platform allows for rather complex, multi-stage analog circuits to be build.

There are different models to describe experiential learning, but they all regard experiential learning as an iterative process, which generates and updates concepts from experience [1]. To foster this process, students should be allowed to develop their own approaches without following recipe-like instructions. Thus, the hardware platform is designed with project-based courses in mind. Moreover, a project-based approach can increase the motivation of the students, as the focus is shifted from merely finishing the course to the development of individual solution strategies [2]. The main characteristic of project-based learning is that there is a goal, which is specified beforehand [3]. This specifically fits laboratory courses as many tasks can be formulated in a similar way. The advantages of using project-based learning [2, 3] match the skills a laboratory course should convey, as described by the following goals:

a. Promote engagement of the students: Students know methods from lectures, but have only limited experience in the application of these methods. A modular design allows for an individual realisation of the experimental setup, which encourages the students to try out various approaches.
b. Promote analysis and synthesis: Students learn to connect theory and practical realisation, e.g. by designing a block diagram and synthesising electrical circuits from it.
c. Build and use correct terminology: Using correct terminology is essential for a laboratory course as it forms the basis for well-founded discussions and the written reports.
d. Further collaboration: This aspect is two-fold, as collaboration takes place inside participating groups themselves, but also between the different groups.

The following section describes how these goals can be achieved by using a modular hardware platform.

2.2 Modular, scalable hardware platform

The fundamental element of the platform are small, generic modules representing elementary functions. This reduces complexity to blocks typically present in electrical systems, such as voltage supplies, bridge circuits, filters and operational amplifier circuits.

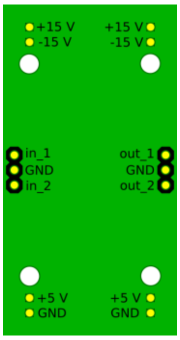

Fig. 1. Module template.

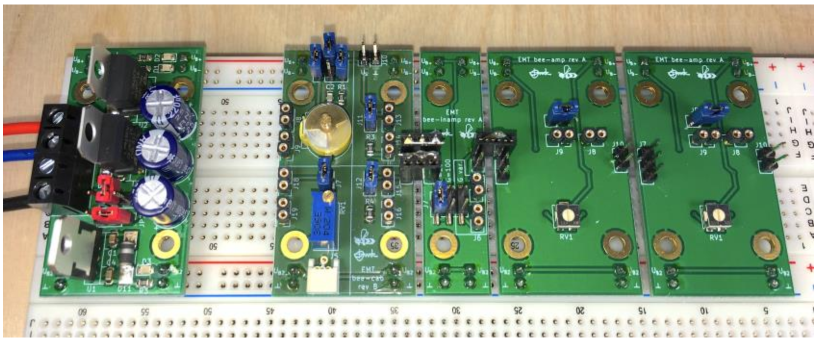

Fig. 2. Exemplary setup with several modules mounted on a breadboard.

The template of a module is depicted in fig. 1. The lower surface of each module has pin headers to connect to the power supply. On the top surface, different pin headers for inputs, outputs and ground can be realised. The basis of the platform is a standard breadboard, as illustrated in fig. 2. This simplifies voltage distribution and allows for additional electrical components to be placed. Besides the electrical connections, the breadboard also provides mechanical stability. Compared to pre-built hardware, this provides flexibility and scalability, as arbitrary combinations of modules can be used. Moreover, new functions can easily be integrated by designing a single, new module. Due to the segmentation of elementary functions, each module can easily be analysed on its own, e.g. via system identification methods, to further in-depth understanding. An experimental setup can be realised individually by the students, which is essential for project-based learning. The existing module designs and templates are published as open hardware [4]. Course instructors are encouraged to apply and extend the available modules in the design of their own laboratory courses.

2.3 Example of usage in a laboratory course

In the course taught by the Measurement Engineering Group at Paderborn University, a gravimetric measurement is to be realised using a capacitive force sensor. The project goal is to determine the mass of an arbitrary object. Groups of three students are provided with the documentation of the available hardware modules and are tasked to develop a suitable block diagram (goals a, b). These diagrams are presented and discussed on the first appointment, which enables the groups to compare and evaluate their solutions on their own (goals a, d). The teacher moderates the event and gives remarks if needed. Thereafter, the experimental measurement setup is realised individually by each group (goal a). At specific points (matching the student’s progress and reacting to problems) the teacher interrupts the group work to begin a discussion, in which the students try to solve problems (goals a, c, d). At the end of each meeting, a conclusion is drawn in plenum and a working plan for the next appointment is set up to synchronise the findings of the groups. After finishing the project, the students write a report, which is especially reviewed with regards to correct terminology (goal c).

3 RESULTS

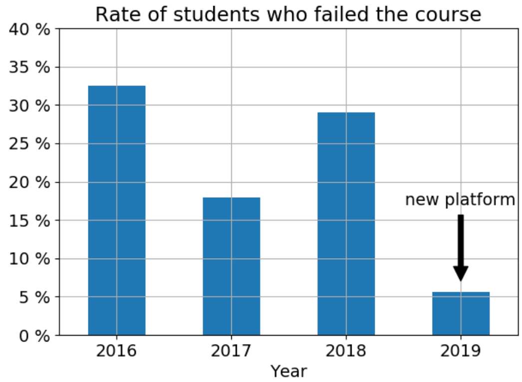

Fig. 3. Comparison of dropout rates over previous years

Tab. 1. Average grade in previous years. Note that grading was introduced in 2017.

Year	Average grade
2016	n/a
2017	2,40
2018	2,76
2019	2,54

Fig. 3 depicts the percentage of students who failed the course in previous years. First of all, the new platform introduced in 2019 led to a significant drop in the dropout rate to 5.6 %, compared to from 18.0 % to 32.5 % in the preceding years. A comparison with the average grades for the respective years (tab. 1, grades range from 1.0 (best) to 4.0 (worst) with 5.0 denoting a fail) shows no significant decrease. This suggests that the decrease in the dropout rate is not achieved by a reduced difficulty of the course. In personal conversations with the students, they emphasised that they liked the possibility to experiment freely. Furthermore, they stressed that they prefer the project-based approach in comparison to the typical structure of working on a single topic per appointment.

4 SUMMARY AND OUTLOOK

A new hardware platform for project-based laboratory courses is presented. It is shown that the application of the new platform led to a lower dropout rate. The platform idea can easily be picked up by other groups, which is currently in progress at Paderborn University.

As the modules are generic, they can also be used for other purposes, e.g. for quick circuit setups in daily laboratory work. Due to the modular nature of the setup, tasks can be scaled to the abilities of the participants. The hardware platform can also be used in secondary schools for small experiments to raise interest in engineering studies or in laboratory courses of other fields, e.g. when a sensor interface is needed.

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