Lessons Learned 2, 2 (2022)
Submitted: 14. 10.2022
Accepted: 09.12.2022
DOI: https://doi.org/10.25369/ll.v2i2.58
ISSN: 2749-1293 (print); 2749-1307 (online).

Saxonian Joint Project D2C2 "Implementing Participatory and Discipline-Specific Approaches to Digitalization at the University: Competencies Connected"

Didactic Insights into (partially) Digitalized Workshops and Laboratories

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Abstract

Das Projekt „D2C2 – Digitalisierung in Disziplinen Partizipativ Umsetzen :: Competencies Connected" setzt sich zum Ziel, aus den Erfahrungen der Covid-19-Pandemie zu lernen und Digitalisierung in der Lehre evidenzbasiert weiterzuentwickeln. Zehn sächsische Hochschulen sowie die BA Sachsen widmen sich zentralen Herausforderungen (teil-)digitalisierter Lehre. In diesem Rahmen fokussiert die TU Dresden gemeinsam mit der HTW Dresden die Lehre in (teil-)digitalisierten Laboren und Werkstätten. Ziel ist es, die Bedarfe sächsischer Studierender und Lehrender aufzugreifen und letztere aktiv dabei zu unterstützen, ihre Lehre in Laboren und Werkstätten weiterzuentwickeln. Dieser Artikel widmet sich einigen theoretischen Grundlagen der Didaktik in (teil-)digitalisierten Werkstätten und Labore mit Fokus auf dem Lehrveranstaltungsformat Praktikum. Es erfolgt eine Differenzierung der verschiedenen Ebenen der Digitalisierung, die im Werkstatt- oder Laborpraktikum und bei dessen didaktischer Umsetzung bedacht werden sollten. Veranschaulicht werden die verschiedenen Ebenen durch Verweise auf good practice Beispiele.

The project "D2C2 – Implementing Participatory and Discipline-Specific Approaches to Digitalization at the University: Competencies Connected" takes the experiences of the Covid-19 pandemic and aims to enhance digitalization efforts in teaching based on evidence. Ten Saxonian universities, joined by BA Sachsen, are addressing the central challenges of (partially) digitalized teaching. In this context, TU Dresden and HTW Dresden are focusing on teaching in (partially) digitalized workshops and laboratories. The goal is to address the needs of students and teachers and to actively support the latter in further developing their teaching in workshops and laboratories. This article is dedicated to some theoretical, didactical basics of how to teach laboratory courses in STEM subjects (German: "Praktikum"). It describes the different levels of digitalization that should be considered in laboratory courses and their didactic implementations. The paper sheds light on these different levels by referencing some good practice examples.

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This article was originally submitted in German.

1. D2C2: Workshops and Laboratories

During the Covid 19 pandemic, teaching in workshops and laboratories either had to be moved entirely into the digital space within a very short period of time, or partially digitalized opportunities for participation had to be created. As a consequence, a multitude of technical as well as didactic questions and problems arose.

The Saxonian joint project D2C2 is dedicated to address central challenges of (partially) digitalized teaching. Within the framework of this project, TU Dresden and HTW Dresden are focusing on teaching in (partially) digitalized laboratories and workshops. Through intensive research as well as broad networking with other universities, we try to enable a versatile exchange of expertise and experiences. The goal is to address the needs of Saxonian students and teachers and to actively support the latter in further developing their teaching in laboratories and workshops. In doing so, we aim to offer a didactically sound, high-quality and future-oriented education to students that takes aspects of sustainability and resource efficiency into account.

Connecting practice and theory is a special characteristic of workshops and laboratories, which in turn makes it necessary to pay close attention to specific didactic considerations. The general learning objectives in laboratories and workshops are extensive and versatile. Exploratory action is to be encouraged in order to gain a conceptual understanding of the subject matter. Hands-on experiences are offered in an experimental setting; students train how to collect data, communicate, and discuss results. Action-oriented skills, creative thinking, and working responsibly in teams are also among the learning objectives in workshop and laboratory [1]. Even beyond pandemic-related developments, work spaces within and outside the university are increasingly digitalized. There is thus pressure on those who teach to modernize courses that take place in laboratories and workshops [2]. Digitalized workflows in workshops and laboratories have long ceased to be a rarity. For example, the term remote laboratory (i.e., remote lab; [3]) has been used for about 30 years to characterize real laboratory setups that are automated and made available via communication technologies [4]. Technological advancements as well as changing job profiles in the professional world require universities to rethink their practices. As a consequence, efforts to digitalize teaching in this area have become increasingly important in recent years.

Various networks and projects at German universities have emerged in connection with digitalized labs, including the research projects Open Digital Lab for You (DigiLab4U), CrossLab, Dist-Lab, MINT-VR-Labs and SHELLS. In addition to these, there are numerous individual projects at universities or individual institutes, complemented by digital offerings from business and industry, e.g., Labster and LabsLand, two commercial internet platforms. All these examples share that they are primarily dedicated to technical challenges of virtual laboratory settings. Didactic aspects are mostly of secondary nature. Therefore, our project sets out to identify didactic challenges and requirements. Together with teachers and students, we aim to develop sustainable solutions of how to best teach courses in (partially) digitalized workshops and laboratories.

2. The Laboratory Course “Praktikum“

Demands placed on digitalization are becoming increasingly subject-specific, making it necessary to develop subject-specific solutions from a didactic perspective. As a crucial component of STEM studies, workshop and laboratory courses are traditionally related to STEM. These traditional teaching formats differ greatly from various forms of workshop and laboratory work practiced in other fields, e.g. in social work, nursing, and the arts and design. Because of its fundamental importance for STEM education, this article is devoted specifically to a teaching format in the STEM field which is known as “Praktikum” among German universities

Contrary to their name, workshop and laboratory practical courses do not necessarily require the physical space of the workshop or laboratory. Rather, they involve a specific continuum of activities in the sense of workshop and laboratory work. Examples include practical courses in science, e.g. in analytical chemistry and molecular biology, practical courses in engineering (e.g. in automotive engineering and electrical metrology), in mathematics (e.g. in numerics and stochastics), and in information technology (e.g.in computer graphics and robot programming).

By the term ”Praktikum” we refer to a practical course in STEM education at universities that is part of the official curriculum. It serves students to acquire or deepen theoretical knowledge while also acquiring practical skills, often also psychomotor skills. Students apply subject-specific theoretical knowledge in a practical way. They handle materials and substances, instruments and equipment or data and information. Work processes and procedures as well as scientific practices, including a critical examination of their own work, ought to be learned and applied to different situations. Conditions pertaining to time and place as well as teaching frameworks vary greatly and are specific to each course, offering students different degrees of independent work time and guidance. Alternative terms for “Praktikum” are laboratory or labcourse, experimental course or practical laboratory exercise.

Subject-specific technical infrastructure and equipment determine the distinction from other courses, such as lectures and seminars. The “Praktikum” is further characterized by students’ independent work with this equipment. It may include, for example, chemical laboratory equipment, mechanical tools, electronic machines, and specialized hardware and software in the IT field. The students’ practical work ranges from measuring and analyzing to experimenting, manipulating, synthesizing, constructing, repairing, controlling, and programming. Such a practical course can last from a few hours (as a single unit) to many hours (block module). Sometimes students work under extensive guidance, sometimes they do so entirely independently.

In a laboratory, the lecturers often do not teach merely by themselves but are supported by employees such as laboratory engineers, technical assistants, student assistants, and doctoral students. In this article, we refer to all of these people as teachers.

The course “Praktikum” consists of three successive phases: Preparation, consolidation, and follow-up. The practical activities of the students happen primarily during the consolidation phase. There are often two examination periods: A preliminary examination or “Antestat” takes place before the consolidation phase begins. A final exam or “Abtestat” is conducted in the follow-up phase.

3. Reasons for Digitalization

The digitalization of practical laboratory courses is usually associated with remote experiments, working in virtual reality spaces, and digital data acquisition. However, this is only part of the possibilities that this topic area encompasses. Digitalization already starts with the use of digital communication channels or teaching materials.

The reasons for and motivations behind digitalizing internships vary (see back, Info Box 1). They range from enabling remote learning to helping students learn how to handle novel technologies relevant to their field of practice. On a purely organizational level, efficiency can be increased and barriers, in terms of time and location, can be reduced for all participants. On a didactic level, the digitalization of internships makes it possible to expand or modify teaching content and thus increase the practical relevance with regard to Industry 4.0. In their 2019 study “Engineers for Industry 4.0,” the IMPULS Foundation offers an overview of current requirements for engineers [5]. The study emphasizes that universities must significantly adapt and modernize the learning goals in engineering subjects – a difficult task since university structures are not very flexible and often lag behind current developments. However, skills in computer science, data science, and data security have become indispensable to any engineering study program. In the natural science, similar dynamics, albeit to a lesser extent, can be observed. Moreover, digital teaching tools are also used for illustration purposes and can thus increase students’ learning success, for example by using various means of digital simulation. We suggest that several reasons play into teachers’ decisions to digitalize practical courses outside of emergency remote teaching. Just as there are different motivations behind digitalization efforts, digitalization can be realized in numerous ways. However, the specific reasons are decisive for what exactly (level of digitalization) and to what extent (degree of digitalization) changes should be implemented. For example, suppose spatial flexibility is desired in a course. In that case, changes to the ways in which teachers and students interact as well as their working environment and equipment should be considered. There are possibilities to either fully or partially digitalize courses. One lesson we learned in recent years is that digitalization in labs or workshops is sometimes quickly rejected, partly because it is associated with a holistic shift of labs and workshops into the digital sphere. The various levels and degrees of digitalization are not always sufficiently specified, so misunderstandings may occur. In the following section, we present various levels of digitalization and provide references to some “good practice” examples from Germany and abroad.

4. Levels of Digitalization

In practical lab courses, students interact with teachers in a variety of ways. They also interact with other students, with their working environment as a learning space, infrastructure or equipment, and with working materials. Furthermore, students encounter processes such as technical procedures or chemical reactions, which they influence through their practical work. The same applies to information and data that they receive, generate, or process themselves. On the one hand, the aspects mentioned reflect the complexity of the course. On the other hand, they indicate the variety of potential possibilities of digitalization. In this context, we describe four levels of digitalization (see Info Box 2). From a didactic point of view, there are specific challenges to be considered for each level. For this reason, a distinction and identification of the respective level are fundamental if teaching practices in workshops and laboratories are to be investigated and further developed.

Work Environment

Traditionally, the term work environment is understood to mean the physical space of the workshop or laboratory. In the context of the “Praktikum,” however, the work environment also describes the subject-specific physical infrastructure and equipment that students use. Students must be able to find their way around the work environment and handle the relevant equipment, machines, and aids safely. If digitalization takes place entirely or partially at this level, the challenge arises of getting to know and handling this changed environment. For example, if a real experiment is converted into a remote experiment, students potentially need different prior knowledge and skills than in the real laboratory. These may include some basic knowledge in data processing and programming or competencies in independent problem analysis, since the experiment may have to be conducted independently at home. Often, groups are heterogenous and students do not share the same knowledge. Instructors face the challenge of identifying what new skills are needed by students and how they can be acquired. Thus, we recommend conducting a survey before or at the beginning of a term, in which students are asked to assess their previous skills. Pfeiffer and Uckelmann, [6] address changing requirements, such as those that arise when working with IoT (Internet of Things), in the information logistics practical course with a modified LabTC approach. In the initial elaboration phase, students can independently work through various learning resources in the learning management system to prepare for the subsequent laboratory experiment. Technical basics, in this case how RFID systems work, are also taught as part of this preparation. Asynchronously conducted units such as these provide a gateway into and subsequent orientation of the on-site working environment.

Processes

In practical lab courses, students learn to initiate, control, manipulate and monitor chemical reactions and technical processes. If these activities are no longer performed traditionally (analog) but digitally, the challenge arises to illustrate processes to students adequately, e.g. a chemical reaction that is controlled and observed remotely rather than directly on site. For an effective illustration, sometimes simply screening video may not be sufficient. Substances and reaction steps may have to be specially characterized by signals such as sound, optical effects, or even magnification and modeling. Staining of the real substances is also an option if they are difficult to distinguish, as is done, for example, in Ines Aubel's biotechnology remote lab in the CrossLab project [7].

Data

In practical lab courses, data from measurements, tests, and experiments are collected, documented, and processed. Traditionally, students read and transfer measures and other data from analog devices and create a handwritten protocol, e.g. by drawing a measured value diagram with a pencil and ruler. The process seems antiquated, but makes the underlying principle comprehensible to students. If data is no longer processed analogously and purely manually, but is automatically collected and processed digitally, the processes involved must be broken down transparently. Furthermore, students must be able to work with appropriate data software. For example, the Department of Physics and Electrical Engineering at the University of Bremen publishes a digital data sheet titled "Hints for Practical Training and Evaluation of Measurement Results" [8] to enhance students' understanding of data handling. Nowadays, data in laboratories is more frequently stored with the help of electronic protocols and lab books. Sebastian Schöning provides a list of possible digital solutions as well as important selection criteria on the website of the Fraunhofer Institute under the topic Electronic Laboratory Notebooks [9].

Interpersonal Communication

This level describes the interaction of (a) teachers and students with each other for the purpose of training and (b) students with each other in the context of group work. According to this classification, two unique features occur in practical lab courses:

(a) The supervision of students by teachers in practical lab courses is often done individually and thus intensive. Training in these courses is characterized by direct feedback (locally and temporally synchronized) at the students' workplace. The interaction often occurs on the spot. It includes, for example, brief verbal instructions on how to proceed with work, comprehensive explanations of theoretical background and safety measures, as well as manual demonstrations and assistance with current work steps. The individual feedback supports students in overcoming obstacles, so that they can successfully complete a practical learning unit in the specified time. If the communication between teachers and students takes place only digitally, e.g. by video conference, the local and often also temporal proximity to the students' practical work is missing. Teachers must find a way to compensate for the difference in location and time. An example of this is the so-called Lab@Home format. Students carry out the practical work at home, e.g. with the help of mobile experimental equipment. Teachers are not on site, but accompany the students' work from a distance, using digital communication channels, e.g. online chats, forums, or video conferences. In this context, it has proven helpful to prepare students for the practical unit by offering examinations or self-assessments, testing the knowledge they later require. Preliminary discussions of practice-specific knowledge, if necessary, can also be helpful. Good examples of this are the LabBuddy project at the University of Leiden [10] and the adaptation of the so-called "Flipped Lab Concept" in the chemistry internship [11] by Dirk Burdinski at the Technical University of Cologne. As preparation, Burdinski offers instructional videos that accurately depict the practical activity. In order to integrate timely and individual feedback, he defines precise time frames that schedule when students perform their work and at what time they receive feedback via video conference. This strategy is also successfully applied in the digitalized physics practical course at the University of Paderborn [12].

(b) The second unique characteristic of practical lab courses on the level of interpersonal communication is students' interaction with each other. They mostly work in teams, i.e. in groups of two or more students. On the one hand, working in teams is a necessity due to limited resources and capacities. On the other hand, teamwork is also often deliberately chosen to train students' collaboration and communication skills. Traditionally, group work takes place directly and synchronously in the workplace of the workshop or laboratory. If this synchronicity is no longer given and the students have to organize their collaboration with the help of digital communication channels, new steps need to be integrated into the work process. Students are asked to coordinate their working conditions in terms of time and place individually. They have to navigate a digital space that is characterized by shared documents and/or remote experiments, and the mutual illustration of practical work steps via digital communication channels. In her blog entry for the Hochschulforum Digitalisierung, Elisabeth Mayweg describes how digital formats of collaborative learning can be successfully used at the university [13]. Among other things, gamification is one way to make optimal use of virtual lab environments in the context of teamwork. Here, playful, even competitive elements and processes are used to increase students' learning success. The Gaming Lab of the Bremen Institute for Production and Logistics GmbH [14] deals specifically with this topic. The MINT-VR-Labs project at Berlin University of Applied Sciences should also be mentioned in this context. In this project, virtual laboratories are created to train students in scientific laboratory experiments [15]. These experiments contain playful components, which create a potential for gamified teamwork and, in turn, show that digitalization can not only be a challenge, but also an enrichment.

5. Didactic Challenges

As the previous sections indicate, digitalization in workshops and practical lab courses is characterized by a complexity that should not be underestimated. In order to better grasp individual challenges, the project D2C2 currently conducts a series of surveys. Based on an analysis of the current situation and further networking, training opportunities are to be developed for teachers that meet their needs. Our research sheds light on achievements and experiences that teachers and students have gained in recent years. We want to share these unique insights in a structured form with other teachers and students. In doing so, we must adequately address ongoing challenges whenever we want to implement new ideas. Although these surveys are still ongoing, we would like to provide a brief insight into a quick survey we conducted during the 4th Lessons Learned conference at TU Dresden in July 2022. Immediately following a project presentation, we asked teachers present at the conference what they view as the biggest challenge in implementing digitalized laboratory courses. Based on the 21 responses we received, we formed five clusters. These clusters provide a first impression of the various challenges that must be faced (see Fig. 1). It is important to note that the results of this small survey cannot and should not be read as representative. The value of such a quick survey lies, among other things, in the specific formulations that participants choose when asked right off the bat. On a discursive level, these answers provide useful insights whenever they are read closely and analyzed in more detail. Firstly though, let us state the basic parameters of the survey: the survey took place unannounced and participation was voluntary. We conducted the survey anonymously, in written form, with both a digital and analog submission form available to participants.

Six of the given answers point to challenges in effectively guiding students. Supervision is made more difficult by high numbers of students and by aspirations of some to involve all students equally. These difficulties are echoed by answers that mention technical problems, which also account for a high proportion. In part, the equal inclusion of all students is made impossible because not all students own adequate technical equipment or experience technical problems. At the same time, the demands on students and teachers are increasing. Among other things, haptic elements are often missing from digital settings, thus presenting a lack of practical relevance. In some cases, however, the focus is shifting to other skills, e.g. the handling of software. The given answers reveal that responsibility for deficits is often placed on the individual students, e.g. "many students cannot handle MS Excel." In their answers, participants did not refer to external structures, e.g. "as school, students were not taught how to use MS-Excel" or "the university does not offer classes that introduce software programs." A similar tension is inherent in the word "motivation," which was mentioned several times by participants. Students are said to lack motivation and active participation in class. Since motivation is not a measurable entity, partici-

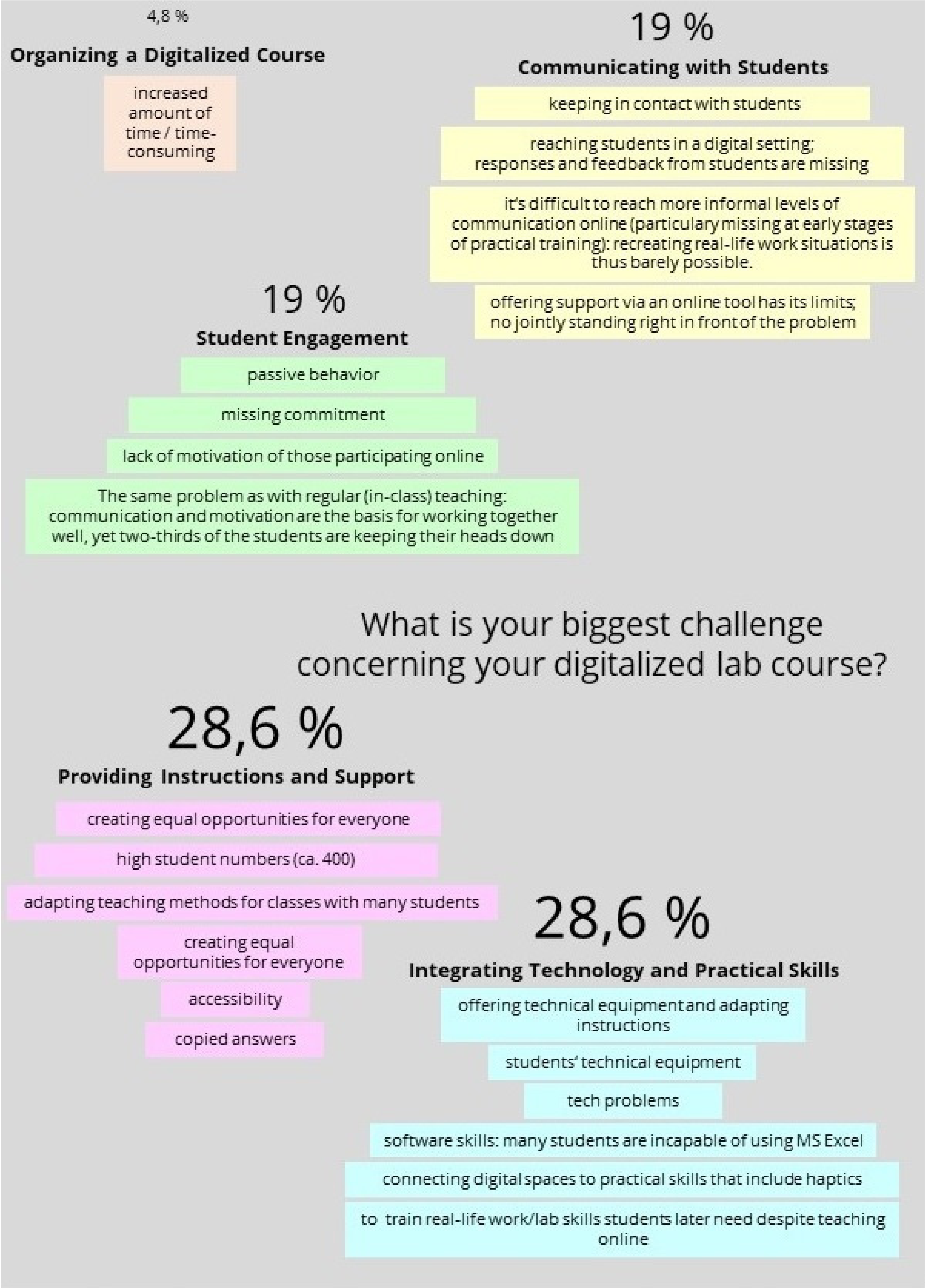

Figure 1: Results of a quick survey conducted at "Lessons Learned" conference (14th and 15th July 2022). Participants were asked, "What is your biggest challenge concerning your digitalized lab course?" Answers were provided in written form, either online (via "invote") or analogous (using file cards). In total 21 answers were handed in. The original answers are pictured in the colored boxes above; for a better overview, they were categorized subjectively. Percentage quotations show ratio of a respective category in regard to the quantity of all answers.
The survey was performed anonymously, randomly, and voluntarily. Results are not representative and do not reflect any scientific findings.

Info Box 1: Potential Reasons for Digitalization in Lab Courses

Organizational Issues

Increasing Efficiency	Removing Barriers
Conserving resources, like time and financial means	Flexible time management for students regarding usage of lab equipment and learning material, e.g. for working or parenting students
Automatization and optimization of processes, e.g. by using data networks or digital tools for control, organization, documentation, communication etc.	Location flexibility: remote teaching is possible, e.g. during a pandemic or to improve inclusivity
	Possibility to join students and teachers at other institutions and work together remotely, e.g. international collaboration
	Informatization: Creating and using digital information, e.g. learning analytics
	Improving working conditions of teachers, laboratory staff, and students, e.g. by replacing analogous with digital instruments, machines, and equipment

Didactical Issues

Improving Teaching Quality	Expanding Course Content	Increasing Practical Relevance
Increasing learning success & illustrating learning contexts, e.g. using virtual simulation	Helping students to grasp recent methods and handling of (partially) digitalized equipment, machines, instruments, hardware as well as modern software	Teaching methods that are relevant in regard to industry and research (in regard to 4IR, Fourth Industrial Revolution)
Creating additional opportunity for exercise, trail and error and repletion of experiments to gain more insight into the learning matter	Creating the possibility to work and learn remotely with laboratory facilities, machines, equipment, hardware, and software that cannot be provided locally, e.g. remote control experiments	Creating extensive connections of theory and practice as well as enabling more profound insight into industry and research by using digital broadcast
Increase in activity during the self-instruction phase, e.g. through instruction videos or interactive screen experiments, in addition to written learning materials	Training of competencies concerning the handling of digital or digitalized objects and applications in the fields of technology and communication	
Extend variety of didactical methods, e.g. gamification as playful competition		
Addition or improvement of examination methods		

pants interpret and classify their students' behavior rather subjectively. It cannot be determined whether the students are, in fact, unmotivated or whether structural reasons underlie this appearance. It is all the more revealing that several instructors have chosen the term/phrase "(lack of) motivation." The answers illustrate a tendency towards student-related problem analysis. At the same time, structural problems are rarely addressed. To be clear, we do not wish to judge any of the given answers. Instead, we want to draw attention to ways in which students are discursively situated within debates about teaching. As

Info Box 2: Areas of Digitalization in Lab Courses

Laboratory environment

- Hardware digitalization:
    - digital addition to analog equipment
    - replacement of analog equipment by digital equipment
- Connecting hardware within a network
    - digital network and interaction of physical and virtual objects
        - local control (e.g. Internet of Things / IoT)
        - remote control (e.g. remote lab)
- Lab@Home:
    - students receive mobile experimentation kits (e.g. Arduino Engineering Kit)
    - students experiment with the help of home supplies (e.g. www.biotopia.net)
    - students experiment with the help of mobile digital devices like sensors of smartphones and mobile apps (e.g. MATLAB mobile, phyphox - Physical Phone Experiments)
- digital simulation:
    - of physical lab environment as (partially) virtual environment in 2D or 3D
        - local simulation (e.g. VR, AR, local simulation on screen)
        - online simulation (e.g. online simulation on screen)

Processes and Procedures

- digital documentation and illustration of processes, e.g. chemical reaction
    - audio-visual presentation only (e.g. video documentation)
    - interactive presentation (e.g. interactive screen experiments, branching scenarios, ultra concurrent remote lab)
- digital modelizing of physical objects
- digital simulation of physical processes
- digital allusion of physical processes

Data

- digital data in- and output
- digital data documentation
- digital data processing and data processing automation
- digital data transfer
- finding and using the digital data of others (e.g. from online database)

Interpersonal communication

- digitalized or digitally created learning material
- digital communication tools:
    - synchronous communication (e.g. video conference)
    - asynchronous communication (e.g. email)
    - digital organization tools
    - digital collaboration tools
- digitally supported work in groups (e.g. LabBuddy concept, multi-camera conference system)
- digital examination (e.g. online test)
- digital survey of student feedback and learning analytics

long as problems are located within the students, changes on a structural level will not take place. However, survey participants also pointed to some structural problems in their answers. Some answers emphasize that it is due to the restrictions of online tools that difficulties arise in creating informal communication in digital settings.

Some answers cannot be assigned to only one level of digitalization (cf. info box 2). Answers that address an "increased amount of time," "lack of student commitment," and "technical problems," touch upon several levels (such as working environment and interpersonal communication). More detailed research would be required to determine the interaction of these different levels. It becomes clear, however, that some of the challenges mentioned are located at different levels of digitalization and must be addressed as such. Only if we distinguish different degrees and levels of digitalization can we successfully enhance digitalization in laboratory courses and meet the needs of a diverse student body. Such a distinction must take place right from the start and be part of any didactic considerations while teaching a practical lab course. More generally speaking, a gradual process that defines individual didactic challenges, considers them separately from one another and meets them step by step will be necessary to enhance digitalization in lab courses.

Literature

[1] Feisel, L. D.; Rosa, A. J. (2005). The Role of the Laboratory in Undergraduate Engineering Education. Journal of Engineering Education 94 (1): 121-130. https://doi.org/10.1002/j.2168-9830.2005.tb00833.x.

[2] Terkowsky, C.; May, D.; Frye, S.; Haertel, T.; Ortelt, T. R.; Heix, S.; Lensing, K. (Eds.) (2020). Laboratories in higher education teaching - didactics, digitalization, organization. Bielefeld: wbv. https://doi.org/10.3278/6004804w.

[3] Thoms, L.-J. (2019). Spectrometry in the distance laboratory: impact of informational presentations in inquiry-based learning. Wiesbaden: Springer Fachmedien Wiesbaden. https://doi.org/10.1007/978-3-658-25708-8.

[4] Ortelt, T. R.; Terkowsky, C.; Schwandt, A.; Winzker, M.; Pfeiffer, A.; Uckelmann, D.; Hawlitschek, A.; Zug, S.; Henke, K.; Nau, J.; May, D. (2021). The digital future of learning and teaching with remote labs. https://link.springer.com/chapter/10.1007/978-3-658-32849-8_31.

[5] Heidling, E.; Meil, P.; Neumer, J. ; Porschen-Hueck, S.; Schmierl, K.; Sopp, P.; Wagner, A. (2019). Engineers for Industry 4.0. IMPULS Foundation, Frankfurt a. M. https://www.isf-muenchen.de/projekt/ingenieurinnen-und-ingenieure-fuer-industrie-40/.

[6] Pfeiffer, A.; Uckelmann, D. (2021). Piloting a didactic model concept for lab-based learning - (Digi)LabTC for DigiLab4U. https://www.wbv.de/shop/Pilotierung-eines-didaktischen-Modellkonzepts-fuer-laborbasiertes-Lernen-Digi-LabTC-fuer-DigiLab4U-6004804w111.

[7] Train, S. (2021). Digital Labs 4.0 - Kick-off for Cross-Reality Labs in Higher Education Project. https://tu-freiberg.de/presse/digitale-labore-40-kick-off-fuer-projekt-cross-reality-labore-in-der-hochschullehre.

[8] Rückmann, I.; Glüge, S.; Windzio, C. (2011). Notes on the practical course and the evaluation of measurement results. https://www.uni-bremen.de/fileadmin/user_upload/fachbereiche/fb1/fb1/Physika/Regeln-und-Infos/hyper_skript_26_10_11.pdf

[9] Schöning, S. (2019). Another non-binding list of electronic lab books (article on Fraunhofer Institute website). https://websites.fraunhofer.de/lost-in-life-sciences/?p=52.

[10] De Grauuw, M.; Huigsloot, M. (2016). Kickoff Lab-Buddy Pilot. https://www.universiteitleiden.nl/en/news/2016/11/kickoff-labbuddy-pilot.

[11] Burdinski, D. (2022) College: better prepared for the lab. Chemistry News 70 (7-8): 14-17. https://doi.org/10.1002/nadc.20224123792

[12] Bauer, A.B.; Sacher, M.D.; Habig, S.; Fechner, S. (2021). Laboratory practicals at a distance. Approaches in the natural sciences. https://doi.org/10.14361/9783839456903-011.

[13] Mayweg, E. (2022) Wie der Einsatz von (digitalen) kollaborativen Lernformen in der Hochschullehre gelingen - Einblicke in die aktuelle Forschung (Article on the website of the Hochschuldidaktischen Forum). https://hochschulforumdigitalisierung.de/de/blog/einsatz-von-digitalen-kollaborativen-lernformen

[14] BIBA - Bremer Institut für Produktion und Logistik GmbH. BIBA Gaming Lab. https://www.biba-gaminglab.com.

[15] Gers, F.; Prowe, S. (2014). Game based learning in the virtual microbiology lab. Conference paper presented at the Conference on Innovation in Higher Education 2014, Heidelberg. See also: https://projekt.bht-berlin.de/mint-vr-labs/.