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The redesign of an introductory physics laboratory course

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Summary. — In this communication, I present the process of transforming the introductory laboratory course at the University of Potsdam from a "concept-based" to a "skill-based" type of course. I describe the new learning goals, the implementation of new activities to reach these goals and the assessment of students' learning in the new setting.

1. – Introduction

Physics laboratory courses (PLCs) are an essential part of the physics curriculum. They offer students the possibility to engage with authentic practices of experimental physics, to understand its nature and to acquire important and transferable skills. However, recent research studies have questioned the effectiveness of traditional prescriptive PLCs to realize those potentials and to improve physics content knowledge [1-3]. Based on these findings, new teaching approaches in PLCs have been proposed [4-6]. Inspired by the literature results and motivated by our own experience, we have transformed our PLC for physics majors at the University of Potsdam (UP) from a "concept-focused" and "cook-book" PCL, which aimed to improve conceptual knowledge acquisition through prescriptive lab activities, into a "skill-based" course, which aims to foster students' experimental skills while engaging them in authentic activities. In this paper, I describe this transformation process and discuss its impact on students' learning.

2. – The course context and transformation

The introductory PLC for physics major students at UP is distributed over the first four semesters of the curriculum. Each semester, students enroll in a separate instance of the PLC. There are typically about 40–60 students per course with an instructor to students ratio of about 1:8. With exception of the fourth semester, there is no formal grading of the PLC.

To transform our PLC at UP we used the model developed by Zwickl *et al.* [7]. It is an iterative process which consists of i) setting learning goals (LGs), ii) developing a

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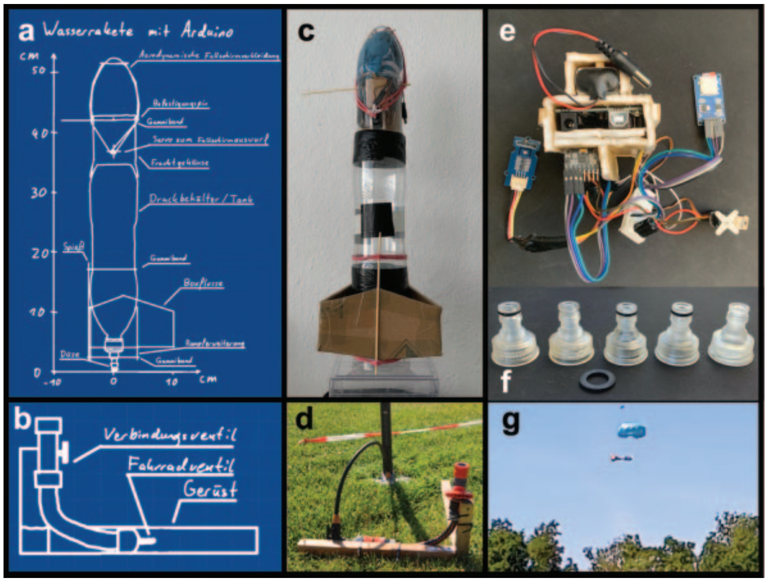

Fig. 1. – Example of a student Arduino-based project. Students studied the flight altitude of a water-propelled rocket as a function of the amount of water in the rocket's water tank and as a function of the launching-nozzle's diameter. (a) Design of the water rocket and (b) launching system. (c) Realization of water rocket and (d) rocket-launching system. (e) Arduino and sensors used for the measurements and motor to activate a parachute system for landing. (f) Nozzles with different diameters for launching. (g) Picture of the rocket descending with the parachute open.

curriculum to reach those LGs and iii) assessing the achievement of those LGs based on students' learning. The results of the assessment are then used to revise the other two components of the model in a cycle.

As new LGs, we want students to acquire the skills of experimental physicists, which can be grouped, as discussed by Zwickl *et al.* [7], into modeling, design, technical and communication skills. Additionally, we want students to develop expert-like views about the nature of experimental physics by engaging in authentic activities (epistemic goal).

We have developed activities that foster a specific set of LGs while keeping the epistemic goal as an overall LG. In those activities, we pay attention to leave students enough space to take initiative and make decisions. This means students are also allowed to do mistakes that do not compromise safety rules in the PLC and are encouraged to learn from them.

To foster design skills, for example, we let students design and realize a self-determined group project based on Arduino microcontrollers [8]. As suggested by Bouquet *et al.* [9], students are free to choose any topic or experimental method for their project. They need to fulfill requirements on safety, budget and time availability and need to measure physical quantities. An example of a student project design is shown in fig. 1.

To foster communication, we created new collaborative group activities in which communication between students is necessary for the successful completion of a given experimental task. For example, a group of 9 students receives several types of lemonades with similar colors and the task to design and construct in four days an optical spectrometer capable of distinguishing those lemonades. Students are only provided with optical elements and a 3D-printer. In order to succeed in the given task in the available time, students have to (self-)organize themselves in subgroups, each one of these responsible for a particular aspect needed to accomplish the assigned common experimental goal. One subgroup of students (subgroup A) is for example in charge of characterizing the optical properties of the sample lemonades. Subgroup B, in charge of the optical design of the spectrometer, relies on the results of subgroup A for the optical requirements. During activities, the subgroups meet on a regular basis to exchange information, keep track on achievements or problems and provide feedback or help to each other.

In the redesigned PLC, we utilize the educational approach called "scaffolding" [4] to support students through their learning process [4]. This is delivered in form of the course structure, framed to let students' abilities grow systematically, through teaching materials and through targeted support by instructors. We also adopt special tools to help students during their experiments, *i.e.*, authentic scientific laboratory notebooks [10], the modeling framework for experimental physics [5] and rubrics [11]. The latter also help us to align our feedback to students with the pursued LGs. An important feature for a successful implementation of the new curriculum, is that all persons involved in the transformation process are familiar with the new LGs and teaching approach. Instructors should in fact support students in their learning in a non invasive way, and keep the focus on students' experimental processes and not on a particular end result.

3. – Assessment

To investigate students' learning, we considered three aspects: i) the feedback of instructors (including the author of this paper), ii) the results of the German version of the Colorado Learning about Science Survey for Experimental Physics (E-CLASS) [12] and iii) students' evaluations.

We collected the feedback of instructors on a regular basis, both directly after each laboratory activity and after students' written work was reviewed. We also asked instructors to provide a general feedback at the end of each instance of the course, describing the main difficulties or problems encountered by students as well as successes. This feedback was used to revise single activities or the general settings of our PLC. After the course redesign, the instructors in the PLC and also the subsequent laboratory courses observed an increase in student abilities regarding measurement uncertainties, systematic errors and laboratory notebook skills. We also observed higher levels of students' motivation.

We used the German translation of the E-CLASS to assess our transformed course. It investigates students' views and attitudes about experimental physics and has been widely used to study PLCs in the US [13] and, more recently, in Europe as well [14, 15].

At UP, we found a small but positive statistically significant overall shift of students' thinking towards more expert-like views [14]. The largest positive shifts are observed for two items regarding students' confidence in solving problems and making decisions (items 17 and 29) [14]. This result is in accordance with our observations that students are engaging more actively and take more (creative) initiative during the lab activities.

We collected students' evaluation throughout the entire transformation process. Students are very satisfied with the reformed PLC. They indicate effective learning in estimating measurement uncertainties and how to work with laboratory notebooks. They also show a higher level of intrinsic motivation during the students' designed projects. The CHE-ranking, the largest German ranking of universities [16] ranked the PLC at the University of Potsdam at the second place among all 38 institutions in Germany. Moreover, the physics students body at UP awarded the transformed PLC in 2021 with the teaching prize of the UP Mathematics and Natural Sciences faculty.

4. – Conclusions

We described here how we transformed the PLC at UP from a "concept-focused" and "cook-book" PLC into a "skill-based" course in which students engage in authentic experimental activities. The details of this transformation are interesting and helpful for the physics education research community and for instructors that plan to or are reconstructing their PLCs.

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