



Blended labs in the engineering sciences - the development of an alternative to laboratory courses using the design-based research approach

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Abstract

There is a great demand for educational formats that can be carried out regardless of location, and inclusion in teaching is becoming increasingly important. Teaching methods should appeal to different types of learners and be accessible to people from different backgrounds. While there are numerous approaches for lectures, seminars and tutorials, the implementation of laboratory courses in alternative formats is still comparatively new and complex.

The compulsory module "Measurement and Automation Technology" at TU Dresden, attended by around 300 students per semester, was faced with the challenge of offering laboratory courses in alternative formats during the COVID-19 pandemic. The choice fell on a blended learning format due to the number of students and because the handling of devices is an essential learning objective.

The research objective is to develop a blended-learning laboratory course on the topic of strain measurement. The study is designed according to the design-based research approach and pursues research questions on the supervision of students and learning obstacles that arise. The evaluation results show that the use of logbooks has led to an improvement in supervision. In addition, initial obstacles to learning were identified during the Blended Lab.

Die Nachfrage nach Bildungsformaten, die ortsunabhängig durchführbar sind, ist groß, und die Inklusion in der Lehre gewinnt an Bedeutung. Lehrmethoden sollten sowohl verschiedene Lern-typen ansprechen als auch für Menschen aus unterschiedlichen Lebensumstände zugänglich sein. Während es zahlreiche Ansätze für Vorlesungen, Seminare und Übungen gibt, ist die Umsetzung von Laborpraktika in alternativen Formaten noch vergleichsweise neu und aufwendig. Das Pflichtmodul "Mess- und Automationstechnik" der TU Dresden, besucht von ca. 300 Studierenden pro Semester, stand vor der Herausforderung, Praktika während der COVID-19-Pandemie in alternativen Formaten anzubieten. Die Wahl fiel, aufgrund der Studierendenzahl und da die Handhabung von Geräten ein wesentliches Lernziel ist, auf ein Blended-Learning-Format. Das Forschungsziel ist die Entwicklung eines Blended-Learning-Praktikums zum Thema Dehnungsmessung. Die Studie ist entsprechend dem Design-Based-Research-Ansatz angelegt und verfolgt Forschungsfragen zur Betreuung der Studierenden und auftretenden Lernhindernissen. Die Evaluationsergebnisse zeigen, dass durch den Einsatz von Logbüchern eine Verbesserung der Betreuung erreicht wurde. Außerdem konnten erste Lernhindernisse bei der Bearbeitung des Praktikums identifiziert werden.

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1. Problem definition

There is a great need for teaching formats that can be delivered from any location. The topic of inclusion is also becoming increasingly important - teaching should not only appeal to different types of learners, but also be flexible enough to be accessible and manageable for groups of people from different backgrounds.

While there are many approaches and research into the implementation of lectures, seminars and exercises, the implementation of laboratory courses in an alternative format is still comparatively new and complex. Alternatives include, for example, laboratory courses as virtual reality or augmented reality [1], remote [2], in blended learning format [3, 4] and as pure simulation [2]. These laboratory formats are explained in detail in the following section.

The Measurement and Automation Technology course is a compulsory module of the Mechanical Engineering degree course at TU Dresden, which is attended by around 300 students each semester. In addition to lectures and exercises, the module includes six laboratory courses. Triggered by the need during the corona pandemic to offer the laboratory courses in an alternative form, the experiments were to be transferred to a new format.

2. Background

When laboratory courses are implemented as **virtual reality (VR)** or **augmented reality (AR)**, virtual elements are added to the face-to-face laboratory or even replaced entirely. The advantage of this approach is that even very complex scenarios can be depicted realistically and authentically. While fully immersive scenarios require the use of VR or AR glasses, partially immersive scenarios can already be realized using computers or smartphones. In both cases, considerable programming effort is required to create these scenarios. One disadvantage of VR scenarios is that students do not learn how to handle the real devices and the errors that occur, as these are only represented virtually. If access to a real laboratory is made possible via a web interface, this is referred to as a **remote** laboratory course. This

allows students to operate the real tools, machines or equipment from any workstation. For such a system, the equipment must be equipped with the appropriate interfaces. In addition, the setup should be carried out in cooperation with the IT department of the respective institution, as access to the university network must be guaranteed. This option is also only suitable for smaller groups of students due to the limited number of remotely equipped workstations in the laboratory [5].

If a laboratory course is implemented in a **blended learning format**, students carry out the experiments at home with the help of the experimental materials provided and digital teaching/learning materials. The exchange about the work process can take place either in person or digitally. As the experiments are no longer carried out in the laboratory or with the equipment available there, the Blended Lab can, in principle, be carried out by any number of students at the same time. As the students no longer have to be supervised for the entire duration of the course, but only at fixed consultation times, there is less need for rooms and the supervision effort is reduced. However, depending on the experiment and the size of the student group, this implementation is associated with high acquisition and maintenance costs.

A laboratory course offered as a purely virtual **simulation** offers the advantage of scalability and enables easy adaptation to a larger number of students. As with the Blended Lab, there is less supervision required and no more rooms are needed to carry out the experiment. As the experiment is simulated by software, there are no material costs for equipping laboratory workstations. However, the students do not practise using equipment or tools. The processes that take place are also simulated and cannot be observed in reality.

The corona pandemic requires a format for laboratory courses that allows to carry them out from any location. In addition, this format must be scalable to a number of participants of approx. 300 students and enable the planning and construction of real experiments. The blended learning format is the only one that meets all criteria and was therefore selected for the new concept.

3. Objective and research question

Teaching-learning formats such as blended learning are becoming increasingly important in higher education. An understanding of the opportunities and challenges as well as concrete experience in the development of Blended Labs are essential for improving the courses offered to students.

Blended learning courses are often characterized by long phases of self-study in which students work independently. In order to provide students with appropriate support during these phases, it is important to be aware of the learning obstacles that arise. This is the only way to improve the support offered and adapt the teaching and learning materials accordingly.

The research objective is to develop a design for an engineering laboratory course on the topic of strain measurement in a blended learning format. The following research questions are derived from this objective:

- How should the supervision of students be implemented in order to provide them with the best possible support in completing their Blended Lab?
- What learning obstacles do students encounter when completing the Blended Lab?

The design guidelines derived from the research presented here can serve as a guide or basis for other teachers to develop their own Blended Lab. They provide important information on the structuring of self-study and attendance phases, the use of digital media and the design of work placement tasks. Overall, answering the research questions contributes to improving higher education in engineering by providing evidence-based insights into the design and implementation of Blended Labs.

The study presented in this paper was conducted according to the design-based research approach. This combines the development and evaluation of innovative teaching-learning approaches in order to generate practice-oriented solutions to real-world problems. A key aspect is the close collaboration between researchers and implementers. The study is carried out in several iteration cycles, each of which includes the following phases [6]:

1. Design or redesign
2. Evaluation
3. Analysis

The evaluation was carried out using a questionnaire containing closed questions and one open question. The closed questions were evaluated quantitatively using descriptive statistics. Qualitative content analysis according to Mayring [7] was used to evaluate the free comments. In addition, interviews were conducted with the caregivers and recorded in the form of key points.

4. Laboratory course (until 2020)

Until the massive restrictions on university operations during the coronavirus pandemic, the laboratory courses in the Measurement and Automation Technology module were carried out traditionally.

The students prepared for the laboratory course independently. After a short technical introduction, the suitability of the students to take part in the experiment was checked by means of a test. After passing the test, the experiment was carried out, evaluated and recorded over a period of three hours. The protocol constituted the graded examination performance.



Figure 1: Structure of the laboratory course "Strain measurement". The positions of the strain gauges are marked with arrows.

The main advantage of the laboratory course is the high-quality equipment that can be used,

which enables precise measurements. This enables students to record reliable and reproducible results. In Figure 1 shows the set-up for the "Strain measurement" laboratory course. The load can be applied via a rotary control and precisely controlled via the force gauge.

5. Methodology

The strain gauges can be connected to the Figure 2 to form a Wheatstone measuring bridge. The disadvantage of this setup is that the actual wiring of the strain gauges is not visible and therefore remains abstract.

The students' task is to select the correct strain gauges, place them correctly in the Wheatstone measuring bridge and thus determine the different proportions of tension or compression, torsion or elongation in isolation.

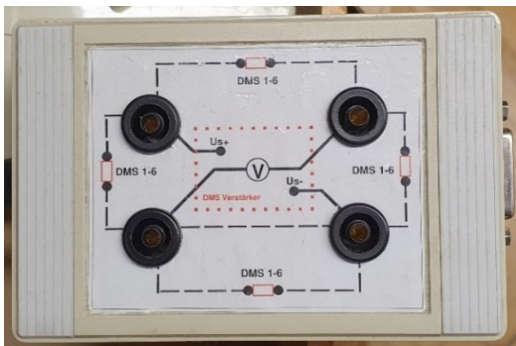


Figure 2: Slots for connecting the strain gauges to the Wheatstone measuring bridge

6. Start design (SoSe2022)

Due to the different prerequisites and framework conditions, the experiments of the traditional laboratory course cannot be adapted unchanged for the Blended Lab. In order to provide all students with the required materials, approx. 300 sets of the experimental setup must be procured. For cost reasons, the set-up should therefore be kept as simple as possible. In addition, the restrictions resulting from carrying out the experiment at home must be taken into account. For example, the introduction of defined loads for certain load types is difficult to implement. Various superstructures with superimposed loads (torsion/bending and tension/bending) were used in the laboratory course. However, torsion, tension and compression cannot be implemented precisely

using simple means. The best load to implement is simple bending.

Bending can be generated in different ways. Two variants that were considered during conceptual design were (a) bending by deflection by a certain distance and (b) bending by applying a defined load. The deflection by a certain distance could be achieved using a set screw, for example. However, this setup requires a comparatively complex test geometry.

Bending by load can be generated by attaching a defined mass to the measuring geometry. This can be realized with very simple geometries, such as the bending beam. The bending stress can then be determined using the lever arm, the acceleration due to gravity and the mass used. All that is needed to determine the mass is a kitchen scale, which can also be found in most student households.

The advantage of the bending beam is also that the calculation of the stress state was practiced extensively in the basic course and is therefore familiar to the students.

Another prerequisite for the design of the experiment resulted from the existing laboratory courses. As the Arduino microcontroller is already used in these, it should also be used in the "Strain measurement" Blended Lab to record the measured values.

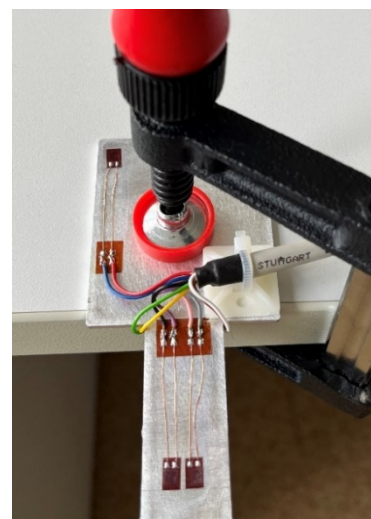


Figure 3: Arrangement of the strain gauges on the bending beam

A design was chosen that allows all Wheatstone measuring bridges to be implemented and requires the fewest strain gauges. A total

of five strain gauges were therefore attached to the bending beam. Two are located on the top side, two on the bottom side and one passive strain gauge on the mounting plate. The arrangement of the strain gages is shown in Figure 3 to recognize.

The principle and the actual wiring of the Wheatstone measuring bridge should also be made directly visible in the newly designed experimental setup. This is easy to implement using the Arduino. Depending on the task, the students can plug together the appropriate Wheatstone measuring bridge on the breadboard. In Figure 4 shows how three fixed resistors are connected to an active strain gauge to form a quarter measuring bridge.

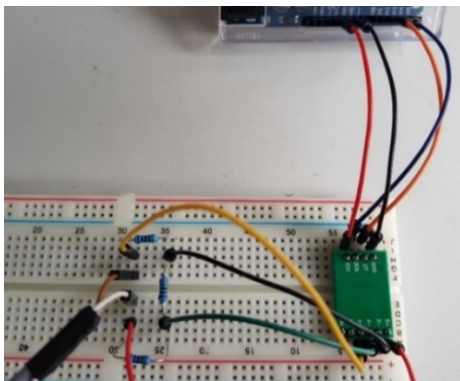


Figure 4: Electrical circuit for the "Strain measurement" experiment

In Figure 5 shows the overall setup of the experiment. The bending beam is attached to the table top with a clamp. A water bottle is attached to the hole using a thread as a weight. A bottle is advantageous as it can be filled with water to increase the load. The analog-to-digital converter converts the analog measurement signal and simultaneously amplifies

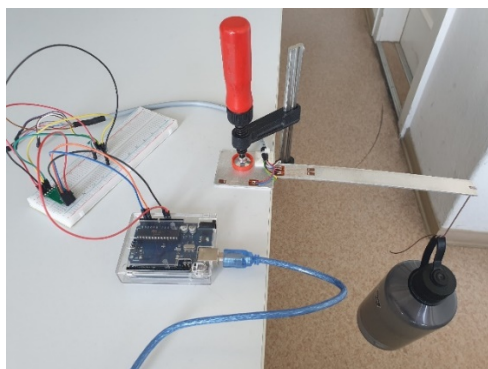


Figure 5: Overall setup of the "Strain measurement" experiment

The diagonal voltage of the quarter-bridge. The values are recorded using an Arduino script and output via the serial monitor.

Procedure

The biggest difference compared to the laboratory course is that the Blended Lab is completed at home in partner work using the components and digital materials provided. Students borrow the experimental materials from the department at the beginning of the semester.

Two face-to-face meetings are offered to support students in their work. One during the processing time (interim meeting), the other after the submission of the protocol (debriefing).

In the interim discussion, the participants solve sub-problems that serve to bring the students into an exchange and to intercept hurdles in the processing in advance.

The students only have one interim meeting, and it is not possible to predict what level of work and knowledge they will bring with them. The tasks are intended to draw their attention to problems that they may not yet have encountered.

The debriefing serves to clarify any questions that remain unanswered and thus ensure the technical accuracy. In addition, the minutes should be returned here and individual feedback given at the same time.

The processing period extends over three weeks and starts with the upload of the digital materials. After one week, the interim meetings begin, which are offered over a period of seven days. Students then have another week to finalize their work and submit the report. The debriefing sessions take place in the week following the submission of the report.

Task

The main objective of the Blended Lab is to enable students to carry out independent scientific experiments. For this reason, the tasks have been designed to resemble the procedure for working on a research paper. The following tasks are to be completed in groups of two:

- Calculation of the theoretical model
- Characterization of the system in the unloaded state

- Comparison of quarter and full gage bridge
- Investigation of interference
- Design of an own circuit for temperature compensation

First, the students should find a model for the theoretical description of the test object in order to be able to validate their measurement results later.

Since the strain gauges were all manually glued to the side beams and therefore behave differently, the system is then characterized in an unloaded state.

In the third task, the bending beam is loaded step by step. The measurement is carried out successively with a quarter and a full measuring bridge. The experimentally determined data are compared with each other and with the theoretically expected values.

When carrying out experiments, it is also important to consider which factors can influence the measurement results. This is the only way to avoid them. Therefore, in the fourth task, the students should consider what interferences exist and examine the effects of three influences in more detail.

In task 5, the students use the knowledge they have gained to plan an experimental setup for temperature compensation and demonstrate the correct functioning of their circuit.

According to the module description, students should spend a total of eleven hours on the Blended Lab, with four hours for carrying out the experiment and seven hours for preparing, evaluating and writing the report.

Results of the evaluation

The evaluation of the initial design focused primarily on the implementation and assessment of the support services. In the evaluation, 53% of students stated that their questions were not answered in the support services. At the same time, the supervisors criticized the fact that the current design of the interim meeting required them to spontaneously provide correct answers to unforeseeable questions.

The feedback also showed that the debriefing does not work as intended. It is not possible to check the protocols in the short period between submission and debriefing. This means

that there is no basis for the feedback discussion with the students. In addition, there is little demand from students for this support service.

The feedback from students and supervisors shows that the supervision concept needs to be adapted for the next round. The students' questions must be answered more reliably. At the same time, the supervisors must be given adequate preparation.

Another major point of criticism was identified from the free comments. 40% of all comments related to the time required to complete the Blended Lab, which students felt was too high ("implementation was far too time-consuming"). To check this, the evaluation will be adapted for the redesign. In the future, students will be able to indicate the amount of time they spent on the Blended Lab so that this can be compared with the planned workload.

7. Redesign (winter semester 2022/2023)

In the next iteration, several measures were taken to improve support. These include the introduction of a logbook to accompany and structure the self-study phase and the submission of student questions before the attendance date to enable the supervisors to prepare in a targeted manner.

The logbooks in which the students write down their questions about the Blended Lab must be uploaded to the OPAL learning platform before the consultation appointment. This allows the group of supervisors to deal with the questions in advance and collaboratively develop a question-and-answer catalog. This is intended to reduce preparation time and the workload of those responsible, as well as to create a uniform quality standard for supervision. The questions also form the basis of the student-centered consultation. In line with the principle of just-in-time teaching, the questions are taken one-to-one from the logbooks and printed on cards. This ensures the authenticity of the event, as the participants can find their own questions and thus recognize that the consultation is about solving actual current student problems.

Due to the low demand and in order to relieve the supervisors, the debriefing is omitted from

the redesign, so that the interim meeting is the only consultation appointment for the students.

The so-called "semester overview" has been introduced to support time management during the self-study phases. This is shown at the beginning of each lecture and places the course in the context of the semester as a whole. The principle is illustrated in Figure 6 illustrates the principle.

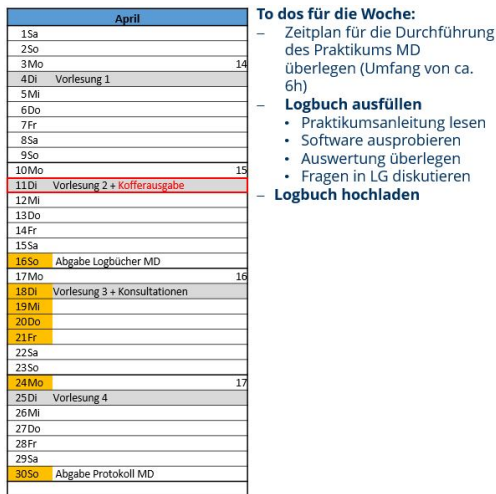


Figure 6: Semester schedule with the tasks to be completed in each week. The abbreviation MD denotes the "Measurement Dynamics" Blended Lab. LG stands for learning group.

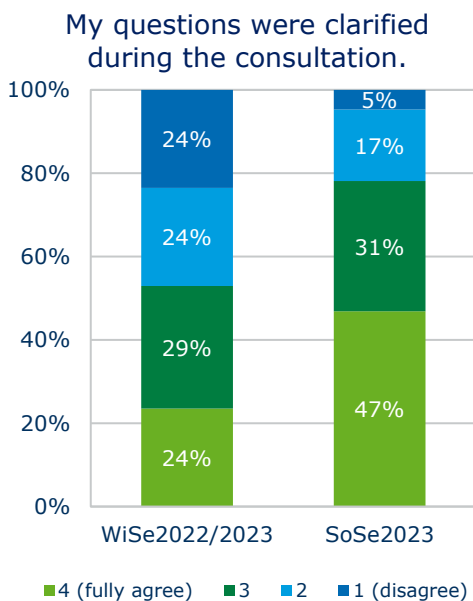


Figure 7: Comparison of the results for the item "My questions were clarified in the consultation" between the consultation in winter semester 2022/2023 and the consultation in summer semester 2023.

This draws attention to important upcoming events such as consultation dates or deadlines. In addition, to dos are listed for the respective week, which are not mandatory, but give students an indication of the tasks to be completed and the workload involved.

Procedure

In contrast to the initial design, the digital materials will be made available at the start of the lecture period in the winter semester 2022/2023. Students will therefore be able to work on the Blended Lab from the start of the semester. In practice, however, the starting time is determined by when the Blended Lab's topic is covered in the lecture.

A new addition is the processing of the log-book, which must be handed in at the weekend before the start of the consultation.

By adapting the care, there is now only one round of consultation appointments, which extend over a week.

Task definition

As the students criticized the time required to complete the Blended Lab in the first run, the task "Investigation of interferences" was shortened for the redesign. Now only two instead of three interferences are to be investigated. The students are also free to choose the bridge circuit, so that the comparison between quarter and full measurement bridges is no longer necessary.

Results of the evaluation

The starting point for the changes to the support described was the result of the first evaluation, in which only 53% of students agreed that their questions were clarified. This was assessed using the item "My questions were clarified during the consultation", for which the students were able to indicate their assessment on a Likert scale from 1 (disagree) to 4 (strongly agree). Values 3 and 4 are rated as agreement, while values 1 and 2 are interpreted as disagreement.

The consultation was then adapted in line with the concept described above. If the result is compared with the information from the evaluation in the summer semester 2023 after the new consultation concept was implemented, a significant increase in approval to 78% can be

seen. It should be particularly emphasized that the largest increase is in the 4 rating (strongly agree) at the expense of the lowest rating 1 (disagree) (cf. Figure 7). The items were rated from $n_{alt} = 68$ respectively $n_{neu} = 64$ students. This trend can also be seen in the free comments. In the first evaluation, 31 participants used the feedback function. Six comments criticized the fact that questions were not answered during the consultation. Four other comments emphasized the need to clarify open questions outside of the consultation: "As no questions were answered by email, we felt very alone."

In the second evaluation, 31 participants also used the free comments. However, only two comments stated that questions were not answered in the consultation. Lack of time was cited once as the reason: "Questions not clari-

fied in consultation due to lack of time." In contrast to the first evaluation, there is also positive feedback in which the consultation is praised ("Consultation is great").

During the evaluation of the redesign, learning obstacles in the preparation, implementation and evaluation of the Blended Lab were also recorded. It was particularly noticeable that the students were very unsettled by errors in the implementation and deviations in the measured values. In addition, there were major difficulties in the evaluation when using Excel. The learning obstacles identified are shown in Figure 8 listed.

When the processing time was surveyed, the students also stated that they needed an average of 21.6 hours for the "Strain measurement" Blended Lab. This is significantly more than expected.

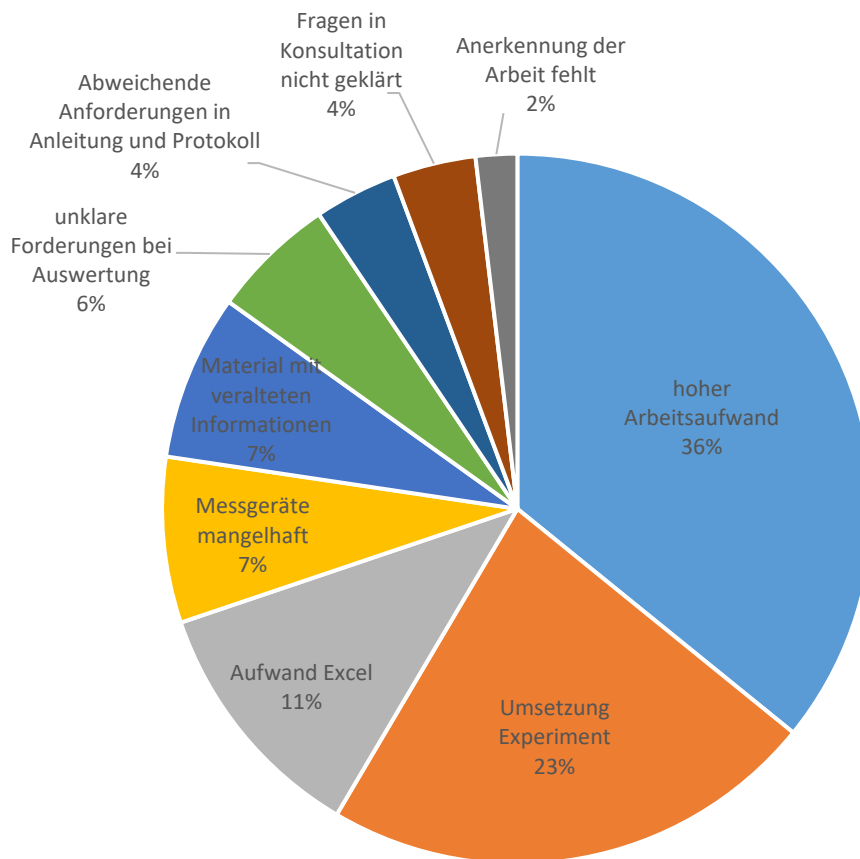


Figure 8: Students' learning obstacles when working on the "Strain measurement" Blended Lab

8. Summary

The results of the evaluation show that the redesign has significantly improved support. The use of logbooks was particularly successful,

not only relieving the burden on the supervisors, but also making the consultation more student-centered. Initial obstacles to learning were also identified by students when working on the Blended Lab, which can be taken into

account in subsequent iterations. The biggest point of criticism from students is currently the high workload. Another aspect is that many students have problems with the implementation of the Blended Lab experiment. There is a great deal of uncertainty when errors occur or results do not meet expectations. In addition, the use of Excel, which is used for evaluation and logging, poses a challenge, as many students are still inexperienced in using this program.

The learning obstacles identified with the help of the evaluation indicate that the Blended Lab requires more planning and organization of one's own work processes and the coordination of partner work. Time management also differs from that of conventional laboratory work placements, which have a clear start and end time. The changed laboratory course format alone means that the skills and abilities required for the work shift. The greatest challenge of the Blended Lab is no longer the pure acquisition of knowledge. Instead, the changed format requires the acquisition and application of so-called 21st century skills. These include independence, the ability to work in a team, initiative, creativity in solving problems, competence in dealing with media, data, information and technologies as well as strong communication skills, which also include the ability to convey one's own thinking in an understandable way [8, 9]. The skills shift towards 21st century skills is a positive development that supports sustainable engineering education. The acquisition of skills made possible by blended labs should be promoted by further adapting the work tasks and supported by a suitable digital presentation.

9. Outlook

The change in requirements due to the format of the Blended Labs was not taken into account in the initial design of the laboratory course. For this reason, the next step is to define the concept of competence in the Department of Engineering in a uniform manner and to re-examine the content, examination performance and competence-oriented learning objectives for coherence in accordance with constructive alignment.

In addition, it should be clarified whether the

acquisition of certain skills can be brought forward. For example, the use of Excel could already be trained in the calculation exercises, which would reduce the Blended Lab's workload. One way of dealing with students' uncertainty in the event of deviating measured values would be to list certain types of errors and their causes in an FAQ. This could make it easier for students to assess and rectify errors.

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