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Learning Science at University in Times of COVID-19 Crises from the Perspective of Lecturers—An Interview Study

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Abstract: The COVID-19 pandemic changed higher education radically and challenged faculties to adapt their teaching to the new circumstances. The aim of this study is to highlight changes, in particular, the advantages and disadvantages associated with them, and to find out what conclusions were drawn for the future in the three experimental natural sciences of biology, chemistry, and physics at the University of Konstanz (Germany). In a guided interview, the majority of the university teachers in the bachelor's programs were interviewed, and their statements were subsequently categorized. While lectures and tutorials in distance learning were held asynchronously or synchronously online, laboratory courses used a variety of formats. The number of disadvantages cited, as well as the number of university faculty citing the same disadvantage, is greater than for advantages. The most commonly cited drawbacks fall into the areas of workload, communication, feedback, and active student participation. Physical presence and a return to the original learning objectives in the lab courses is wanted by the majority. The results point to commonalities between the science subjects and should encourage science departments to work together on similar problems in similar formats in the future. Furthermore, there is an urgent and ongoing need for the training of natural science teachers in competence-oriented digital teaching.

Keywords: technological pedagogical content knowledge; science education; higher education; COVID-19; pandemic; digital readiness; teacher professional development; remote laboratories; ICT-enhanced learning; DiKoLAN

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1. Introduction

1.1. Theoretical Background

The appearance of the first SARS-CoV-2 diseases in December 2019, first in China and, a few days later, also in Germany, led to great uncertainty in the universities and, within a few months, to their closure and the conversion of teaching from face-to-face to a remote setting [1–5].

In the course of this conversion, it quickly became apparent that neither the necessary technical requirements nor the digital skills of the lecturers were available across the board for a switch to online teaching [1–8] During the pandemic, difficult legal issues also arose, such as how to conduct remote examinations while balancing data protection and the protection of subjects' personal rights with monitoring the proper conduct of the examination and preventing attempted cheating [9].

Lecturers were not the only ones who had to adapt their teaching workflows to the new situation. Students also had to adapt to new teaching formats [10]. First-year students in particular lacked contact with their fellow students [10]. The lack of social integration had a negative effect on students' motivation [11], which lecturers also had to take into account when designing courses [5,12–14]. Particularly during the first university closures, new ways of communication and collaboration [7,8] and tools for motivating and activating students [5] had to be developed, in addition to new presentation formats [11,14].

In addition to the rather unspecific new demands on university teaching, lecturers in the natural sciences were also confronted with subject-specific problems. Important questions are, for example, how scientific experiments can be demonstrated in videoconferences but also how students can acquire experimental skills themselves if they are not allowed to work in a hands-on laboratory due to pandemic-related access bans to universities [15]. Many substitute options are conceivable here [16]. One approach may be to have a lab technician conduct the experiments in a videoconference as instructed by the students, with the students observing the conduct [17]. However, there is always the risk of the lab technician influencing the students. Direct confrontation with the operation of unfamiliar experimental materials is also an important component of hands-on lab courses [18–21] that is omitted in a remote setting of this type. Alternatives that allow for higher student engagement include remote lab experimentation [22,23], simulations, interactive screen experiments [24], smartphone experiments [15,25], and low-cost home experiments [26,27].

In many places, didactic workshops were immediately offered for lecturers so that they could develop the digital teaching skills needed for online teaching. However, these workshops tended to focus on digital teaching skills that were not specific to a particular subject and minimally on the more subject-specific digital teaching skills needed for science teaching [28].

A competency framework that addresses the specific needs of science digital university teaching has been lacking for a long time [29,30]. This paper, therefore, draws on an internationally recognized [15,31–37] competence framework for the digital competencies of science teachers: DiKoLAN—Digital Competencies for Teaching in Science Education [30,38] (Figure 1).

Figure 1. The DiKoLAN framework (https://dikolan.de/en/, last access on 26 February 2023) [30].

In its surface structure, DiKoLAN precisely contains those competencies that are needed for the transfer of teaching from a face-to-face situation to synchronous and asynchronous online teaching, as described above [39]. It is true that the competency expectations formulated in DiKoLAN are operationalized for schoolteachers. However, the DiKoLAN can excellently differentiate between more general and more subject-specific competencies, thus, pointing out the urgently needed science-specific competencies for university teaching and giving related implications for future subject-specific training measures for science lecturers.

For the planning and design of such science-specific training courses for the acquisition of digital teaching skills, it is of great importance to find out how the lecturers themselves experienced the change in teaching during the pandemic [40], what different teaching formats were used, and what similarities and differences can be identified in this respect between the sciences. Furthermore, it will be particularly important for the acceptance of future training measures whether and, if so, which of the changes due to digitization in teaching are considered worth keeping by the lecturers. Finally, there is a chance that lecturers who were previously rather averse to digitization would now be willing to integrate digitization-related elements into classroom teaching as well [40]. This would also promote the digitization-related competencies of the students and, thus, follow versatile demands from politics, business, and industry [41].

Since the courses considered here are attended by both science students and pre-service science teachers, there is a second particularly important aspect with regard to the integration of digital elements into digital teaching. Prospective teachers need comprehensive digital competencies in order to promote the digital competencies of their students. Experiencing digital teaching in science courses can, in the sense of cognitive apprenticeship [42], serve as a role model to motivate students to acquire their own subject-specific digital competencies [43]. Well-trained schoolteachers then, in turn, serve as multipliers at school, so that it can be expected that in the future, school leavers will take up science studies with better developed digital skills and, thus, also enter the job market with broader digital skills [31].

In order to best achieve the goals of subject-specific training for science lecturers as described above, a site-specific analysis of the current situation is required. To this end, the following research questions were investigated.

1.2. Research Questions

1. How did the teaching change at university during the COVID-19 pandemic?
2. How are the changes perceived by the teachers?
3. What are the implications of these changes for future course design?
4. What are the differences between lecture, tutorial, and lab courses during the COVID-19 pandemic?
5. What are the differences between biology, chemistry, and physics?

1.3. Hypotheses

In light of the above questions, the following hypotheses were formulated:

1. Due to the pandemic, lecturers used more digital media in teaching.
2. The teachers were previously rather dismissive of digital media in teaching; at least, digital media did not obtain a foothold in teaching (cf. [44,45]) Now they see advantages and disadvantages.
3. Teachers consider retaining parts of the changes that have been force-tested.
4. The digitalization rate is higher in the area of lectures and exercises. Practical courses take place less digitally and less at a distance.
5. The wetter an experiment is, the stronger the rejection of digitalization in the field of practical courses. For lectures and tutorials, on the other hand, there is no difference.

2. Materials and Methods

2.1. Development of an Interview Guideline

The Kvale guided interview method [46] was chosen to capture the research questions. For this purpose, possible interventions for the research mentioned above were, first, collected and then, subsequently, reviewed and sorted. The structure of the guideline can also be seen in Figure 2. It was decided to use an open-ended introductory question ("Think about teaching in the previous winter semester, when you offered your course digitally for the first time. How has teaching changed in the winter semester 2020/2021 compared to teaching in the winter semester 2019/2020?"). In the following, the participants were asked about the associated advantages and disadvantages before they were asked to reflect on which changes in teaching should be maintained in terms of digital technology used, changes in subject matter and content, or methodological changes. Furthermore, the participants were asked whether their overall attitude toward digital media in teaching had changed. The interview was concluded with questions about newly acquired technical equipment, support offered and perceived, as well as areas where support was lacking.

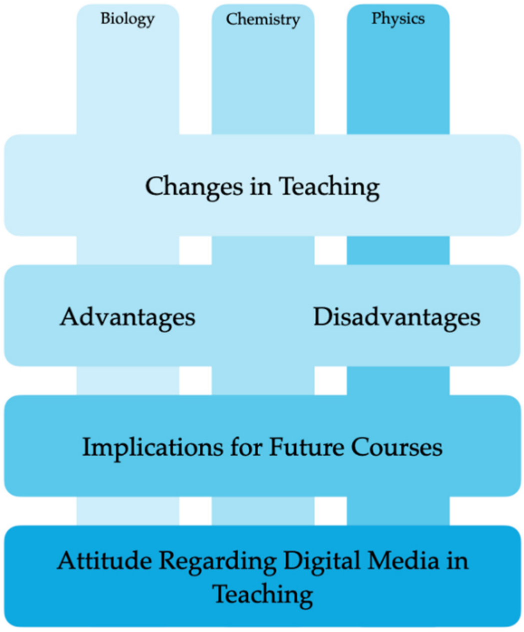

Figure 2. Participants of the three faculties: biology, chemistry, and physics, were asked about these topics.

In conducting two mock interviews with research assistants (pursuing PhD degrees) involved in undergraduate teaching, no need for revision of the guideline was identified.

2.2. Selection and Invitation of Subjects

The focus of the interview study is on subject-specific courses. These are only taken once in a course of study, so students cannot reliably assess how teaching has changed as a result of the COVID-19 pandemic. For this reason, only lecturers were surveyed. (It is not about general study conditions but explicitly about science courses (lectures and practical courses)). Among other reasons, since there was already a nationwide large student survey of all subjects, a further survey of students on the study conditions did not make sense here [47].

In the selection of subjects, all lecturers in the undergraduate program whose courses are attended by both Bachelor of Education and Science students were contacted via a personal email and invited to the interview, which lasted approximately 75 min. In total, there were 18 biology teachers, 13 chemistry teachers, and 12 physics teachers asked to participate. The interviews were conducted via zoom due to the given framework conditions. In order to achieve a higher cooperativeness to participate, no audio or video recording was made, and instead, the answers were taken down. The interviews took place in the summer term of 2021.

2.3. Sample

Seven lecturers (university teachers) from biology, nine from chemistry, and nine from physics participated in the interview study. Thus, a total of just under 40% of the requested biology lecturers, 70% of the requested chemistry lecturers, and 75% of the requested physics lecturers took part (Figure 3).

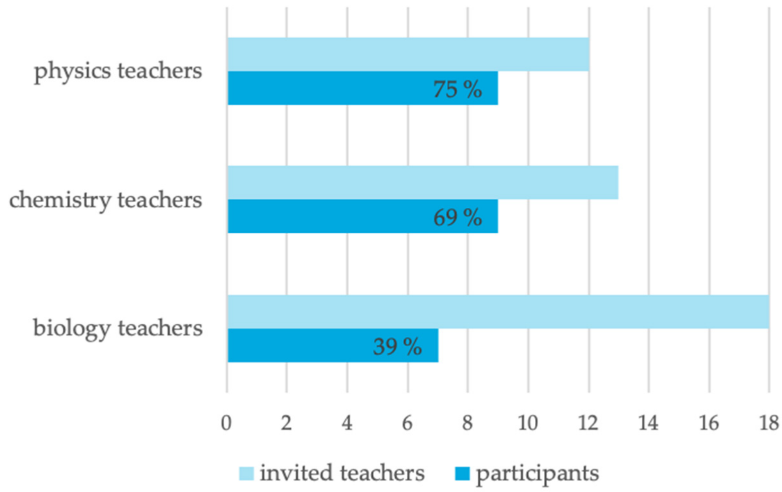

Figure 3. Population and sample. The plot shows the relationship between invited university teachers (population) and the participants (sample).

Twenty-one of the participants reported on their lecture, eleven on their lab course, and eighteen on the tutorial accompanying the lecture or lab course. Demographic data are not provided here in order to protect the anonymity of the subjects. To answer the research questions, the responses were transcribed, pseudonymized, and thematically summarized.

3. Results

3.1. Overview of the Results

In this subchapter, the results in relation to the research questions are summarized. A more detailed insight into the results for research questions 1–3 can then be found in Sections 3.2–3.6.

3.1.1. Research Question 1: Changes in Teaching

A little more than half of the lectures were held live via web conferencing tools, and the remainder of the lectures took place in asynchronous formats. In live sessions, slides were shared. For asynchronous lectures, either a screencast of slides or a screencast of taking notes on a tablet was provided. Previously, several lecturers used the chalkboard to write down notes in lectures.

All tutorials were implemented in web conferencing tools, and worksheets were distributed digitally. If necessary, the exercises were also submitted electronically.

In lab courses, several formats were used: from in person during the semester or during the semester break to hybrid, online, and offline labs at home and a mixed formats lab.

3.1.2. Research Question 2: Perception of the Changes

Several participants perceived it as a benefit that recorded files were available afterwards and students could watch them again. Furthermore, more time flexibility for students and lecturers was noted. Another advantage was the availability of software and hardware for online teaching that was achieved.

The number of disadvantages mentioned was larger than the number of advantages. The same applies for the number of university teachers naming the same.

The most frequently mentioned disadvantages of changes in teaching were related to communication, feedback, and student engagement in distance courses. A further main topic was the greater workload caused by the changes in teaching.

3.1.3. Research Question 3: Implications for Further Courses

Most of the participants wanted to return to the lecture hall and not to continue online teaching. A fourth could imagine maintaining online teaching during travelling. One of six lecturers wanted to reuse recordings accompanying the in-person lecture.

In lab courses, returning to the pre-pandemic learning goals was wanted by six of them, but three could imagine adopting rethought structures as well.

3.1.4. Research Question 4: Differences between Lecture, Tutorial, and Lab Courses

In lectures and tutorials, the conversion to distance learning was successful without having to adapt content. Laboratory courses, on the other hand, could not maintain the same learning objectives and content online. Either new learning objectives were defined for a new format or the course was held in the laboratory at the university with the same or reduced content, as far as legislation allowed.

3.1.5. Research Question 5: Differences between Biology, Chemistry, and Physics?

Almost all chemistry lecturers gave their lectures in an asynchronous format, whereas all biology lectures and most physics lectures were held synchronously online. In tutorials, no differences could be found. In all three sciences, there was at least one on-site lab course at the university, but there was only one remote lab in physics. Other at-home solutions were again provided for all three subjects.

3.2. Changes in Teaching

In this subchapter, the changes in teaching are described that provide an answer to research question 1. The results are divided into changes in lecture, tutorial, and lab courses.

3.2.1. Changes in Lecture: Almost Half of the Lectures in Asynchronous Formats

Format

On one side, a lecture was held in an asynchronous format for nine out of twenty-two interviewed lecturers, mostly by chemistry teachers. Three chemists said that students requested this format. Another chemist complements that, according to him, the synchronous formats were not desired by the university. In addition to the asynchronous inputs, one question and answer session was offered per week by four lecturers.

On the other side, a lecture was held in a synchronous format via a web conferencing tool for 14 lecturers. Three of the participants explained that this was because they wanted to hold the time schedule for the students unchanged. Four of the participants went on to say that the live session was recorded and made available for all the students via a learning management system afterwards, but there were four clear statements against the recording of the lecture: first, because of the loss of interaction ("If I make an effort and include interactive elements, then I come close to a live event. For example, I've included breakout sessions.") and, second, because of the loss of spontaneity (e.g., "I also make a joke now and then, which loosens things up."). Third, a fixed schedule was thought to be required by many students. ("There are definitely many who would like to have a fixed schedule. They think it's good to be there and stay on the ball.") Finally, in the live sessions, students had the opportunity to ask questions.

Methods and Materials

Mostly, presentation slides were shared during the synchronous session. For the asynchronous sessions, either a screencast of slides was created or the script was written down on a tablet computer and made available as recorded. One lecturer also used the tablet computer to write down the script in a live session online. Videos were produced to show demonstration experiments in the beginner's lecture. Within the live session, the recorded slideshow was presented by one participant as a video, and in the end, questions were clarified.

Previously, several lecturers wrote their scripts on the blackboard, and the students took handwritten notes. One lecturer explained his opinion concerning the blackboard writing as follows: "The ulterior motive was that the speed is so limited, you don't rattle off the slides, you can develop, the students have to copy it down and so they certainly wrote it down once. That's where the term comprehend comes from. Not with slides/reading through".

Three reasons for the material chosen were given by three lecturers. The decision of the first one for a slide-based lecture was made because recording the blackboard writing did not work. Another tried to transfer the format with the blackboard to his online lecture by writing on a slideshow with blank pages in the live session with the drawing tablet. The decision for a tablet computer was made by the last one because, with a digital slide-based presentation (e.g., with PowerPoint), the tempo would be too fast and, therefore, a tempo similar to the blackboard writing was reached.

Several but not all lecturers then used the learning management system to make slides, scriptures, or recordings available.

Time and Interaction

Three lecturers mentioned that the typical content for a 90 min lecture is covered in less time. One lecturer noted that, unfortunately, the rest of the time could not be used for further occupation. Another lecturer reported that the rest of the time was used for newly implemented quiz questions at the beginning of the online live session.

Concerning the interaction, one lecturer said that questions were collected in the live session via microphone or the implemented chat function and clarified at the end of the lecture. In another lecture, everyone or pairs was/were prompted to ask a question about something that was unclear. It was mentioned that this strategy worked out well. When the possibility for asking questions was given before, there were always no questions.

One lecturer proceeded in the way that, during web-conference sessions, videos of all the members were shown on a second screen, because that felt closest to an on-site lecture.

A chat server was included by one teacher, and the asynchronous lecture was accompanied by an online forum in the learning management system by another.

3.2.2. Changes in Tutorials: Tutorials Took Place in Web Conferencing Tools and Worksheets Were Distributed Digitally

Format

All tutorials took place online via a web conferencing tool.

Methods and Materials

Homework was presented in the conferencing tool. Either the students or the tutor presented the solutions as before. They used screensharing of a photo or submitted pdf-files to present the right solutions, or the tutor wrote them down using a tablet computer or used notebooks with touch screens. Some tutors also created a slideshow with good solutions. Some used screenshots for backup; a sample solution was distributed by others.

The handing out of the exercise sheets, as well as the handing in of the solutions, were realized via the university-run learning management system or with other, unspecified electronical ways.

In one tutorial, the students could take online tests in the learning management system to achieve bonus points for the exam.

One lab manager said that the he himself was in the main room, and the students were divided in six breakout rooms with one tutor and ten students. The tutorial was implemented in this way because the students should have time to talk about the topics and have contact with each other, and the learning alone was intended to be interrupted.

The group size in one tutorial for a lecture was smaller (Instead of 7, there were only 5 members per tutor).

3.2.3. Changes in Lab Courses: Great Variety of Formats Was Implemented and Content of Lab Courses Was Modified

Format

Many different formats were used: All types, from in person during the semester or in the semester break to hybrid, online and offline at home or remote lab up to a mixed format lab, were represented.

Three lab courses were implemented as full online lab courses. In all three courses, data from previous courses were handed out to the students, and they had to work with those. In the third, furthermore, simulations and video materials from other universities were used.

For another lab course, a digital unit was prepared for those who could not participate and supervised during the live session by a student assistant.

Two other biology lab courses were implemented as hybrid lab courses. Half of the students worked on site and the other half either made evaluations only at home or took part online at home.

Four lab courses were offered in person as before the pandemic and another as a compact course in the semester break.

For several physics labs, a complete at-home type was implemented with mixed-methods. First, there were prerecorded interactive multimedia representations of the experiments used. Second, it was possible to run simulations, and third, students could perform simple experiments at home. The decision for a lab course at home was made due to the plannability; in this case, no spontaneous changes were necessary.

Another complete at-home solution was found for one biology lab course, in which the students had to explore an area by their own choice in groups of two and evaluate their findings based on the material provided.

For a further lab course, there were some deliberations in transmitting the sample material to the students' homes, but for three reasons, the decision was made against the home solution. First, letting them collect the material was difficult, as well as letting them buy it themselves, because they were not at their place of study. Furthermore, the technical equipment was missing at home, and finally, it was difficult to control the safety regulations.

For an advanced lab course in physics, three remote experiments were found and the students were then guided through those three setups. Another lab manager explained it would have been a possibility that single experiments were offered remotely, but he had refrained from it because there was too great a number of students and experiments.

Colloquia

One lab manager transferred the colloquia to an online format; another was handing out sheets for it. Both had the aim to reduce the time spent on-site.

Groups and Group Size

For in-person courses, mostly the group size was reduced. In one case, the number of teams of two per room was reduced, and in another group, the size was similar, but the rooms must change because of the room size.

A lab manager switched the care. Previously, each tutor always supervised the same experiment; then, fixed tutor–student groups through all experiments were implemented, because it turned out for him that this results in a better interaction between students and tutor in the case of the pandemic lab-course mode.

Materials and Methods

Two lab-course managers said that materials from other universities were reused (e.g., from the FU in Berlin [24,48]); another used content from an educational software. Professional pictures of almost every preparation from previous years could be used intensively by another lab manager.

Due to the content changes in several lab courses, all instructions had to be rewritten and the valuation guidelines were changed.

In all physics lab courses, materials and handing in the report were already online. Then, additional paper reports were eliminated. Furthermore, the students of these courses were encouraged to use ShareLaTeX for their reports. (ShareLaTeX is an online LaTeX editor that enables real-time collaboration, as well as direct compilation of LaTeX source code to PDF via the web interface).

3.3. Changes in Attitude towards Digital Media in Teaching

In this subchapter, the results are presented with regard to the question of whether the changes in teaching also brought about a change in attitudes towards the use of digital media in teaching.

Twelve of the participants said there was no change in attitude. For five lecturers, the attitude was positive before, one said it was as negative as before, and the rest did not specify their attitude. One lecturer tried several things, but in-person teaching seemed more effective to him. Finally, one lecturer summarized that he was neither for nor against ("There must be a good mix and you have to decide according to the situation. Didactic, pedagogical or convenient is the question.").

There was a change perceived by another twelve participants. One lecturer was grateful to the COVID-19 pandemic that it forced them to prove that it was possible to teach online and that there could be promoted equivalent competencies in the lab course. For eight lecturers, the attitude regarding digital media in teaching was more positive. For one lecturer, digital media was not useful for teaching. Another was convinced that online lectures plus a question-and-answer session and tutorials in-person sounded like a good concept. Digital media was perceived as great for research by two lecturers. Finally, one university teacher concluded that they had become more experienced and now advantages and disadvantages were seen.

Three participants said it was difficult to answer, on the one hand, because it is hard to leverage the high potential of digital media with the current structure of lecturers, and on the other hand, digitalization is so unspecific.

3.4. Advantages of the Changes: Recorded Files Are Available Afterwards, More Time Flexibility for Students and Lecturers, and Software and Hardware Is Available for the Online Instruction

In this subchapter, the advantages of the changes in teaching are described that provide an answer to research question 2. The results are divided into advantages of formats, methods and materials, and interaction.

3.4.1. Format

The most mentioned advantage of the changes was that the students could look at the lectures again if there was a recording (it was mentioned by 6 lecturers) and furthermore, they could watch the videos individually. With the recordings, more time flexibility for students was perceived by four lecturers, as well as for themselves by two lecturers, and in asynchronous formats, the video material could be edited before publishing. As a further benefit of asynchronous/blended teaching, it was mentioned that the students came prepared to the attendance time and the attendance time remained for problem solving. Another tutor said the exercises were completed much faster because there was no need to write on the blackboard and, therefore, more attention was paid to understanding.

3.4.2. Methods and Materials

In terms of materials, it was mentioned thrice that equipment for online and hybrid instruction was made available. The learning management system worked great then for one participant, and it was an advantage for another that the use of digital media (e.g., the learning management system) was trained.

The newly implemented use of iPads was perceived as an advantage, either because of the possibility to store the written material and upload it afterwards or because the writing is not gone if a tablet is used instead of a blackboard ("It is possible to scroll back to previous chapters and it is stored.") or, third, because the iPad offers more possibilities: e.g., pictures or videos, and fourth, the switch between the "blackboard" screen and the computer is easier.

In case of asynchronous teaching, the content of lecture and tutorial could be adapted by one easier without a time offset.

The use of multimedia reduced the workload for two lecturers: On the one hand, the evaluations of online tests for bonus points in the exam were available immediately, and on the other hand, the video material was available for further courses.

Within the videos for the experiments, it was easier for two university teachers to show important details than in the lecture hall or in the lab course.

The students liked the recordings, and the advantage in the script being available beforehand was added by one lecturer.

A benefit of the pandemic that was perceived by one lecturer was that the teaching could be reconsidered. Having time to focus on promoting other competencies, such as critically engaging with subject matter in the lab course, is one perceived benefit called out by another.

3.4.3. Interaction

Three lecturers noted that more students attended the lecture or looked at the recordings during the pandemic compared to before, and so they were better prepared, and the discussion in lecture or question-and-answer time worked online better for three other lecturers.

It was a twice-mentioned benefit that inviting external people to a lecture is easier (e.g., "I now have full freedom to invite excellent people with little money.").

However, there were also three lecturers that could not see any advantage.

3.5. Disadvantages of the Changes

In this subchapter, the disadvantages of the changes in teaching are described that provide an answer to research question 2. The results are divided into disadvantages of formats, methods and materials, interaction (feedback, communication, relationships), and workload.

3.5.1. Format

Concerning the format changes, there were several individual opinions. Two lecturers complained about the missing 3D impression, either because a lower dimensional visual impression limited perception or because it is not healthy to always have the same eye distance and no movement. As a further drawback of asynchronous formats, the missing rhythm for students was mentioned. For online lectures, less variation was lamented and for online lab courses, students' own curiosity could not be considered, which made the lab more like a lecture.

The mentioned disadvantages of an at-home lab course were that the accident insurance does not apply, and the students were not supervised.

3.5.2. Materials and Methods

The blackboard was missed by three lecturers: first, because working with the blackboard is more flexible (e.g., parallel work with wooden pointer stick and overhead projector) and, second, because the presentation of larger contexts is difficult with the limited space of a tablet, and if slides are changed, a context break occurs online. Furthermore, one lecturer feels more comfortable with the blackboard, and fourth, performing and perception are another consideration if the person and presentation are harmonious aligned with each other.

Missing technical equipment on the site of the students, as well as a bad internet connection, were a further negative that was mentioned by three participants.

Five lab course managers said the digital redesign of the lab course did not promote manual skills (e.g., "This means that essential technical skills are missing."), and the haptic, olfactory, and sensory parts of practice were lost. Neither textbook nor videos could convey this, and in addition, the fact that size ratios were difficult to represent online was supplemented by one. Furthermore, it was mentioned by two others that, due to the adopted changes, not all learning objectives could be reached.

Two lecturers noted that the teaching was led, unfortunately, to a more school-like way of teaching: It was more about knowledge transfer and less about acquiring problem-solving strategies or learning from one's own drive.

Finally, it was constated by one lecturer that it was difficult to control whether asynchronously provided materials were watched by the students or if non handwritten submissions were copied.

3.5.3. Less Interaction, Feedback, Communication, and Relationships Were Declared as Main Negative Side Effects of the Implemented Changes

Feedback was missed by thirteen participants in all types of teaching (tutorials, lab courses, and lectures), as well as interaction in general by three further. Eight of them clarified that it was missed because, without feedback, the teaching could not be adopted to the audience (e.g., "In the lab room, I see what they think about it, and I can do explanations and justifications or shorten if everything is clear."). The higher inhibition threshold for active participation was mentioned by four lecturers as a reason for the missing feedback.

Communication with the students was perceived as limited by eight, as well as communication among the students by six university teachers. It was explained by one participant that communication via digital media had to be learned first, and according to another, how to implement interactional parts had to be learned as well. In particular, the lack of scientific discussion was perceived as a disadvantage by one lecturer.

It was criticized by three university teachers that it was difficult to establish a student–teacher relationship, the personal contact was missed by five lecturers, and everything informal was perceived as lost by one. As reason for the need of a student-teacher relationship was mentioned that it is important to feel comfortable to ask questions.

Furthermore, three lecturers declared that the social life of the students was missing, and therefore, (the essential) cooperation among students was more difficult, and team spirit was missed by one lecturer.

On the one hand, students' cameras in online live sessions were often turned off (noted by seven lecturers), and on the other, more interactivity and active participation in the question-and-answer sessions was wished for, as well as more participation ("No more than half were present."), and two disclaimed that it did not work and that the students came prepared.

It was noted nine times that being on-site in person leads to significantly more engagement: Online or asynchronous formats lack engagement from the students, and it was more difficult to activate students, especially shy and lazy ones. Moreover, if students did not take notes and, respectively, only watched the recording, they were disclaimed as just consuming by two lecturers (e.g., "If they have to write down what they hear and see, then they have to be active in a completely different way."), and there were certain doubts with regard to the entertainment character. It was a personal experience that calculations should be performed by the students to enable them to deal with them. Furthermore, two lecturers explained that it was difficult to concentrate online for 90 min because the temptation of distraction was great. One lecturer remarked that everyone might be more fixated on themselves. Group dynamic processes were missed by another, and therefore, it was more or less a self-study, and one teacher remarked it no longer felt necessary.

One lecturer said good students got along well, bad students got lost every time, but unfortunately, midfield students got lost as well.

3.5.4. Workload

A greater workload was complained about by ten lecturers. The reasons given for the greater expense were greater time and stuff commitment in lab courses. Furthermore, learning the video software (e.g., editing and downsizing the files); creating screencasts, slideshows, or the script; making recordings; learning the functions of the learning management system; and selecting video material for the lab course were time consuming. Finally, it was mentioned that it was twice the effort to offer a lab course hybrid.

3.6. Implications for Further Courses

In this subchapter, implications for future courses are described that provide an answer to research question 3. The results are divided in implications concerning the format, methods and materials, and interaction.

3.6.1. Format

Most of the university teachers want to return to full in-person lectures, tutorials, and lab courses. Another lecturer said there should be at least a quarter of the students in person to be interactive. Streaming can be continued, as was mentioned twice, if it is accompanying an in-person lecture. One of them could further imagine continuing to record the sessions, but another did not want hybrid solutions. Reasons for the wish to return to in-person learning were in each of the several cases once mentioned: The lack of direct feedback from students and the fact that physical contact is not substitutable for teaching, motivating students to take part actively is no longer wanted, and the content is more compressed if it is created in an online mode. Furthermore, a benefit of in-person learning is that the discussion of solutions is more beneficial; many interactive capabilities are lost, and the teaching content cannot be recovered in virtual labs. In addition, it is perceived to be nicer when the students ask a lot of questions in person.

Six lecturers want to continue the use of the web conferencing system, either to give a lecture while traveling or to invite external guests. Another could imagine recording the lecture in case of traveling.

According to one lecturer, it should be discussed whether asynchronous formats are better than in-person teaching. A useful advantage was listed that students do not have to be on-site, which allows students from other universities to take part and, thereby, more freedom of choice is possible.

One lecturer wanted to stay flexible to offer something digital.

Concerning the learning goals in lab courses, it was mentioned six times that returning to the original ways is wanted, but three lecturers could imagine adopting rethought structures as well. The online attempts could be used as backup (e.g., for catch-up days because of illness) by another.

3.6.2. Materials and Methods

It was generally said by one lecturer that the material generated could be reused. Furthermore, recordings could be offered additionally by four chemistry lecturers. Moreover, the currently available script of the lecture could be reused. Others did not want to use or keep recordings.

The use of the tablet computer as a writing tool for the lecture hall instead of the chalkboard will be continued by one lecturer.

The videos of the demonstration experiments were perceived as a nice backup, because there were some losses of quality with the camera in the lecture hall. Therefore, subtle effects were more visible in the video. Nevertheless, the experiment should be shown in the lecture hall and the video should be only used as backup, according to one lecturer.

The use of the learning management system has to be maintained, according to the opinion of one lecturer.

Two mentioned that the online submission of exercises should be maintained, but if the digital delivery is maintained, sample solutions should not be kept.

Blended learning formats are wanted by two lecturers. Both want to provide the material in advance; students could then either create 10–15 slides on a topic or deal with three to four more in-depth questions, and then the topic and the questions would be discussed in an attendance hour. Another lecturer could imagine outsourcing some content, but it was already done before the pandemic. A fourth was thinking about teaching the lecture well once, recording it, and then planning what to offer to support the recording, using the free capacities for a problem-oriented concept.

Further videos for work instruction sections were wanted by a lab manager, but these were not so easy to find on the internet. It would be desirable to have time to produce them.

A lab course manager was positively surprised that by not teaching a number of skills, they were able to teach more learning content. The virtual part had to be shortened for further courses to promote the handcrafted parts again, but the repertoire of tasks had simply become larger.

3.6.3. Interaction

Several individual aspects were mentioned to be maintained. One lecturer wanted to include more pulls in future courses. Another said that online communication should be improved, but a third did not think that a seminar atmosphere could be reached online.

A further lecturer wanted to keep a 10 to 15 min discussion time in a lecture, because the discussion was very valuable and the ability to ask and answer questions still needed to be practiced. Another also wanted to encourage active discussion: critical questioning, learning to doubt, and not trusting what is said but in a more informal way.

4. Discussion

4.1. Main Findings

A diverse picture emerged with respect to all research questions, but also, commonalities could be found across all three sciences regarding lab courses and demonstrating and conducting experiments. In particular, no satisfactory solutions were found by the participants of the study to implement laboratory courses in distance learning. This could be because lecturers do not have sufficient competencies to profitably convert their lab courses to a digital version. Additionally, it was found that the differences between individual teaching formats (lecture, tutorial, and laboratory courses) were greater than the differences between individual natural sciences.

It is possible that the disadvantages associated with the changes in teaching also outweighed the advantages seen in lectures and tutorials because the use of new methods was necessary in many places (e.g., replacing chalkboard lectures). The frequently mentioned higher workloads suggest that these methods had to be found first and, finally, trained.

Another issue often mentioned in the study was difficulty engaging students, which may also be because lecturers lacked the knowledge or ability to use digital media to interact with students or to promote interaction among students.

Benefits that might be expected from the use of digital media, such as anonymity leading to higher participation or the use of digital methods being seen as easy by students as *digital natives*, were not observed.

A great amount of diversity was also found with regard to attitudes towards digital media in teaching, although it emerged that lecturers were very concerned about whether parts of distance learning should be retained (e.g., lecture recordings for follow-up work and the possibility of not having to be on site).

When it comes to changes in teaching, more digital media were used, indeed. However, solutions were often sought to translate existing structures 1:1 into online teaching. There were few reports of new methods being possible when using digital media. The potential of digital media is not being fully exploited at this point.

4.2. Limitations of the Data

The interviews were conducted at the University of Konstanz. In physics and chemistry, three quarters of all undergraduate lecturers participated, and in biology, approximately 40 percent. Therefore, it represents the situation at the University of Konstanz very well. Nevertheless, the results are only transferable to other locations to a limited extent since the total sample was only 25.

Another aspect was that the data were based on self-assessments by the lecturers. There were no participant observations, but the lecturers reflected on their own actions.

For the sample size, it was necessary to resort to self-assessment in interviews since participant observation was not technically feasible (25 times, at least 90 min per week, with time overlaps).

The lecturers reflected on their own behavior over an entire semester and drew conclusions for the future, which is why it can be spoken of as a long-term observation.

Re-surveying in a few semesters is necessary to verify the occurrence of the implications mentioned above for the future, keeping in mind that the changes may be attributable to both the COVID-19 pandemic and a general digital slide in teaching.

4.3. Data in Relation to Current Research

It is consistent with other research that most courses could be offered without content changes [28]. As a main drawback of online synchronous teaching, the limited exchanges between students was considered by Dietrich et al. [49], which was constated as a huge disadvantage in this study as well.

Analogous to this sample, problems with students who turned off their cameras in web conferencing systems were also found [8,50], and it was stated that the workload was higher [8]. It was shown before the pandemic that asynchronous learning can be associated with problems in student engagement [51]. Analogous to the cohort described in this article, these problems also occurred in Burnett et al. [28]. In addition, participants in this study reported that there were also problems with student engagement in synchronous online lectures or tutorials. Other research projects have also identified a lack of visual feedback to adapt teaching to the audience [50].

Some instructors spoke of concerns that students learn less because of a purely consumptive attitude in online live sessions or watching lecture recordings. If students learn in a purely passive role, the fear coincides with the ICAP model [52], which states that planning and design of media-enhanced instruction is goal-oriented when student learning activities are primarily more active, constructive, and interactive. Following the model in performing this way, deeper cognitive learning processes are stimulated, which increases the likelihood that learning will be more effective.

A further concern regarding the use of online teaching was also that students may be less likely to learn because of the less dimensional approach. If the Cognitive Theory of Multimedia Learning (CTML) according to Mayer [53] is consulted, it can also be found there that communication takes place in two ways, the auditory and the visual. Each path has only a limited capacity, which is why, conversely, if only one channel is used, less content can be transported.

Both of these concerns can be addressed by ensuring that neither channel is overused in the design of the teaching and that the work assignments are designed to involve students in a more active, constructive, and interactive way, even in lectures, which was pointed out by the results of [50].

While Chans et al. developed an online chemistry laboratory course using real-time demonstrations conducted by the teacher, videos of laboratory experiments, experiments carried out by the students at home, and virtual simulations [54], it remains unclear in this sample which method was used in the distance laboratory course, but the concerns whether such a course can be implemented can be destroyed. In their study, a generalized positive attitude towards the implemented modes and an appreciation of having earned meaningful knowledge were shown.

In the case of chemistry lab courses, the tendency to eliminate in-person lab courses and to offer instead old data from previous courses can also be seen by Dietrich et al. [49].

5. Conclusions

The study we conducted fills a gap in previous research; unlike other studies, ours is a long-term perspective that extends beyond the COVID-19 pandemic and completely includes the period when there were restrictions on teaching at universities. In addition, for one site, we were able to survey the majority of the faculty, not just a few. The study also shows similarities and differences in the three experimental sciences, while most other studies only focus on one science at a time. In addition, we examined all teaching formats (such as tutorial, lab course, and lecture) and did not just focus on short-term impacts on one format. We have made a small contribution with our studies, which makes it possible that in the future the departments of chemistry, biology, and physics will work more closely together on similar problems in similar formats—even in times of crisis—and solve problems together.

In particular, after the acute ad hoc measures, structured competence building should be sought for the future. The DiKoLAN competence framework can be used for this purpose, for example, as it has already been shown that this promotes structured competence development for university teaching. Further subject-specific and digitalization-related training measures for teachers at the university are still needed.

Although the COVID-19 pandemic can clearly be seen as a catalyst for the digital transformation of university teaching, many lecturers would like to see at least a partial return to the forms of teaching that were commonly used before the pandemic. Most lecturers feel that they have increased their technology-related skills, and the technical hurdles that had to be overcome at the beginning of the pandemic are no longer in the foreground. Nevertheless, many lecturers still find it difficult, for example, to actively engage students in distance learning. In addition to the more general, subject-independent issues of digital teaching, there are also problems specific to the natural sciences, e.g., how experiments can be demonstrated in online teaching and how students can be given the opportunity to actively conduct experiments themselves. According to the available insights, it cannot be assumed that all science lecturers are aware of all the possibilities for digitalizing science teaching at universities. Since lessons could be learned from the experiences during the pandemic and both the students' desire and the lecturers' general willingness to digitalize university teaching in the natural sciences is apparent, there is an urgent and sustained need for competence-oriented professional development in digital didactics for lecturers in the natural sciences. The DiKoLAN framework, which has already been successfully used in the training of science teachers [55,56], can provide a useful starting point for planning, structuring, and categorizing such training measures. However, adaptation to the university context will certainly be necessary.

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