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The Power of Problem Based Learning beyond its Didactic Attributes

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ABSTRACT

Hybrid courses with a focus on practice-orientated education and self-guided learning phases are on the rise on the higher education sector. Disciplines in Life Sciences implicate a high degree of practical laboratory expertise. The University of Applied Sciences (UAS) in Vienna, Austria, has thus been endeavoured offering students a high qualitative education integrating hybrid courses based on PBL principles, which consist of on-site (including the transmission of necessary background and practical laboratory training) and off-site (including self-study phases) sessions. As practical laboratory units are central in those courses, the restrictive measures, including the transition to a complete online teaching format due to the first Covid-19-pandemic lock-down, had severe effects on the implementation and the quality of the curriculum. According to surveys made specifically to address this problematic situation, it can be concluded that on-site practical units are fundamental for certain disciplines such as Life Sciences.

Keywords: Hybrid-PBL-methods, Life Science, Covid-19

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INTRODUCTION

A career in life sciences implicates a high practical workload. In order to prepare our students at the University of Applied Sciences (UAS) in Vienna, Austria, for a successful and rapid transition to a professional scientific career, the focus in all study programs of the faculty of "Life Science Engineering" lies in practice-oriented and problem-oriented education. Thus, practical laboratory courses are an elementary cornerstone of the bachelor study program "Biomedical Engineering", and the master study programs "Tissue Engineering and Regenerative Medicine" and "Environmental Management and Ecotoxicology". Especially the master study programs are unique in the European higher education sector, not only due to their high degree in specification, but also due to a high proportion of courses using applied PBL-oriented didactics. The majority of our graduates pursue successful careers in research and development in the public as well as the private sector. In annual meetings, alumni regularly reflect on their career development and how the studies at the UAS contributed to their success, which underlines the high quality of education provided at the UAS as well as the effectiveness of conventional and novel concepts in PBL.

A significant number of courses in the afore-mentioned study programs are based on the classical PBL principle, including the seven golden standard PBL elements (Barrows, 2000). They involve a real or realistic current problem within the field, which has to be addressed actively by students usually within small teams in intensive research and self-study intervals. Especially in the master study programs, project-based approaches corresponding to the Aalborg model are commonly employed (De Graaf & Kolmos, 2003); more advanced students have the ability to elaborate a real-world project autonomously by acquiring necessary background information and then addressing objectives by a practical working phase in the laboratory.

Several practical laboratory courses at the UAS, which aim to train students with fundamental basic laboratory knowledge, are not fully based on PBL-orientated principles. However, a plenary lecture and additional lectures with self-study intervals provide the students with necessary background information, which are then followed by practical units in the laboratory to complete and intensify expertise on certain topics. They allow students, after having received theoretical background in a lecture, to address a topic independently and at their own intensity/speed/preferred method, which can differ individually. In a subsequent practical unit, students then have the opportunity to apply their theoretical background and intensify their knowledge. While theory is often abstract, practical courses enable a better understanding and memory. In addition, practical units grant intensive discussion and interaction with lecturers. Scholars agree that such hybrid-models of guided and autonomous study phases in a laboratory setting have been proven successful to equip students with the "scientific mind-set" and competences needed in order to succeed in their later working lives and thus need to be an integral part of any scientific education (Allen & Tanner, 2003; DiCarlo, 2006; Adams, 2009; Wallen & Pandit, 2009).

The recent crisis around the Corona virus pandemic has drastically changed our lives. Measures to reduce social contacts to a minimum led to a lock-down in spring 2020 and to a complete halt in on-site teaching at universities for almost the entire summer semester 2020 in most countries worldwide. However, the intention of the UAS, as of many other universities, was the continuation of all study programs to enable all students the best possible education so that they are able to finish the semester without any detriment. Therefore, the teaching and administrative staff of universities had to switch from classroom teaching to e-learning at short notice and convey teaching contents online only. Although several study programs already use digital teaching methods - certain distance study programs even entirely rely on digital teaching - the application of online tools is restricted, particular in study programs with a high degree of practical courses.

This was the case for all study programs at the faculty of “Life Science Engineering” and lecturers were facing a myriad of challenges in order to identify, adapt and finally implement digital teaching methods that are adequate for the needs of highly diverse courses. While lectures, seminars and interactive courses could be continued with the help of digital services and online conference tools, courses based on high interaction and participation of students with obligatory attendance presented a more complex situation. The most challenging courses were certainly practical courses requiring special equipment, special safety regulations or another special framework.

A combination of physical and virtual laboratories has been described as beneficial to conceptual understanding and learner flexibility (De Jong et al., 2013). Studies on student’s perceptions concerning the implementation of solely virtual labs, however, showed ambivalent results; for instance, in a study by Stuckey-Mickell & Stuckey-Danner (2007) students believed they had learned less in virtual labs than they would have in a face-to-face lab, while Flowers (2011) found that students perceived virtual laboratories to be even more effective than face-to-face labs. Major challenges for conceptualizing virtual PBL environments are to find ways to engage discussions (Boelens et al., 2017) and to develop a collaborative and engaging learning environment (Kebritchi, 2017). Especially, ensuring that tasks are not simply distributed among students, but that collaboration still takes place, can be more difficult when facilitator and PBL groups do not meet in person (Verstegen et al., 2016).

As the major goal of the UAS is quality education, an evaluation of restructured courses and used online teaching formats should pinpoint positive as well as negative aspects. The identification of limitations of e-learning concepts and/or additional problems, especially in courses with a high degree of practical laboratory exercises, is essential to improve courses in future. Since many universities are currently facing similar problems, we intend to share our experiences that we have gained during summer semester 2020 within this report.

We aim to analyze if and how quality teaching despite restrictive measures can be maintained by e-learning tools and to examine putative solutions on two levels:

a) What can be learnt, especially by lecturers and administrative personnel, from the sudden switch from on-site to distant teaching?
b) How can PBL-based and in particular practical courses be implemented without presence units and via virtual classrooms?

To address the first question, we have collected the overall opinion of lecturers as well as students concerning the maintenance of quality teaching during the lock-down in summer semester 2020 within a faculty-wide survey. In the discussion we highlight lessons learnt that will be helpful also in future.

To address the second question, we describe how practice-oriented courses with a high degree of on-site laboratory units had been restructured to pure online courses with virtual laboratory exercises. We have chosen three representative courses, one of each afore-mentioned study programs.

First, we describe the conventional structure of the courses and how they had been restructured with an emphasis on alternative hybrid-PBL methods including online- and offline tasks. Second, we analysed the opinion of students in an evaluation of the restructured courses. And finally, we conclude our results and give future recommendations on the implementation of hybrid-PBL methods in a framework of pure online teaching.

METHODS

Lecturer/student population and department/course information

The faculty Life Science Engineering at the UAS Vienna offers two bachelor and five master study programs with a total of approximately 730 students per academic year. To assess the situation of spontaneous re-structuring didactic concepts from on-site teaching to a pure online teaching concept, we have designed a faculty-wide questionnaire for lecturers and students. The sample size for evaluating the transition from on-site to pure online teaching of students consisted of 115 students, where 47% were male, 46% were female and 7% other/no answer. The exam evaluation during pure online teaching was asked in a separate survey and the cohort comprised of 80 students, of which 49% were male, 50% were female and 1% did not give an answer. In the survey designated for the lecturers, ten male, five females, one other, participated in the survey with two additional lecturers who did not answer this demographic question. Demographic questions including age, gender, study program, semester, years of teaching, type of employment, difficulty coping with access restriction and additional time loss were added.

Evaluation of adapted hybrid-courses

Evaluation of the chosen hybrid-courses “Biochemistry Laboratory (BCL)”, "Special Applications of Measurement and Environmental Technology (SAUT)" and “Methods in Cell Biology (MIC)” was done at the end of the semester. Out of 80 students attending the BCL course 39 volunteered in the survey (n=39; 48,8%). The MIC course comprised 31 students, out of which 23 participated in the survey (n=23; 74,2%). Finally, 25 students were enrolled for the SAUT course and 13 participated in the survey (n=13; 52%). In addition, information on age and gender was requested. Furthermore, we required a better understanding for certain problems, therefore we have invited three students, one of each chosen hybrid-course, for an interview. The students were asked to think carefully about the questions and then to answer them in written form.

Survey structure, procedure and data analysis

The overall survey structure was designed according to the course feedback structure students and lecturers are used to, in order to ensure re-recognizability. The number of questions was limited to a minimum and questions were formulated concisely. Each survey consisted of several question groups for easier access and overview. The question types single choice, multiple choice, open text, matrix, and rank order were utilised. For the majority of questions Likert scale response options were constructed. Within those no true middle category was offered, wherever possible, with the intention to request respondents to make a decision and to reduce central-tendency bias.

Surveys were performed using LimeSurvey Professional, a web-based, open-access platform commonly utilized for performing opinion and feedback collection. LimeSurvey can be adapted as required for the intended purpose, the source code can be modified. Six surveys were performed at the end of the semester, out of which three evaluated the adapted hybrid-courses and three the unprepared transition from on-site to pure online teaching. Every answered survey was anonymous and could not be led back to individual participants.

Lecturer and student perceptions were collected and then transformed into percentages by LimeSurvey using the number for one answer and dividing it by complete sample size. GraphPad Prism was utilized for creating bar graphs.

RESULTS

Lessons learnt from the sudden transition from on-site to distant teaching

The discontinuation of classroom teaching at universities due to the spread of Covid-19 has forced a sudden and unprepared switch to e-learning in the last summer semester 2020. Importantly, the ministry of education and the directorate of the UAS forbid entirely the access to the university buildings to both, students and lecturers. Rare and highly controlled exceptions were made for only certain personnel responsible for necessary maintenance duties. From the notice to the implementation of a complete lock-down lecturers had less than two weeks' time for the transition to a pure online teaching system of all study programs.

In the study programs of the faculty of "Life Science Engineering", a focus lies in practise-oriented and problem-oriented teaching. Almost all courses contain certain elements, which foresee direct interaction of the lecturer with the students to different extents. Many lecturers include *e.g.* discussions in small groups of students and a presentation phase within their courses. Especially integrated lectures (hybrid-courses with many practical parts) and laboratory courses require the presence of students and lecturers.

We were therefore interested in evaluating this unusual and stressful situation and have analysed how lecturers and students have experienced this unforeseen and unprepared transition of on-site to off-site teaching.

Maintaining quality teaching despite the restrictive measures undoubtedly posed a major problem for lecturers. Importantly, most lecturers at the faculty cover more than one type of course, which required different adaptations to the sudden transformation. Consequently, they are able to assess various difficulties concerning different course types. The different types of courses are lecture/seminar, integrated lectures with large amount of exercises, laboratory courses and supervision of scientific papers of students *e.g.* bachelor and master thesis (Figure 1, Panel A).

Since most study programs rely on various hybrid-PBL methods in courses, a sudden transition can require, amongst other challenges, different amount of time. Therefore, the lecturers were asked if they had to increase their effort and time requirement for preparing lectures, seminars etc. (data not shown). The majority of lecturers claimed to have invested more time into the creation of written documents, teaching material, written feedback (*e.g.* via e-mail, corrections of scientific work or exams), recordings (audio, video, tutorials), assessments, creation and provision of exams.

Next, communication in the respective teaching-forms was assessed. Approximately 90% of the lecturers claimed to have more contact with students in person rather than online (data not shown). For instance, active engagement of students including asking questions, participating in exercises and discussions can be supported more easily in person during class than online. Guidance of exercises and group work as well as coaching and supervising project work is easier to hold in person, since negotiating a meeting online can be more difficult when additional factors (such as taking care of a person, etc.) limit the time frame and concentration. However, around 20% of lecturers judged coaching and guiding project work as suitable for online communication. Feedback and counselling by lecturers was also sufficient by using online communication.

The examination modalities required extensive adjustment. Question types and modalities used before the transition were single choice, multiple choice, open questions, written assignments, and oral exams. After the transition open book assignments with a time limit specified by the lecturer were introduced. At the end of the semester students were asked if the newly provided material had helped them pass the exam. More than half of the students rated the studying with the e-learning material as sufficient to pass the exams (data not shown).

Before the sudden transition to pure online-teaching only 5% of lecturers felt very confident to handle digital technologies to generate e-learning/e-teaching materials (Figure 1, Panel B). After the transition a significant increase in confidence can be observed (36%) and no lecturer felt very unconfident (before = 11%, after = 0%). We cannot clearly discriminate whether lecturers had indeed improved their e-didactic skills or whether simply their critical self-assessment had changed due to the sudden regular use of those tools.

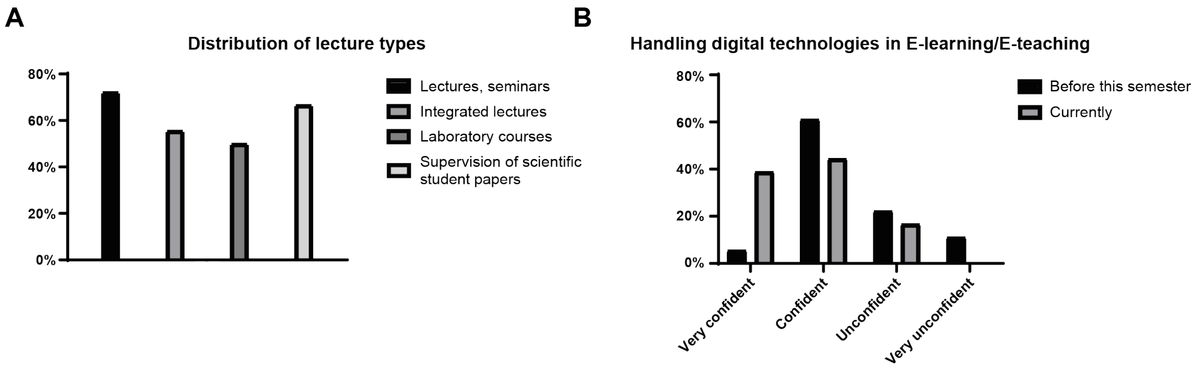

Figure 1: LimeSurvey of lecturers. (A) Distribution of lecture types at the faculty of „Life Science Engineering“ at the UAS, including lectures/seminars, integrated lectures, laboratory courses, and supervision of scientific papers. The statistical analysis was performed by using LimeSurvey Professional (n=18). (B) Confidence in handling digital technologies used in e-learning/e-teaching before and three months after the lock-down. The statistical analysis was performed by using LimeSurvey Professional (n=18).

Remarkably, both lecturers and students were satisfied with the restructuring of courses to a pure online format. Only 11% of the teaching staff did not want to use the newly created online-teaching formats anymore and less than a quarter of the students would prefer that the old presence form is resumed (data not shown).

Interestingly, many lecturers mentioned that they found themselves confronted by a PBL case, facing a new and real problem and identifying possible solutions within teamwork. This led to lessons learnt that are highlighted in the discussion.

Lessons learnt from the restructuring of three hybrid-courses

Although the sudden transition to online teaching has been assessed relatively positive by students and lecturers, we were interested to analyse hybrid-courses with a high degree of practical laboratory work in depth. These practical laboratory courses require a special framework, such as equipment and safety precautions, and were therefore particularly challenging to adapt for online formats.

We have chosen three representative hybrid-courses of different study programs to enlighten how these courses with practical laboratory exercises had been restructured to online courses with virtual laboratory exercises.

Original structure of chosen hybrid-courses

As explained in more detail in the introduction, many courses in study programs of the faculty of "Life Science Engineering" at the UAS are hybrid-courses, which combine self-study phases with conventional lectures and practical laboratory exercises. While self-study phases can be individually and autonomously performed by students, lectures and in particular practical laboratory exercises have usually been held on-site in dedicated classrooms and laboratories, respectively.

The courses "Biochemistry Laboratory (BCL)" in the second semester in the bachelor study program "Biomedical Engineering" (Figure 2) and "Special Applications of Measurement and Environmental Technology (SAUT)" in the second semester of the master study program "Environmental Management and Ecotoxicology" (Figure 3) are structured in a similar way and follow the same didactical concept. The courses aim to introduce state-of-the-art methods in the respective field and to teach students how to write a scientific report.

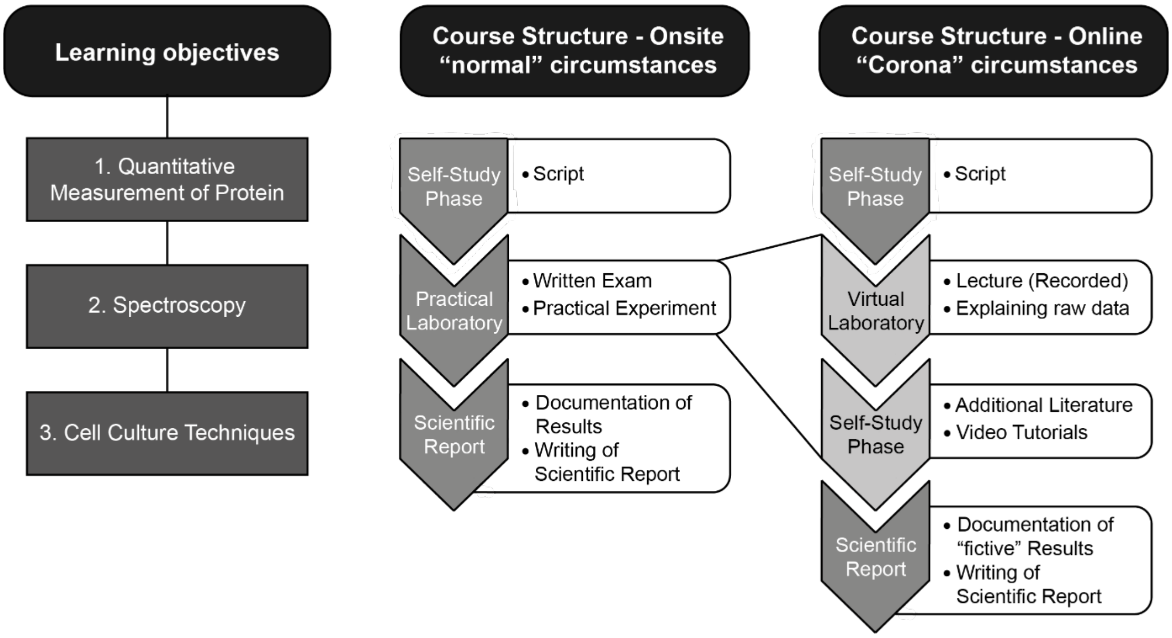

Figure 2: Outline of BCL structure. Three major learning objectives are addressed. The original course was structured in a self-study phase, practical laboratory and writing of a scientific report. The restructured course affected mainly the practical laboratory, which was split in a virtual laboratory and a second self-study phase.

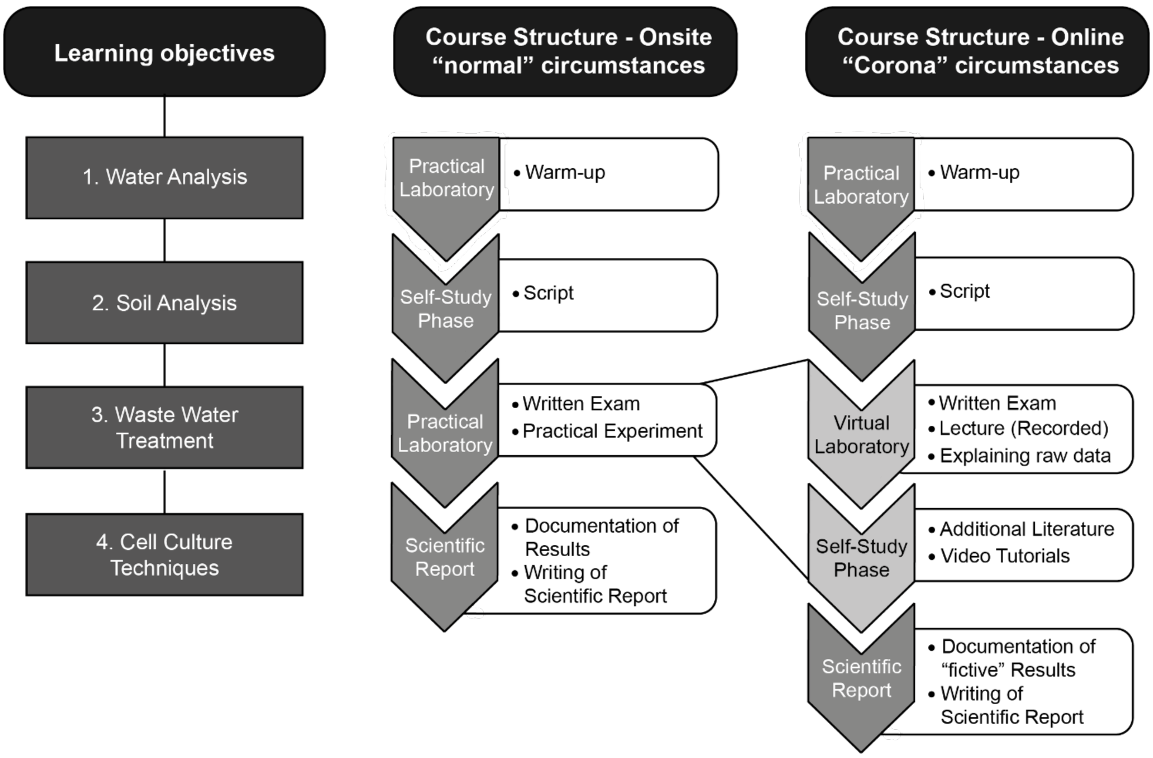

Figure 3: Outline of SAUT structure. Four major learning objectives are addressed. The original course was structured in a laboratory warm-up, self-study phase, practical laboratory and writing of a scientific report. The restructured course affected mainly the practical laboratory, which was split in a virtual laboratory and a second self-study phase.

One difference between the two courses is that at the beginning of the SAUT course students receive a “warm-up” training in the laboratory. As students of this master study program have different educational backgrounds, students with less laboratory experience get the chance in the “warm-up” training to compensate for it. This is not necessary in the BCL course, as students are still at the very beginning of their higher education, thus representing a more homogenous group with roughly the same and rather little laboratory expertise.

The BCL course is divided in three, the SAUT course in four major topics, which are addressed using the same didactic strategy by lectures with profound expertise on the corresponding subjects. First, in a self-study phase the students have to familiarize themselves with the topic and the methods they will practice at a later moment in the laboratory. Therefore, a script is provided and students are encouraged to independently research on the subject. Second the practical laboratory unit is held on-site. At the beginning, the students have to pass a small written exam proving their knowledge of the theoretical background. Only those who pass this test are allowed to participate in the laboratory exercises on that day. Afterwards, the most important theoretical contents are briefly discussed by the lecturer before the practical part begins. A total of about eight students carry out the laboratory on the same day. Usually they work together in teams of two. Finally, after the laboratory exercise the students have two weeks to write a scientific report.

The work load can differ individually, however we estimate an average distribution as follows: 30% self-study phase on the theoretic background of the topic, 10% practical work in the laboratory and 60% report writing, which is also reflected in the grading with 30% exam, 10% participation in the laboratory and 60% report, respectively.

Although only 10% work-load of the courses are accounted for practical training in the laboratory, this opportunity to directly apply theoretical background information is extremely valuable. Practical implementation of acquired theoretical knowledge and collaboration enhance the understanding and the long-term memory of the learnt matter (DiCarlo, 2006; Schmidt et al., 2011). We therefore claim that the benefit of practical courses is not in direct correlation with their actual time investment and want to underline the importance of practical courses.

The course “Methods in Cell Biology (MIC)” in the second semester in the master study program “Tissue Engineering and Regenerative Medicine” (Figure 4) builds on previously acquired advanced knowledge in cell biology, protein chemistry and practical cell culture methods.

In comparison to the BCL and SAUT courses, the MIC course is much more comprehensive, as more diverse topics are covered. It is divided in two parts, of which Part A addresses four specific subjects with similar didactical concepts as described already for the BCL and SAUT courses. Briefly, each subject combines self-guided study of the theoretical background with provided literature and scripts, frontal lecture elements by specialists, and practical application of the acquired theoretical knowledge in the form of laboratory exercises. Students are working in groups of four and have to write a group report after the course. For two of those laboratory courses, students are asked to complete web-based learning exercises followed by online examinations to prepare for the practical work.

Part B of the MIC course comprises four theoretical frontal lectures with homework assignments to consolidate and deepen the knowledge of those topics.

Grading elements of the course include two written examinations (total 50% of final grade), an initial examination covering the theoretical background of the laboratory courses at the start of the semester (Part A) and a final exam covering the topics of the frontal lectures at the end of the semester (Part B), and grading of the four individual laboratory reports and four homework assignments (total 50% of final grade). All grading elements are weighted according to the teaching hours spent on the subject.

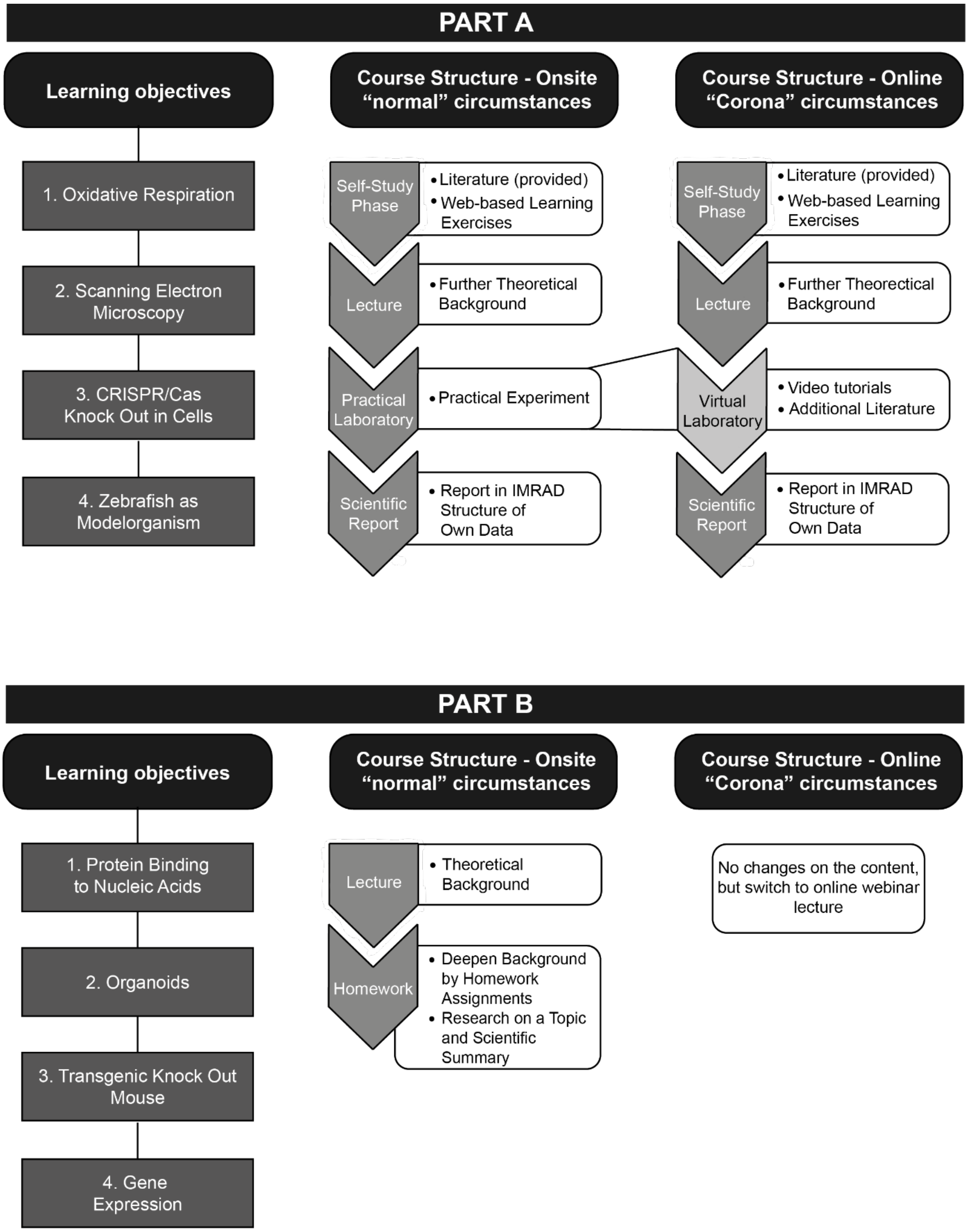

Figure 4: Outline of MIC structure. The MIC course is divided in two Parts (Part A and B), each containing four major learning objectives. In Part A, the practical laboratory was restructured in a virtual laboratory.

Adaptation to pure online structure of chosen hybrid-courses

While the self-study elements as well as conventional lectures were not affected, as they could be held through online tools (BigBlueButton and Zoom), the practical laboratory exercises had to be re-designed.

Due to time pressure, an emergency conference of involved lecturers and PBL-experts was convened. It was decided to teach students practical laboratories online in so-called virtual laboratories, which can differ depending on the respective subjects and methods. However, they usually comprise further specific background information on the subject in special lectures, a detailed guidance through the practical work procedure and finally additional educational material for a second self-study phase.

The guidance through the practical work procedure was usually based on fictive data or data obtained from previous courses with an emphasis on common technical problems, troubleshooting advices, calculations, discussion of equipment and specific computer software. The exercise on scanning electron microscopy (SEM) in the MIC course included an *in silico* hands-on part, thus representing a good example of a real virtual laboratory. Using the virtual SEM simulator (https://myscope.training/) allowed students to navigate a virtual microscope and to generate their own images. Due to the simulator students were enabled to experience an almost real-laboratory situation.

The final aim of the virtual laboratory units was also to write a scientific report. Therefore, students were provided with raw data and additional educational material on certain topics including recordings of special lectures, helpful literature, and pre-existing and open-access tutorial videos, such as provided from the science education platform JoVE (Journal of Visualized Experiments) and certain biomedical providers (e.g. ThermoFisher and SigmaAldrich). If available for certain methods, guidance through the application of *in silico* methods (performance of scientific experiments by means of computer simulation) was also provided. All mentioned information and material for self-study phases was provided on the central website platform on Moodle.

The adaptation to virtual laboratories with the three chosen hybrid-courses is outlined in Figures 2-4.

Evaluation of chosen hybrid-courses

In voluntary and anonymous surveys, we analysed the opinion of the students on the restructured courses in order to obtain an idea of the quality of virtual laboratory courses and the satisfactory of the students.

The majority of students claimed to have been informed sufficiently and in time about the restructuring of the course (data not shown). Most of the students stated that the adapted course contents had been explained and conveyed in an understandable manner and that the quality of the Moodle BigBlueButton video-lectures was satisfactory (data not shown).

As the final goal of all evaluated hybrid-courses was the writing of a scientific protocol, we paid special attention on this particular learning objective. We were satisfied to hear that according to the majority of students the necessary background knowledge and goals of the virtual laboratory exercises were adequately explained in order to subsequently write a protocol. Consequently, 74% of students in the BCL, 60% of students in the SAUT and 59% of students in the MIC course were satisfied with the theoretical background. However, one should not disregard that a significant number of students (20% of students of the BCL, 30% of students of the SAUT and 36% of students of the MIC course) experienced the virtual laboratory exercises as not sufficient to write a report (Figure 5, Panel A). Despite the ambivalent assessment of the laboratory exercises, the students were overall satisfied with the provided documents and online resources on Moodle for the self-study phase (data not shown). Interestingly, lecturers involved in these courses agreed that the quality of reports of all three hybrid-courses was of better quality and above average. Theoretical connections could be better explained by the students during the final examination compared to previous years. This might be due to a special emphasis during the online lectures on how to write scientific reports and explaining in more detail theoretical background. In addition, students were able to listen to recorded lessons more often and go through the learnt matter in their own speed.

Next, time management and workload were evaluated. Comparing to an estimate workload of the course under normal circumstances, one third of the students from all three hybrid-courses estimated a similar workload of the course with virtual laboratory exercises. While the rest of students from the master study programs participating in the MIC and SAUT courses on trend estimated a higher work load of the courses with virtual laboratory, the rest of students from the BCL course (bachelor studies) claimed the contrary (Figure 6, Panel B). These results indicate that certain differences might arise from the different background and education level in bachelor and master study programs.

Most students of the BCL course (74%) and of the MIC course (66%) claimed that the learning objectives “understanding of the theoretical background” and “understanding of practical methods” were achieved in the virtual laboratory exercises. In case of the SAUT course the assessment was more heterogeneous and only half of the students (55%) agreed on having achieved the learning objectives, while the rest (45%) disagreed (Figure 5, Panel C). The positive evaluation could be confirmed by the lecturers due to the high-quality reports, also in the SAUT course, in which students proved their newly acquired skills and theoretical expertise.

After the students had completed the virtual laboratory exercises, we were wondering how students self-assess their practical skills. We were surprised that more than half of the students in the bachelor study program (59%) feel well prepared to be able to carry out the tests and experiments in the laboratory. Students from the master study program attending the virtual MIC course assessed this question differently and the majority (85%) claimed to feel not well prepared to carry out certain experiments independently (Figure 5, Panel D). These opposing results could be explained by the different educational status. Although master students have already acquired valuable practical expertise, they feel less prepared to translate theoretical knowledge transmitted by virtual laboratory exercises. What looks as being a lack in self-esteem is in fact a much more realistic self-assessment of somebody who has enough experience in order to evaluate such a question.

The assessment whether the students experienced the virtual laboratory course more difficult than in comparison to previous courses with practical laboratory units was individually very different, however with a similar distribution within the three hybrid-courses. While students of the BCL and MIC courses experienced the adapted courses on trend more difficult, students of the SAUT course experienced it on trend less difficult (Figure 5, Panel E). Those who had stated that is was more difficult added that due to very limited experience in practical laboratory work, the virtual laboratory was too abstract.

Clearly negatively evaluated was the limited and to a minimum reduced discussion between students and their colleges and students and lecturers. More than 60% of the students attending all three hybrid-courses claimed that the online format affected negatively scientific discussions that would otherwise occur in the laboratory spontaneously (Figure 5, Panel F). Although lecturers encouraged students during the online sessions to actively participate in discussions, the online tools used (like BBB and Zoom) have limited resources. In addition, the atmosphere of the laboratory, where students and lectures work together as small teams, is more friendly and more appropriate for scientific discussions. Most importantly, many questions only arise when performing actively an experiment in real and not when watching passively somebody explaining its principle.

To summarize, the evaluation of the re-structured hybrid-courses resulted in ambivalent conclusions. Several aspects were assessed positively, such as additional teaching material (literature, tutorials and recording of online lessons) that helped to elaborate the theoretical background and therefore the understanding of the learning objectives, while others were criticized, such as the difficulty of translating theoretical knowledge into practical skills and the lack of open discussions. Although the majority of students were satisfied with the restructuring of the course under the present circumstances (data not shown), they clearly expressed their preference towards the conventional mode of the course with practical laboratory work (Figure 5, Panel G). The majority of the students mentioned that additional study material, as it had been provided, as well as a second round of a self-study phase would be beneficial in future courses as an add-on to the practical laboratory exercises.

To conclude, online virtual laboratory exercises cannot replace practical courses. However, in addition to the self-learning phase prior to the laboratory work, sufficient time should be scheduled for a detailed explanation of theoretical concepts and data evaluation by the lecturer.

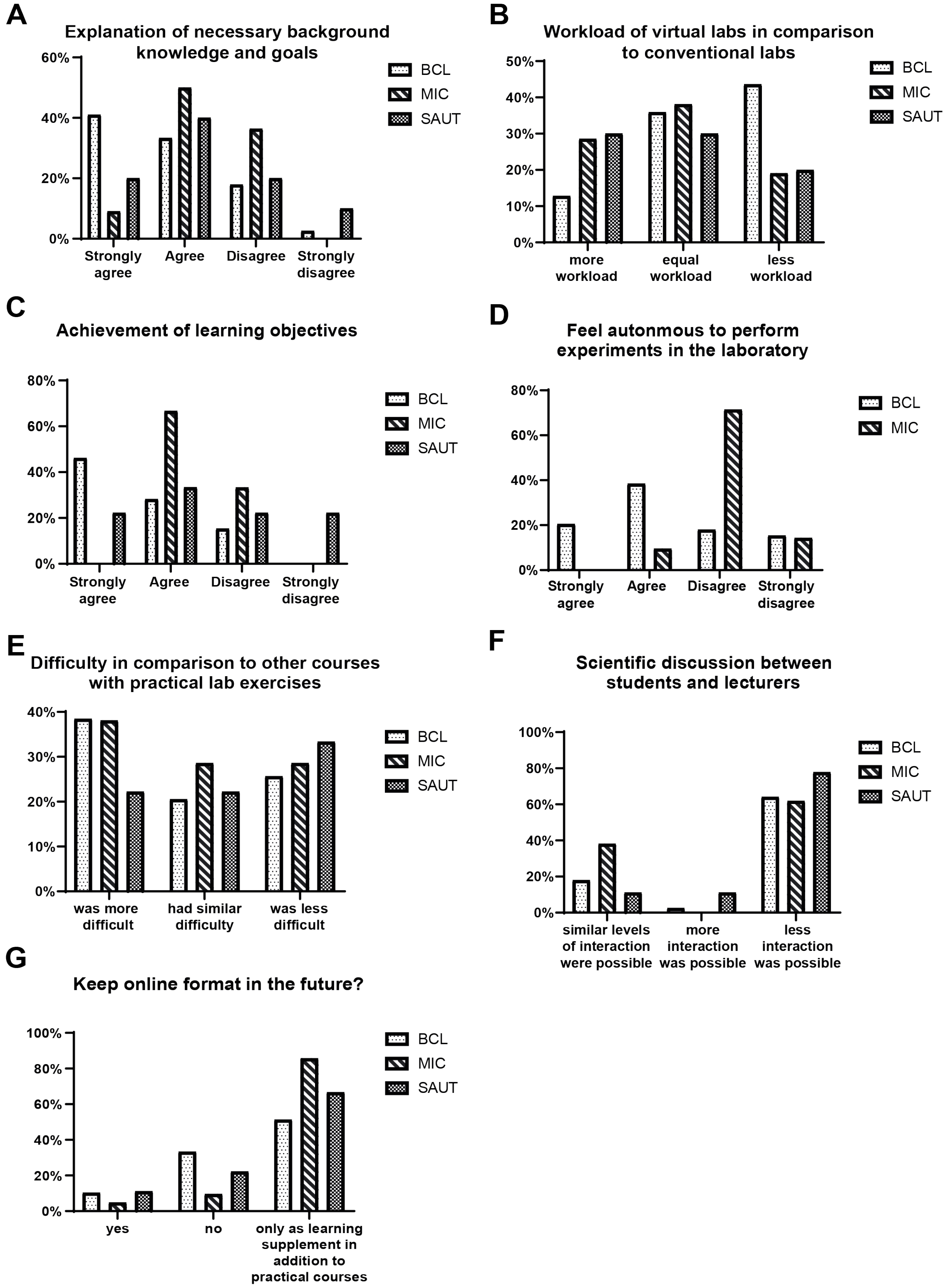

Figure 5: LimeSurvey of three chosen hybrid-courses. The restructuring of practical laboratory to virtual laboratory of BCL, MIC and SAUT courses was evaluated. 48,8% of students of the BCL, 74,2% of students of the MIC and 52% of students of the SAUT course participated. For each question three to four possible answers existed. The statistical analysis was performed by using LimeSurvey Professional. (A) Explanation of necessary background and goal. (B) Workload of virtual labs in comparison of conventional labs.(C) Achievement of learning objectives. (D) Feel autonomous to perform experiments in the lab. (E) Difficulty in comparison to other courses with practical lab exercises. (F) Scientific discussion between students and lectures. (G) Keep online format in future.

DISCUSSION

Lessons learnt from the sudden transition from on-site to distant teaching

Maintaining quality teaching despite the restrictive measures undoubtedly posed a major problem for lecturers. Analysing the solution to this problem from both the student's and the lecturer's perspective with a faculty-wide survey, we come to the conclusion that the sudden lockdown in summer semester 2020 has clearly accelerated the development of e-didactics in the faculty and increased the lecturer's skills to enable learning processes using the new media.

Importantly, the Corona crisis accelerated the future strategy by the UAS to expand blended learning. As investments in infrastructure and teaching support had already been planned before the lockdown, online tools and technical support could be brought forward relatively quickly and are now permanently available. Reactions to the first lessons learnt in the pandemic included, for example, the strategic and sustainable selection and licensing of one online conference tool for everyone, Zoom, and the expansion of a teaching and learning center, which supports students as well as lecturers in technical aspects and by making experiences and practice examples available to improve blended learning concepts. In addition, computer rooms at the university were equipped with professional recording (audio and video) devices and streaming software, in order to guarantee best-quality teaching conditions for blended formats.

Almost everybody agreed that communication in online formats is impaired in both ways, qualitatively and quantitatively. As professional communication is of utmost importance for transmitting a subject as well as for creating a comfortable ambience, this poses a major challenge, especially if online teaching formats will be kept in future. However, we are convinced that with an optimistic state of mind and the use of certain features of online tools, such as video conferences with activated camera, breakout rooms in Zoom, student chats and others, we will be able to circumvent these communication limits.

Although lecturers and students were affected by an increased workload and a more difficult time management, most people believe that with time and more experience with online tools the work load might actually decrease. In fact, several tutorials and online teaching materials that were created are still being currently used. Even though practical exercises are taught back on-site in the laboratory (respecting strict Covid-19 safety regulations and measures, such as limited number of people in laboratories, respecting a two-meter distance to colleagues and wearing FFP2 masks), all other courses are held online. In addition, most exams have been held online, which required the creation of open book exams and of competence-oriented question catalogues. While it is more time consuming for lecturers to develop and correct open book exams, students are encouraged to apply and critically question the course contents as well as profit from detailed and individual feedback. This is in line with the student's assessment of exam questions.

Remarkably, both lecturers and students were satisfied with the sudden transition to online teaching during the lockdown in summer semester 2020. From the current perspective, in which on-site teaching was resumed for practical laboratory exercises only, however all other lessons are still taught online, we are confident that blended teaching formats are a satisfying compromise also for the future.

Lessons learnt from the restructuring of three hybrid-courses

As courses with a high degree of practical laboratory exercises were in particular challenging to restructure to pure online courses with virtual laboratory exercises, we analysed three hybrid-courses in more detail.

From the results obtained by student-surveys it is obvious that students were overall satisfied, but regretted very much not to have had the opportunity for practical work in the laboratory and therefore gaining more practical expertise. Although lecturers pointed out a better performance of students in writing reports and in exams, most probably due to more focus in explaining theoretical background, they agree that practical training is extremely important in the field of life sciences and cannot be adequately substituted by virtual laboratories. However, this also points out that under normal circumstances, even more emphasis should be laid on the explanation of the theoretical background.

Another reason for the better performance in writing reports and in exams might be the fact that students had the possibility to listen to recorded lessons more often and to work on the topics in their own speed. Additional learning material, such as literature, screen casts and/or useful internet links were also provided on Moodle, which certainly supported the positive learning outcome. We therefore suggest that in future, study material for self-study purposes should be provided and actively integrated in the course structure, independent of the course format (online vs. on-site). For instance, a guided study or a well prepared screen cast on the theoretical background summarising the already completed laboratory exercise, common mistakes in protocol writing or common problems in data analysis could be provided one week after the practical work. At this point, most of the students have already started working on the protocols, however would still have enough time to implement information from the guided study materials. It would also lead to a critical reflection on the exercise and the written report.

Due to a complete interdiction of entering laboratories in the university buildings during the lockdown in summer semester 2020, even for lecturers, possibilities for restructuring laboratory courses were very limited and restricted to already existing video tutorials.

Now that laboratories are accessible again, we are currently elaborating which topics and laboratory exercises would be suitable and prepare measures for tutorial videos. However, even though better designed online virtual laboratories might be used in future, our results indicate that neither students nor lecturers believe that solely virtual laboratories should be used. We insist that they should only function as an additional didactic tool as part of an integrated blended learning concept as described by De Jong et al. (2013), or in the case of a similar situation as in spring 2020 as emergency tools. However, they can never fully replace real on-site laboratory courses, due to the specific skills needed to handle equipment in life sciences. In students' interviews, participants also stated very clearly that - if possible - practical laboratories should never be substituted by any other means.

As already mentioned, communication is greatly affected in online formats. This influences critical PBL elements such as the interaction of students in the problem analysis phase as well as guidance from lecturer side. Our observations further underline the fact that an interactive atmosphere, in which lecturers engage students in discussion and debates and that encourages questions, increase the learning outcome (Verstegen et al., 2016; Boelens et al., 2017; Kebritchi et al., 2017). As in current times it is advised to continue online teaching when applicable, we elaborated possible solutions to this problem. We asked students under which circumstances they would feel more comfortable to participate in online discussions. Many stated that working in smaller groups and activating the camera might improve the situation. This indicates, that participation increases when students have the feeling, that their presence is being noticed, generated by virtual eye-contact which leads to a feeling of being addressed personally. We therefore conclude that breakout rooms in Zoom are useful features, which allow a more comfortable setting needed for discussions. This is in particular important in first semesters of study programs when students do not know each other well.

Finally, virtual laboratories were assessed to be more time consuming. In student interviews we wanted to understand why the work load was in average higher and whether students assume that this correlated with a better understanding of the addressed subject. Interestingly, they mentioned that due to recordings of courses, they could go back to lectures several times and at their own pace, which led to a high time amount. While lecturers assume this to be at least partly the reason for a better performance in exams, a way to estimate the learning objectives, students did not see a correlation to that.

To conclude, hybrid-courses with a substantial amount of practice-oriented learning by laboratory exercises can only be unsatisfactorily substituted by online teaching methods. While the implementation of hybrid-methods, such as a combination of self-guided study phases, transmission of theoretical background and practical training, of which the first two parts could be done via online tools, has proven very successful, a complete transition to virtual laboratories clearly affects the learning quality negatively. Hybrid solutions including online and on-site teaching however are a satisfying compromise and have even proven certain benefits, as providing additional study material and guided self-study phases.

Although the Covid-19 pandemic and the complete lockdown in summer semester 2020 have bestowed a myriad of challenges on lecturers and students alike. They have certainly taught us to stay flexible and optimistic, two qualities of utmost importance.

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References

Adams, D. J. (2009). Current trends in laboratory class teaching in university bioscience programmes. *Bioscience Education*, *13*(1), 1-14. https://www.tandfonline.com/doi/pdf/10.3108/beej.13.3?needAccess=true

Allen, D., & Tanner, K. (2003). Approaches to cell biology teaching: learning content in context—problem-based learning. *Cell Biology Education*, *2*(2), 73-81. https://www.ncbi.nlm.nih.gov/pmc/articles/PMC162197/pdf/03-04-0019_p073.pdf

Barrows, H. S. (2000). *Problem-based learning applied to medical education*. Southern Illinois University School of Medicine. http://www.sciepub.com/reference/129322

Boelens, R., De Wever, B., & Voet, M. (2017). Four key challenges to the design of blended learning: A systematic literature review. *Educational Research Review*, *22*, 1-18. https://biblio.ugent.be/publication/8526490/file/8526491.pdf

De Graaf, E., & Kolmos, A. (2003). Characteristics of problem-based learning. *International Journal of Engineering Education*, *19*(5), 657-662. https://www.ijee.ie/articles/Vol19-5/IJEE1450.pdf

De Jong, T., Linn, M. C., & Zacharia, Z. C. (2013). Physical and virtual laboratories in science and engineering education. *Science*, *340*(6130), 305-308. https://users.gw.utwente.nl/jong/dejonglinnzacharia%20science.pdf

DiCarlo, S. E. (2006). Cell biology should be taught as science is practised. *Nature Reviews Molecular Cell Biology*, *7*(4), 290-296.

http://www.cellbiol.net/docs/10%20cell%20biol%20taught%20as%20practiced%20DiCarlo.pdf

Flowers, L. O. (2011). Investigating the effectiveness of virtual laboratories in an undergraduate biology course. *The Journal of Human Resource and Adult Learning*, *7*(2), 110. http://www.hraljournal.com/Page/12%20Lawrence%20O.%20Flowers-1.pdf

Stuckey-Mickell, T. A., & Stuckey-Danner, B. D. (2007). Virtual labs in the online biology course: Student perceptions of effectiveness and usability. *MERLOT journal of online learning and teaching*, *3*(2), 105-111. https://jolt.merlot.org/vol3no2/stuckey.pdf

Verstegen, D. M., de Jong, N., van Berlo, J., Camp, A., Könings, K. D., van Merriënboer, J. J., & Donkers, J. (2016). How e-learning can support PBL groups: A literature review. In *Educational technologies in medical and health sciences education* (pp. 9-33). Springer, Cham.

Wallen, M., & Pandit, A. (2009). Developing research competencies through a project-based tissue-engineering module in the biomedical engineering undergraduate curriculum. *Proceedings of the Institution of Mechanical Engineers, Part H: Journal of Engineering in Medicine*, *223*(4), 443-448.