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Engineering education amid a global pandemic
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**A R T I C L E   I N F O**

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**A B S T R A C T**

To investigate the impact of the sudden shift to online education triggered by the COVID-19 pandemic, a survey was conducted among international mechanical engineering students, specializing in manufacturing technology, at the TU Dortmund University. The surveyed students, were exposed to differently structured online courses from different institutes, as well as dynamic developments in each online course, over the semester and thus were able to effectively assess the pros and cons of the different teaching styles. To get the viewpoints of both the involved parties on how a successful online education course needs to be structured, a similar survey was also conducted among manufacturing engineering professors involved in Germany. The survey, a combination of Likert-scale and free-text questions, tackled the aspects of motivation to teach and learn, ensuring effective teaching and learning, and proper assessment of the learning outcomes in an online education system. The results show that both parties initially struggled with the transition, but later adapted quickly to the new style of online teaching that was inspired by the conventional flipped classroom concept. Certain structures and approaches to online teaching, such as pre-recorded lectures; interactive Q&A sessions; quizzes for self-assessment, are preferred by students and teachers alike. Aspects where the viewpoints differed could be explained by the difference in age and the experience in using digital equipment. A challenge specific to online engineering education is on offering laboratory experiences to students. Possible solutions such as virtual labs, remote labs and digital-live labs that aid in overcoming this challenge are presented. Finally, based on the survey results and the author experiences on digital laboratories, best practice guidelines are presented that will help the readers in the design and deployment of online engineering courses.

1. Introduction

Engineering education is traditionally a bastion of content-centered, hands-on and design-oriented teaching with a special focus on the development of analytical thinking skills (Bourne et al., 2019). Several tools and methodologies, such as active learning (Lima et al., 2017), project-based learning (Mills and Treagust, 2003), flipped classroom (Bishop and Verleger, 2013) etc. are available to educators to aid in improving the efficacy of their teaching.

In the past decade, online education has been establishing itself as an additional important tool available to educators. Even though online education has its advantages, it is usually met with apprehension and resistance from both educators as well as students (Vivolo, 2016). Transforming a conventional classroom course to an online format is time-consuming and requires significant effort from the instructor as well as familiarity with the tools available at their disposal (Asgari et al., 2020). Another point of contention is the difficulty in ensuring a fair and transparent online assessment system that minimizes the risk of cheating or plagiarism (Lee-Post and Hapke, 2017). From the student’s perspective, the majority prefer to learn complex concepts in a classroom environment and believe that online education does not facilitate a deep level of learning (Holzweiss et al., 2014).

An unexpected turn of events lead by the outbreak of the COVID-19 pandemic, forced educators around the world, regardless of their stance on online education, their familiarity with it and their level of preparedness, to transition into a completely online system of education and with hardly any time available to do this transition. Hence, teaching methods and assessment methods had to be developed or implemented on the fly (Dhawan, 2020).

It was not only teachers who were facing difficulties, but these unprecedented times also took a toll on the students. Students might have experienced negative emotions due to the hurried switch to an unfamiliar learning situation (Park et al., 2020). This feeling would have been exacerbated by the academic stress and other stress factors such as...
reduced face-to-face social interaction in general, limited networking with peers and teachers, longer response time for communication via digital mediums and extended hours of screen time (Adnan and Anwar, 2020). According to UNESCO statistical data, in the first six months since the onset of the pandemic, more than 1.5 billion students worldwide (90.1% of total enrolled learners) have been affected by the COVID-19 closures and subsequent educational changes (UNESCO, 2020).

Just like their counterparts around the world, the educators at the Technical University (TU) of Dortmund, Germany were obliged to shift towards a complete online system of education. At the Institute of Forming Technology and Lightweight Components (IUL), among others, the Forming Technology-II (FT2) lecture offered to the international masters in manufacturing technology students (MMT) was a key lecture that had to undergo this transition in the summer semester (Apr-Sep) of 2020. The experience of the authors in conducting this lecture and the students attending it over the semester shall serve as the basis for this submission.

The IUL has been at the forefront of engineering education research in Germany thanks to its involvement in the BMBF funded ELLI projects and has done extensive research on the significance of remote laboratories in engineering education of the future. An overview of the completed works can be found in (Grodotzki et al., 2018). Even with this prior experience, the switch to a complete online style of education was a challenge at the beginning and over the semester, the tools and methods used were dynamically altered to ensure the best possible learning experience for the students. To further improve this experience, at the end of the semester, an extensive survey of both the involved parties: the educators as well as the students, was conducted. The results of this survey as well as the observations of the authors will be used to identify best practice methods to ensure the most effective teaching and learning experience in engineering education.

Sharing the results of this study with the global educators’ community facilitates educators all around the world to benefit from the author’s experience and ensure a robust and effective online education in the upcoming pandemic driven digital semesters. More so, it can help in the general improvement in online engineering education even in the post-pandemic era. Although the opinions are derived from the interactions with an international group of students, the findings will be applicable for engineering education in general.

In the following sections, the methodology used for data acquisition will be elaborated. Subsequently, the student’s, followed by the teacher’s, perspective regarding three key problems associated with online education will be addressed. The first problem is how to ensure that the students and teachers continue to be motivated during such a completely digital form of education. Then the question of how to ensure effective learning and teaching through digital tools and methods is addressed and finally, the topic of effective assessment of the students’ performance is tackled. To address the problem of the digitalization of laboratory courses, three approaches are presented and compared regarding their ad- and disadvantages. Finally, the findings are compiled in the form of a concise “lessons learned” section and aspects that can be further improved are tackled in the outlook.

The following figure, Fig. 1, gives a broad overview of the timeline of events important to understanding the developments of the course Forming-Technology II. The reader is invited to familiarize themselves with the events, given the numerous references to this timeline throughout the main analysis of the survey’s results. Furthermore, the time at which the survey was conducted is important considering that the surveyed students had by then experienced various adaptions to the style of teaching presented to them during this course.

**Fig. 1.** Timeline of events important to the Forming Technology II course at the TU Dortmund University and the analysis of the survey’s results.
2. Methodology & data acquisition

For this paper, several sources of data were compiled and analyzed. The main body of the data stems from an extensive survey of 2nd-semester students from the international MMT study program at the Technical University of Dortmund. A total of 32 students, that is the entire batch of the year 2019, participated in the survey. With the entire batch participating, a fair distribution of opinions and personality traits is ensured. The students come from 11 different countries and around a third of the students got stuck in their home country due to corona restrictions. It is common among international students to return home during the semester break in March. That was when the lockdown and travel restrictions were imposed in many countries around the globe. Hence, the survey reflects the perspective of students who could have, theoretically, participated in an on-campus semester and from those who could not have. In some cases, the statements of the international students were compared to the feedback from the German-taught mechanical engineering master students, who were asked similar questions as part of regular lecture evaluation. Since no significant deviations were observed between these two groups, in the following the results from the international student survey are presented.

Given that teaching and learning are basically two sides of the same coin, an additional survey was conducted among German engineering professors. Some of whom are involved in the MMT study program, others are engineering professors at the TU Dortmund and the rest are working at other technical universities in Germany. A total of 11 professors participated in the survey. The combination of both perspectives, the teacher (T) and the student (S) perspective, on various topics such as motivation (M), effective teaching and learning (E) methods as well as assessments (A) offers a unique opportunity to get a more holistic view of digital education during the pandemic. The raw data can be accessed under the following link: https://tu-dortmund.sciebo.de/s/a8Bi6xtasYxYIDD.

In the subsequent sections where the survey data is analyzed, the corresponding questions pertaining to the aspects being discussed will be referenced according to the following format: AB#c-#, where A identifies the topic of discussion (M-Motivation; E-Effective teaching/learning; A-Assessment), B identifies the perspective (S-Student; T-Teacher), the first index # identifies the question number. Wherever applicable, the next lower case alphabet c identifies the sub-question and the second index identifies the index of the free-text answer corresponding to that question in the raw data.

It should be pointed out that the type of survey included a “neutral” opinion as part of the answer sheet. As a result, if a majority of students answered in favor of something whereas the rest maintained a neutral stance on the subject, it can be concluded that, by incorporating the subject or aspect, the majority of students will benefit from the change whereas the rest will not suffer from it.

Further data was taken from the YouTube analytics section. With the lectures being hosted on the YouTube platform, it is possible to derive useful information about the viewers’ behavior. The analytical data can be validated against some of the answers provided by the students in the survey.

Throughout the entire digital semester, other sources of data were acquired for further analysis. In every Q&A session notes were taken manually, including the number of questions asked, who asked the questions (the personal information was not recorded), the topic of the question among other information. Apart from the notes, the results from quizzes throughout the semester and the results from the final exam at the end of the semester were used to gather insight into the students’ behavior and their performance and how the two might be linked.

One reason why this particular set of students are especially suited for the basis of such an analysis is that throughout the semester, the style of (digital) teaching evolved. In different courses, the style of teaching evolved at a different pace. So the students, at the time they were answering the questionnaire, had seen many different types of teaching with different approaches and methods. With this unique background, the students offer valuable insights on how to improve the (digital) teaching for the foreseeable future of this pandemic.

3. Glossary

This section shall provide definitions for terms and abbreviations which are frequently used throughout this paper.

Video Conference Software (VCS): Such a software is used to digitally communicate through the internet. Typically, this involves audio and video transmission, so that people can see and talk to one another. Common tools are Skype, Zoom, Teams, WebEx among others.

Learning Management Software (LMS): Using LMS teachers can organize their courses digitally. In most cases, each course is represented individually. Students find material, can ask questions in forums, hand in assignments and stay updated regarding the course schedule. Typical examples are Canvas, Blackboard, moodle among others.

Video lecture: A digital representation of a traditional (teacher-centered approach) can come in various forms. The easiest option is using videos that were recorded from previous years during in-class lectures. Such videos usually have a very good and authentic feel since the teachers were in their natural teaching environment. If such recordings do not exist, the teachers can opt to record the lectures at home or in a seminar room without the students being present. No interaction with students is given here. The recordings are then uploaded to the LMS. Alternatively, the teachers have the options to do live teaching using some sort of VCS. The latter is more frequently used for exercises since there is typically more interaction with the students compared to lectures.

Screen cast: Here, it is referred to as a pre-recorded lecture, where only the slides or the screen is recorded together with the audio of the teacher. This typically means that the teacher is not visible in person.

Q&A session: Using a VCS, it is a dedicated appointment where students can ask questions about lectures or exercises which are then answered by the teacher. This is an integral part of the flipped classroom concept.

Quizzes: Form of online assessment, where students answer multiple-choice questions (MCQ), short calculations, pick-and-place tasks or general free-text answers. In most cases, such quizzes are graded automatically. The information about the learning status helps the teachers and students alike to adjust their teaching or learning respectively. Such quizzes can be done weekly or after the completion of a certain topic.

Digital schedule: In traditional on-campus semesters schedules are typically provided per course. It specifies the attendance in class, the due date for assignments, exam days and other course-related activities. During a digital semester, where for instance videos of lectures are uploaded, a digital schedule helps the students to stay on track. Therefore, it should include voluntary due dates or virtual attendance times.

4. Motivation to teach and study

Based on a constructivism centered understanding of learning (Steffe and Gale, 1998) it is vital that any type of learner, not necessarily students, is intrinsically motivated to study. Only then, the newly acquired knowledge will have a chance to stick and become part of the ever-growing understanding of the world, constructed by the learner himself/herself. Shifting from a social learning environment, i.e. the classroom or laboratory, to an isolated setting at home, with often no or only limited contact to other people, the chances of successful motivation and thus learning is further impaired.

4.1. Motivation - student perspective

Under the special circumstances of this first, completely digital semester, the students initially struggled to self-motivate themselves for studying (MS1). This resulted in a low rate of viewers actively

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In classical learning environments, like on-campus group study rooms or libraries, the effect of studying in groups (peer-motivation) is also well understood (Petress, 2004). Being forced to stay at home due to the pandemic induced lockdown, direct interaction with peers was impossible, be it for studying or purely for social interaction. Therefore, the pandemic induced lockdown, direct interaction with peers was also well understood (Petress, 2004). Being forced to stay at home due to the option to engage in collaborative tasks would not motivate them; it is interesting to note, that for most of the students (40 %, MS7) the rooms or libraries, the effect of studying in groups (peer-motivation) is impossible, be it for studying or purely for social interaction. Therefore, it is interesting to note, that for most of the students (40 %, MS7) the option to engage in collaborative tasks would not motivate them strongly to deal with the content more intensely. It was expected that the lack of social interaction, which is usually cited as one of the most severe changes due to the pandemic (Hemanth, 2020), would drive the students to actively seek such opportunities. The studying of the content would rather be a by-product of such social interactions. With the VCS available to everyone, even for their personal use, students did not make use of these tools to create and engage in collaborative learning groups, as they used to do during on-campus semesters. The reason for that seems to be that such an effort, e.g. to watch a recorded lecture together and talk about it as well as share questions with each other, is considered not motivating (41 %, MS10). Hence, if the students believe that it would not help them in any way if they engage in such online group learning activities, they will simply not do it.

Even with the students stating they have overcome their initial lack of self-motivation (MS2), the data from the viewing analytics, cf. Fig. 2 and a zero questions being posted in the LMS during the first four weeks, pointed towards a continuation of a low rate of content consumption. This triggered a shift in the teaching approach and opened up the chance to investigate the influence of extrinsic factors which affect the students’ motivation. One simple thing to change is to introduce a voluntary schedule for the consumption of digitally available content, similar to conventional classroom lecture schedules. The vast majority (72 %, MS4) confirmed that such a schedule helps or, based on their experience from the change after such schedules were introduced in week 5, helped them to get motivated to deal with the content of the lecture. An element that can be used instead of, or in addition to a schedule, is the element of gamification, whose positive effect on learning and students’ motivation has been investigated thoroughly (Brull and Finlayson, 2016). One classical approach of gamification is to have students unlock the next chapter of a class upon completing a small task, e.g. an online quiz. Such elements can complement schedules in the sense that the schedules would suggest when to complete a task. Alternatively, the students also have the freedom to rush through all the content by unlocking everything in a short amount of time, and, thus, being ahead of the schedule. Hence, this system gives the students a great deal of flexibility while at the same time acting as a source of motivation. A striking majority (88 %, MS5) of students stated that such a gamification based structure, where they can unlock the next chapters by answering online quizzes, would significantly help them to get motivated to deal with the content. In such a case the quizzes should be designed, such that only by having a thorough understanding of the content of each chapter, the successful completion of the quiz is possible.

To tackle the low rate of students asking questions in the LMS forums and the lack of direct interaction due to pre-recorded lectures, after week 5, weekly or bi-weekly Q&A sessions were introduced, see Fig. 2, showing when the first Q&A session dealing with the content of the first lecture was announced and held. In those Q&A sessions, only questions regarding the content of last week were permitted. Hence, the sessions served as a further schedule, since the students - to be able to ask meaningful questions - had to deal with the content in the week leading...
up to the Q&A session. For most of the students (72%, MS8), this element worked very well in improving the motivation to study. Interestingly, this motivation seems to be mainly intrinsic (even with the sessions themselves being an extrinsic factor), as the students mostly state (41%, MS11) that tracking the attendance during the Q&A sessions would not motivate them to participate in those sessions. On a similar note, the students (47%, MS9) indicated that if bonus points would be granted for active participation by asking meaningful questions (not merely “can you repeat this calculation please?”) would not increase their level of motivation. This is a surprising result, given the fact that usually providing bonus always lifts the level of students’ motivation (Richter et al., 2015). In general, it can be said, that simply by offering such an additional element like the VCS based live Q&A sessions, the students are encouraged to stay on track according to a pre-defined schedule.

The answers on the bonus points for meaningful questions is even more surprising if the data on content consumption is taken into consideration after the Q&A session was enhanced by online quizzes during week five. The first four Q&A sessions were mainly just discussion sessions, but starting with week five the students could earn a bonus by completing a small quiz on the same subject of the session at the beginning of it. This extrinsic motivational factor clearly increased the overall rate of consumption, cf. Fig. 3. For cases where the Q&A session was not mandatory, it was found that the rate of attendance also increases with the introduction of such graded quizzes. Further aspects of those quizzes will be analyzed in the section on effective teaching and learning.

Analyzing the behavior of this particular set of students provides a unique insight into how the consumption of content-related media, mostly the lecture videos, is affected by extrinsic motivational factors, like the bonus points from the quizzes. This is because the same students have experienced conventional classroom lectures during the winter semester of 2019/20 (WS19/20), the semester before the one analyzed in this paper. In that winter semester, they participated in the course Forming Technology I, which was held in-class, and these lectures were recorded and provided to the students a few days later in the LMS. Instead of weekly quizzes, there was a classical mid-term exam which covered the content of the lectures 1 through 6 (out of 13). Similar to the quizzes, participating in that mid-term exam would yield additional bonus points that were added to the points achieved in the final exam. Hence, the two concepts, quizzes and mid-term exam, are comparable with respect to the level of extrinsic motivation. The difference is in the amount of content covered. The quizzes take a weekly approach focusing on a single lecture, whereas the mid-term spans roughly half of the content (6/13).

Fig. 4 provides the viewing count for the winter semester for the lecture 3. This lecture was uploaded two days after the in-class lecture. As indicated by the number of views, in the week before the mid-term exam, the students intensely watched it as part of their preparation for the mid-term. This indicates a strong similarity to how the quizzes function as extrinsic motivation. The main difference is that there is not a single spike, which can be explained by the larger number of videos that the students had to watch in order to prepare for the mid-term exam. It can be concluded, that regardless of online or offline learning, the students only watch or re-watch the videos if there is an extrinsic incentive that works towards their grading. Comparing the way weekly quizzes or a mid-term exam affects the study behavior, it can be stated that the quizzes engage the students in a more regular manner and ensures continuous learning process compared to a single mid-term exam.

Another factor that was investigated as part of the survey of the digital semester 2020 was the influence of the lecturer on student motivation. The students who participated in this survey are exposed to various types of lecturers: professors, post-docs, PhD students, TAs and sometimes student assistants. Most of the students (72%, MS12) mentioned that the presence of the professors themselves positively affect their tendency to participate in the live interaction sessions. This could be attributed to the fact that international students are usually lectured directly by the professors during their bachelors in their home countries. However, the presence of the professor did not encourage the students to turn on their camera voluntarily. This phenomenon of students preferring to remain “invisible” was also recently investigated by (Castelli and Sarvary, 2021).

![Fig. 3. Views per day of the fifth lecture video shown over the semester. Important events regarding this lecture are added to correlate the students’ behavior to intrinsic or extrinsic factors.](image-url)
With some of the students being stuck in their home country and also among the students who remained in Germany, there were a lot of uncertainties regarding the overall semester, including the exams. Since exam regulations are very strict in Germany, wherefore the exams must be in written, non-digital form, the fact that not being able to take the exam significantly affected the overall motivation of the students as well. In direct conversations with the students at the beginning of the semester, the aspects related to "unknown factors" and the general uncertainty were mentioned frequently by the students. Here, the universities must act quickly and assure the students that such semesters will not be lost semesters, in the sense that it will not prolong the overall time to finish the program. An overview of the survey results pertaining to this section is shown in Fig. 5.

4.2. Motivation - teacher perspective

With many of the current students coming from the “Digital Native” generation, the switch to a digital-based learning style from home was,
as one has seen above, not an easy shift, but still, they were not over-
whelmed by the technology. On the other hand, many of the teachers
grew up and studied in an entirely non-digital world. Hence, many
maintained a rather non-digital teaching style throughout the years.
That explains why, as shown in Fig. 6, roughly one-third (ET1) of the
lecture content, typically improves the overall education more (Harper,
2018). Still, around half of the teachers, do not favor this flipped
classroom concept over the traditional teaching approach (MT5), even
though they desire direct interaction with the students. This contradic-
tion can be attributed to a misunderstanding of the concept or the lack of
experience with the concept of “flipped classrooms”. However, since the
digital semester forces many teachers to adopt some sort of this concept
due to high demands from the students, it is expected that the attitude
towards this approach will likely shift in the future. Especially so, if the
teachers realize that the students value the additional opportunity to ask
questions.

The flipped classroom concept, as described above, usually circum-
vents another aspect, that teachers feel as demotivating or annoying: the
invisible student (ET7-#6) (Barber and King, 2016). As was observed
throughout this semester, during live online lectures, typically all the
students will turn off their cameras. With the teacher talking to a screen
and not seeing any students, it is a similar feeling and, thus, as (de-
motivating as if one is recording the lecture without an audience being
present (MT2, ET4a-#3). During Q&A sessions, if the students are asked
to do it, they would usually turn on their cameras. This creates a much
more familiar traditional in-class feeling for both, students and teachers,
but mostly the teacher since the students usually always see the teacher.
On a similar note, many of the teachers cite the overall lack of direct
interaction with the students as an impediment to being motivated for
pure online teaching (MT1(A1a-#4). As stated above, with the lack of
prior experience and the technology not fully developed and used by all
teachers, it is expected that the overall amount of interaction will in-
crease in the future. Therefore, the motivation will likely rise in the
upcoming, digital semesters regarding this aspect. The best way to
interact with the students during such online semesters, as of now, is
to split the lecture and Q&A sessions. While the basic content is provided
through pre-recorded videos, the Q&A sessions are used to answer
questions by the students directly during that session. Unsurprisingly,
two-thirds of the teachers (MT6) experience a higher motivation during
such Q&A sessions compared to live online lecturing. Moreover, teach-
ers also value Q&A sessions as a vital element to assess the current
learning status of the students and address potential misconceptions
directly (MT6a-#10).

5. Effective teaching and learning

With the first problem of motivating the students during a digital
semester tackled, the next issue which needs to be dealt with is how to
effectively communicate and deliver the content to the students so that
maximum learning effectiveness is ensured. Here it is taken for granted,
that even in a digital semester, the mere sharing of lecture slides with the
students is not sufficient and these slides must be accompanied by an

| Percentage of teachers agreeing or strongly agreeing with… |
|-----------------------------------------------------------|
| not being in the classroom affecting the motivation        |
| equivalence of screen-cast recordings to live lectures     |
| positive effect of personal recording                     |
| positive effect of teaching from home                      |
| preferring flipped-classroom concept over traditional     |
| enjoying Q&A sessions more due to increased interaction   |
| negative effect of high effort to switch to digital teaching |
| digital teaching saving time in the long run               |

Fig. 6. Summary of the results from the teachers’ motivation survey. The question code is given on the left.
oral talk by the lecturer. Or else, there would be no point in conducting classroom lectures during conventional semesters as well.

5.1. Effective learning - student perspective

With this basis, arises the question, “In what form should the lecture talks be made accessible to the students?” There are two broad options available a) Conducting a live lecture via VCS or b) pre-recording the lecture talk as a video and sharing it with the students. Both have their merits and demerits, but the results of the survey have shed light on the students’ perception of the two variants.

The advantages of conducting a live lecture via VCS are that this allows more instantaneous interaction between students and the lecturer, while also acting as a motivator and helping students be on track with the planned course syllabus. However, this approach carries few drawbacks as well. First, there is the problem of technical difficulties. Such an approach is heavily dependent on having a stable and fast internet connection and any deficiencies here can completely spoil the learning experience. In cases where there are students from around the world taking part in a course, the differences in time zones might cause inconveniences to one or the other. In later sections, the importance of being able to revisit a lecture multiple times in quest of better comprehension is elucidated. Conducting a live VCS lecture does not allow students this comfort and based on the survey results, is a major drawback of this approach. Considering the above-mentioned drawbacks and the advantages of the second variant which will be elaborated in the following paragraph, it is of no surprise that only 20 % of the surveyed students preferred this variant (ES4) as observable from the Fig. 7.

For students, the second variant of sharing pre-recorded lecture videos is the preferred way to access content in a digital semester. Almost half of them prefer it even over traditional classroom lectures (ES2). The main reason for this being the ability to watch the videos at their own convenience, at a pace comfortable to them and how many times they want. This is supported by the fact that the overwhelming majority of students watch the lecture videos at least two times before they feel confident about the topic and even this they do not do it in one sitting, rather they prefer watching the videos in intervals of 30–60 min (ES13). A key point raised by all students is that merely streaming them. This allows them to download it on to their devices and consume the content at their comfort, for example even while commuting, without worrying about internet accessibility or usage. Similarly, an overwhelming majority are for uploading all of the lecture videos in one go at the beginning of the semester as opposed to uploading one lecture per week (ES1). This approach allows students who want to go through multiple lectures at once to do so without affecting in any way the students who would prefer to view the lectures weekly. Regarding the nature of these lecture videos, the majority of the students (60 %) preferred if these videos were recorded when the lecturer was actually taking a conventional classroom lecture as opposed to recording the lecture in front of a camera without an audience (ES3). The students are indifferent to whether a video of the lecturer is also recorded along with the lecture slides (picture-in-picture) or not (ES5). However, if the lecture feels that recording oneself helps to be more motivated as expressed in their answers to the question MT3, then it becomes critical that the quality of this video, as well as audio, is of a high quality (ES6) as poor media quality distracts the students and makes concentrating on the lecture content harder.

Finally, to ensure effective learning, the topic of interaction must be addressed. The students must be allowed to interact with the lecturer and clarify their questions. This can be done via a dedicated forum on the LMS platform where the students can post their questions and these questions can be answered by the lecturer or even by their fellow peers. However, the initial 3-week experience with such a system showed that no student used this opportunity and the survey results supported the findings with the vast majority of students not being comfortable with such an option (ES7). This is because the students find it difficult to lucidly express themselves via text and it takes too much of their time. Additionally, some feel shy to post on the forums and the lack of immediate response is also a deterrent. This does not allow for a dynamically developing discussion.

In contrast, the alternate option of offering live VCS Q&A sessions with the lecturer had overwhelming support from the students (85 %;
ES8). Paraphrasing one survey participant “The live Q&A sessions are the most important aspect of online learning employed in this course as it offers the opportunity to directly ask questions about aspects which are not clear. Moreover, watching the lecturer answer the questions of other students enables one to learn even more”. The authors observed that the activity of the students and the quality of the questions asked was on a higher level in comparison to a conventional classroom lecture session. This can be attributed to the fact that the students have had a week to go through the lecture and thoroughly understand it. However, in the case of real classroom lectures, the students do not have the opportunity to grasp everything as its being explained and ask meaningful questions based on that. This could be a reason why almost half of the students find such live Q&A sessions more interesting than conventional lectures (ES9). However, the problem of being shy to ask questions still persists and thus almost half of the students would prefer the Q&A sessions to be one on one rather than a group discussion (ES10).

5.2. Effective learning - teacher perspective

In the previous section, the expectations of the students to ensure a fruitful digital learning experience was outlined. The next important question is to find out whether the teachers are in the position to effectively fulfill these expectations. An overview of the survey results pertaining to this section is shown in Fig. 8.

The requirements of a digital semester are significantly different compared to a conventional semester and sadly none of the surveyed lecturers had undergone any specific digital teaching-related training (ET3). However, the majority of them had prior experience with digital teaching methods and tools and thus were not stepping into completely unknown territory (ES1). This also explains why the majority of them had the necessary equipment for conducting an online semester such as webcams, headphones, VCS Softwares etc. readily available and did not have put much effort into procuring these (ET2). Unfortunately, this feeling was not shared across the participants, with a few participants ruing the lack of necessary hardware/software as well as the lack of support from their universities in procuring them on time (ET7).

A key outcome of the survey of the students is that they prefer pre-recorded videos to live VCS lectures. The teachers share the same sentiment and prefer recording their lecture videos for several reasons (ET4). They opine that recorded videos allow for reduced errors, thus improved quality lectures. It is much more efficient and is easier to focus on the important aspects. Also, it is interesting to note that, even in the case of live lectures, the majority of the students do not switch on their cameras and thus it is as good as speaking to a blank screen (ET4a).

Similarly, the importance of an interactive Q&A session as a follow up to the lecture videos was clearly established. The vast majority of the lecturers initially missed this interaction with the students and some were even concerned that this lack of interaction would lead to a less satisfying learning experience (ET7). As the semester progressed, the lecturers made an effort to improve their interaction. This was done via online consulting sessions or Q&A sessions using VCS and they made use of digital interaction tools such as whiteboards, annotations etc. to further improve the experience. (ET5).

Parallel to the FT-II lectures for the international students, the authors were involved in the first semester lecture Manufacturing Technologies for the German bachelor study program. The main difference here is that this class had 700 students enrolled. Since this lecture was started later in the semester, the lessons learned from FT-II could directly be applied to such a large group of students. Owing to the fact that the style of teaching was same over the entire semester for the German lecture series, the group was not involved in the survey. Nevertheless, based on the personal observations of the authors, it can be stated that the aspects regarding the effective teaching and learning methods, are applicable to larger groups as well. Among the important differences, the differences in number of questions being asked should be highlighted. The more the number of students, the more the number of questions likely to being asked in an interactive Q&A session. If the time assigned for a particular Q&A session is not sufficient, it is recommended to note down the remaining, unanswered questions and respond to them via recorded video answers. On a similar line, it is advised to request the students to post their questions in a written form during the Q&A session, for instance, using a chat-wall. It was found that especially first semester students are more hesitant than master students to activate their camera and ask the question vocally. On average only one out of 20 questions were brought forward in that way, whereas the others were posted on the chat-wall. In such cases, there should be two instructors moderating the Q&A session. Typically, the professor would answer the questions, whereas a teaching assistant would continuously check the chat-wall, collect the questions, fine-tune them and ask them to the professor on the behalf of the students.

6. Assessments

In the free of charge German higher education system having a single, all-encompassing written exam at the end of the semester - or even during the break - was and mostly still is the status quo. This applies also to engineering programs where, at technical universities, a strong focus is put on assessing the understanding of theoretical and mathematical concepts. Another driver for this style of assessment is the student-staff ratio. Usually in traditional in-class courses, there is no dedicated TA available to handle the queries of the students, sometimes numbering in the hundreds and thus multiple intra-semester assessments are not feasible. Hence, a single written exam at the end of the semester was the preferred go-to option for teachers in large courses. With the rise of digital teaching tools and LMS, new options for assessing the students are now available that can be used with a significantly lesser amount of personal effort.

According to (McDonald and Boud, 2003), every learner should have the opportunity to (self-)assess his or her current learning status before entering a final assessment such as an exam. As described above, this

![Fig. 8. Summary of the results from the teachers' survey on teaching methods. The question code is given on the left.](image-url)
was typically not the case, thus putting the students under pressure to perform during this exam.

6.1. Assessment - student perspective

For the students of this survey, who are used to a system, which does not involve having the option to self-assess during the semester, the majority of the students, as portrayed in Fig. 9, welcomed that option (69 %, AS1) during this digital semester. This opportunity gives the learner the chance to know if he or she is on track or not. The basis for an accurate self-assessment though is, that it is clearly communicated to the students if the self-assessment tasks are on a comparable level to the final exam/task. If the options for self-assessment, e.g. quizzes or sample tests, are significantly easier or more difficult than the final exam, then the takeaway from these are lessened and diminish the potential and accuracy of the self-assessment - unless the learner knows about such differences upfront.

An interesting result from this survey is related partially to the motivation of the students. When asked about whether they would use such self-assessments voluntarily, i.e. if no bonus points are granted for finishing the task, most of the students (60 %, AS2) answered yes, with 19 % choosing neutral. Analyzing the actual data from the LMS yields a very different picture though. In the German masters course, the quizzes which are optional and not graded were used on average by around 20%-25 % of students. In the case of MMT where they were graded, yet voluntary, quizzes, which provided additional bonus points for the final grade, the participation rate was between 90% and 100 %. This clearly shows that students will not use such self-assessment options on a purely voluntary basis. Hence, it is up to the teacher to decide, whether to simply provide such opportunities or also give a clear incentive to use them.

On a similar note, the seriousness of the students regarding these tests was also investigated. In the LMS, the teacher can decide to display the correct answers after finishing a quiz. If the students are aware that in a voluntary quiz they will be shown the correct answer at the end, this can affect their seriousness towards this quiz. This is because the students would have to intrinsically simulate the circumstances of an actual, graded assessment. Otherwise, since it is voluntary and ungraded, they might simply click through the quiz to take a look at the correct answers. By virtue of this, such quizzes rather become additional learning material rather than meaningful self-assessment opportunities. While 63 % (AS3) answered they would still take such quizzes seriously, the current semester did not provide clear chances to check whether or not this is actually the case. One possible option to evaluate it is the time taken to finish a quiz. If a student simply clicks through the quiz, just to get the correct answers displayed, then it should be visible in a very short time that was logged by LMS. If the student takes it seriously and uses it for self-assessment purposes, then the time to finish it should be significantly longer.

Apart from simple online quizzes, which according to Bloom’s taxonomy (Anderson et al., 1994) are a practical tool to assess the students’ basic understanding of concepts, various other types of assignments can be given to the students. These might include videos or presentations about a specific application or topic from one of the lectures, computer simulations or traditional essays. This list is far from complete. All these different types are targeted at assessing different skill sets and also different taxonomy levels. The digital semester does not hinder any such assignment in being as effective as during non-digital semesters. So the teachers have plenty of options to choose from. When the engineering students were asked about the different types of assignments, many preferred doing a computer simulations study and show their results through a pre-recorded video (AS6). Both, computer simulation and recorded videos are aspects that were pushed during the digital semester, since any physical presence, i.e. being in the laboratory or in a seminar room, is not required to complete this type of assignment. Moreover, the students feel that both skills are useful for their future career - one that is most likely more digital than ever before. Some students also raised arguments supporting essays and mid-term exams. By writing essays, they could prepare for potential project and master thesis reports, while through mid-term exams they could learn about the style of the final exam. The latter is especially useful for new students and even more so if they switched from a very different system/country to the current place of study.

One aspect of assignments is whether it is done by an individual or by a group. Usually, students are afraid of free riders in group projects, which give them the feeling that they are doing the work not assigned just to them but also to others (AS7a). But, during the digital semester, the perception of group work has shifted for a couple of reasons (AS7). Now, with a significant shortage in personal, social interaction, working in teams is valued as a welcomed form of social interaction (AS7a), in addition to its ever-present professional importance. The students state that it is always helpful, especially for challenging engineering tasks, if ideas come from many sources and are shared between the members. On top of that, soft skills regarding teamwork are promoted in an online working environment. Interestingly, the students often mentioned that they find it motivating to work in a team which is contradictory to what they stated in the motivation section (MS7).

When it comes to the final exam, 66 % of the students (AS4) prefer the known, familiar type of a traditional written exam over an online version. This result can be partially explained by the fact that the students did not have any exposure to online exams other than the quizzes throughout the semester. When asked about their decision (AS4a) they listed several reasons in favor of written exams. In many cases, they argued that due to technical issues, which they have been facing throughout the semester, they might lose valuable time. This aspect is even more relevant for these particular students since they oftentimes would stay in their home country and take an online exam halfway across the globe. Also, in their home country, a stable internet connection might not be available in many regions. Moreover, in written exams, the students feel they can better focus and concentrate because of

![Percentage of students agreeing or strongly agreeing with...](image)

Fig. 9. Summary of the results from the students’ survey on assessment methods. The question code is given on the left. Omitted questions are free-text or multiple-choice answers.
the special environment during written exams. Taking the final exam from home, where the students also spend their free time during the lockdown, might be negatively affected by a couple of things that potentially can distract them. Interestingly, some students also gave the easier opportunity to cheat during online exams as a reason not to favor it. It remains unclear if those students feel they would do it themselves more likely or that they feel peers might gain an advantage over them.

Additionally, the students were asked about their preferences of free-text versus multiple-choice questions (MCQ). Even though they had favored written exams, listing the opportunity to freely express themselves (AS4a) during such exams, half of the students (AS5) actually prefer MCQ as the main form of the exam. It seems that the students if given the chance, would follow the easier path, which MCQs usually are. A typical proof for that is that the percentage level to pass MCQ exams is higher than that for written, free-text exams. In the detailed answers (AS5a), many of the students give a more precise and differentiated view on their opinions. MCQs should be used for digital exams and free-text for written exams. Some even state, that by MCQs the knowledge of a master student cannot be adequately assessed. This is in line with the constructive alignment and Bloom’s taxonomy, from which it is known that MCQs are more suited to test the basic understanding of concepts. For testing higher taxonomy levels of conceptual understanding, free-text exams are the medium of choice, because it also naturally allows for calculations, drawings, diagrams and other forms of expression.

6.2. Assessment - teacher perspective

For teachers, assessing the students goes beyond the simple use of exams and quizzes to evaluate the current learning status. As shown in Fig. 10, for all the teachers (AT1) the direct contact to and interaction with the students is an important part of the assessment, but also, the teaching activity in general. It additionally serves as one of the main motivators for teaching as well (AT1a, see also MT1 and MT6). In line with their answers in the motivation section, most of them still prefer the in-class interaction rather than via VCS (AT2a). During online sessions, students are often not visible and are not as engaged (AT2a). On the other hand, online sessions are viewed as a bit “more informal” (AT2a) compared to in-class lectures, because of the additional distance between teacher and student. This might help those students to ask more questions, who would otherwise remain silent in the classroom.

In traditional semesters, the teachers are used to interacting with the students every week. With the digital semester providing more flexibility regarding the schedule, the teachers remain mostly neutral (AT3) regarding a weekly rhythm or a different schedule regarding direct interaction. They elaborate on more flexible scheduling, for instance, that at the beginning of a semester, a weekly online meeting might be too much, where students will rarely ask any questions, whereas just before the exams, a twice a week meeting might be highly appreciated by the students (AT3a). Overall, direct interactions, e.g. during Q&A sessions, are viewed as an important way to assess the students’ current level of conceptual understanding (AT4) and also better suited to do this compared to indirect forms of interaction (AT6). However, on a purely quantitative level, quizzes are also viewed as a useful tool to assess the students (AT6). Paraphrasing one of the answers (AT6a), it can be summarized that no one such tool is sufficient for the analysis of the students’ learning status. During the semester it should be a combination of quizzes and Q&A sessions, whereas for the final exam a free-text exam (AT7) with the option to include some MCQs is the preferred choice.

7. Analysis of the student performance

Assessing and analyzing the performance of the students in the digital semester lends us important insight into the overall effectiveness of the implemented online teaching methods over the semester. The most basic way to understand the effectiveness of the digital semester is to compare the performance of the students from the previous batch, who had conventional classroom lectures, to the current batch in the exam on the same subject, namely Forming Technology-II. The 29 students in the current digital semester scored on an average of 72.7 % while the 27 students from the previous batch had a similar average of 73.5 %. Ignoring the bonus points awarded based on their performance in the quizzes, or scientific essay writing in the case of the 2019 batch, and thus comparing purely the performances in the final exam, there was hardly any difference in the performance. The current batch had an average of 60.1 % compared to the 60 % average grade of the 2019 batch. These results show that even though digital teaching is not without its challenges or limitations, the learning effectiveness of the students is not negatively affected and they performed as good as their counterparts who attended the conventional classroom lectures. This reinforces the viewpoint of (Nance and Nance, 1990) that the majority of the actual “learning” occurs not in the classroom but at home when students go through the content once again.

To analyze the performance of the same set of students in a conventional set-up compared to in a digital semester, the average grades of the students in Forming Technology-I (FT-I) was compared with the grades obtained in FT-II. A significant increase in the average grades was observed with the students attaining an average of 71 % in FT-II as opposed to 61 % in FT-I. However, it has previously been observed that the students always performed better in the second semester FT-II compared to first-semester FT-I as for most of them giving an exam under the German regulations is a new experience. Thus, attributing the entire improvement in performance to the digital semester would be a fallacy. However, the data does reinforce the general assumption that a properly organized digital semester is in no way inferior to a conventional semester with regards to learning effectiveness.

As mentioned in section 4.1, weekly quizzes were conducted and bonus points awarded based on the performance to give the students an extra incentive to study the lecture content weekly and to enable them to...
be better prepared for the interactive Q&A sessions. The performance of the students in these quizzes was compared with their final exam grades to find any possible correlation or trends. As seen in the graph below where both the grades are normalized and represented on a scale of 10, the grades in the quizzes were in almost all cases higher than the exam grades. The improved performance of students in the quizzes, which in the objective opinion of the authors were as difficult as the exam, tend to signify that the students have a good understanding of the individual lecture concepts, but find it difficult to perform in the exams, where their memory as well as ability to perform under pressure is also tested. As seen in Fig. 11 a weak trend was observed with regards to the performance in the quizzes being indicative of the subsequent exam performance. However, it is difficult to read much into it as the student with the highest exam grade was in the bottom 10% of the quiz grades and similarly, the student with the highest quiz grade was outside the top 10% of the exam grades.

Likewise, no correlation could be found between the students’ activeness in the Q&A sessions to their exam performance. The student who scored the highest grade in the exam asked not even a single question during these sessions whereas of the three most active students, 2 of them did not feature in the top 25% of the class.

8. Tools for the digital manufacturing laboratory

Along with the proper imparting of the theoretical knowledge through lectures and exercises, which was extensively investigated and discussed up to now in this paper, engineering education and, in particular, manufacturing related education, also needs to achieve a practical understanding of complex processes and coherences. Manufacturing education therefore often relies on switching from the classroom to laboratories, so that students can observe, perform and analyze experiments and processes - at best, on their own. With campuses being shut down, at least for students in many places around the world, access to laboratories was not possible anymore. In the following, four different approaches to tackle the problem of practical learning at a distance are presented and analyzed regarding their advantages and disadvantages.

The first category of digital laboratories are the so-called remote laboratories. Remote laboratories are defined as real experimental equipment that can be used and controlled by students online (Colwell et al., 2002). When the students perform a task with such a laboratory, they can typically observe the machines, steps and results via web-cams and additional information, such as graphs, tabular data among others. How to best create, incorporate and maintain such remote laboratories have been recently investigated based on almost a decade of working on and with such laboratories (Kleinschnittger et al., 2020). One of the biggest advantages is that students can perform experiments regardless of their location and according to their schedule. After finishing the lab, the students can work on their individual data which they generated by running their experiments. If they combine their information with other students' data, collaboratively they can investigate the statistical aspects of their experiments and also assess the influence of more input parameters on the results. Fig. 12 shows the remote material characterization lab, developed at the IUL. This remote laboratory is used by around 150 students each year as part of their lab courses. The main goal is to understand fundamental aspects regarding forming related material parameters and how they are gathered through experiments.

Among the disadvantages or challenges, the resources to create such a lab are the most noticeable to mention. In many cases, the machines need to be upgraded and also the process needs to be fully automatized. Further, manufacturing related laboratories often require machines like robots or presses, which if operated automated without human supervision, need to fulfill many various safety aspects. For further details on the advantages and disadvantages, the reader is kindly referred to (Grodotzki et al., 2018; Kleinschnittger et al., 2020).

An alternative approach to digital laboratories is their full virtualization. This means that the entire laboratory, including the environment, the machines, materials and the kinematics of the machine-material interaction, is transferred to the digital world. The most common approach is to use a game engine, e.g. the Unreal Engine, to create the virtual copy of the laboratory as described in (Ortelt and Ruider, 2017).
Fig. 13 shows the virtual representation of the same material characterization laboratory which was mentioned in the paragraph above. Such virtual laboratories can be used for different learning goals, depending on their level of accuracy and complexity. Students can explore the environment and familiarize themselves with the machines, which they will later use in a hands-on or remote laboratory. Further, the principal steps of experimentation are available to the students, such that the time for explanations in the real lab can be reduced and the actual time the students are working with the experiments is increased. Another advantage is that students can study all these aspects in a safe environment which cannot be damaged or destroyed. In this advantage lies a disadvantage as well. The students might think that the actual laboratory equipment behaves the same and can be handled equally to the virtual one. For expensive and sensitive machinery this is a dangerous conclusion which needs to be preemptively tackled by the supervisor. Alternatively, the virtual lab can be enhanced to account for potential hazards and dangers of breaking equipment. In general, the development of such a virtual is time and resource intense, especially if the required skill sets are not readily available among the people working on the hands-on laboratory. However, the clear advantage over a remote laboratory is that there is no wear and tear and that an unlimited number of students can learn and study with a virtual lab at the same time, for instance, during an exercise.

The third approach was developed due to closed campuses and the lack of time to develop virtual or remote laboratories. It can be termed as digital live laboratories or human-remote laboratories. In such a lab, one or more instructors, which are granted access to laboratory equipment while obeying the Corona protection measures on the campus, equip themselves with cameras and microphones. The cameras can be either webcam, DSLR capable of live streaming or in the best case, a head-mounted camera, like the Microsoft HoloLens. Additional, non-handheld cameras can be placed on tripods across the laboratory and pointed at relevant targets. Fig. 14 shows the preparation of the instructor and the laboratory environment.

There are several advantages of this type of digital laboratory. Most important to mention is the easy development and low-cost investments, i.e. cameras, tripods, etc., for such laboratories compared to virtual and remote laboratories. This enables many lab instructors to conduct lab courses with and for the students even during times of lockdowns where students are not allowed to access the laboratories on campus. In this case, the students would simply dial in into the live lab session where they can select individual cameras or choose to observe all camera feeds at the same time. In such a scenario, the instructor becomes the eyes and hands of the students, enabling a realistic use of the actual equipment. It is important to understand that a simple demonstration of the experiments by the instructor will not yield sufficient learning outcomes.
among the students as if the instructor let the students “do” the work, where he or she is simply the executor of the students’ decisions. This environment fosters a vivid interaction between the students and between the students and the instructor. Open questions, which might arise during virtual and remote laboratories, can directly be answered by the instructor. Compared to virtual and remote laboratories there is technically no limit to the range of parameters that can be tested during this type of laboratory. In virtual and remote laboratories, the set of parameters that students can investigate is often very limited, due to various reasons, be it safety or complexity related.

Among the disadvantages, scalability is most important to mention. Typically, the instructor would meet with one group of students. Preliminary results from a survey conducted in such an environment showed that even scaling from one group to two groups working with the instructor and the equipment at the same time impairs their likelihood of engaging in the digital laboratory. Hence, for large batches of students, the instructor needs to repeat the lab for each group to maintain a high level of interaction, significantly rising the time and labor-related costs over a long period, compared to e.g. virtual laboratories. However, a break-even point is only reached after many years, since the initial development costs of virtual and remote laboratories are very high.

Another use case for such kind of digital live laboratories is given by digital live lectures from other experimental sites which are not part of actual laboratory courses. Many manufacturing-related institutes own or have access to machines and equipment which is predominantly used for research not teaching purposes. Using the approach described above, lectures can be given live from experimental halls such that the instructor can directly relate theoretical knowledge with the real-world explanation. It further provides the students with an overview of ongoing research topics. Compared to on-site teaching, where only a limited number of students can be in such an environment at the same time, conducting such live lectures from the lab using digital tools, all the students from one batch can participate at once. To maintain the active participation of the students, instructors can rely on app-based audience response systems. Using such tools instructors can ask for the student’s opinion, for instance about the outcome of an experiment that is conducted after the theoretical content was presented. By that, students can test their internally constructed images on certain topics and the instructor can assess the learning status.

The authors used both, digital live lectures and digital live laboratories extensively during the summer and winter semester of 2020/21. Based on direct feedback from the students these types of digital lab and lecture are highly appreciated by the students. Among the most valued features, the students named the direct interaction with the supervisor, the feeling of being “on campus”, at least virtually, and experience to connect their theoretical knowledge with practical applications.

9. Conclusion & lessons learned

As a result of the pandemic-induced lockdown in Germany and many other countries around the world, any type of teaching activity, be it at schools or universities, were forced to make the transfer to digital teaching quickly with little time to prepare for this shift. Even though the transition to online education was clearly visible throughout the last decade, the lockdown has accelerated this process significantly.

To better understand the impact of digital teaching in international engineering study programs, where this semester, the students were spread across the globe, a survey amongst these students, but also the teachers involved in such programs, was conducted. It focused on three main aspects: (1) the motivation of students and teachers alike, (2) the use of digital teaching tools and methods and (3) the assessments in a digital environment.

The analysis of the exam results has shown that the style of implementation of digital teaching in this semester did not negatively affect the learning outcome as measured by the final exam and the bonus point tasks, which in this case, were online quizzes.

Therefore, in the following, general guidelines for an effective and successful digital teaching of engineering studies will be outlined. These lessons learned are, on the one hand, based on the objective analysis by
the authors of the final results, giving insights on which methods worked and which did not. On the other, the guidelines will incorporate the findings from the survey. Though being a subjective way of analysis, the unique circumstances and the special set of participants, allow deriving various useful conclusions from their answers. As stated, these guidelines can be applied regardless of the batch size, with only minor adjustments necessary for large groups.

How can I maintain a high level of intrinsic and extrinsic motivation for students and teachers alike during a fully digital semester?

• Communication is key - this comprises information conveyance as well as interaction.
• Providing the students with a voluntary schedule helps them to stay motivated and track their progress.
• The use of the live sessions, which are best for answering questions as well as clarifying misconceptions and doubts, and gamification elements (bonus points, badges ...) is highly recommended. Interactive sessions also prevent common screen fatigue.
• Asking the students to turn on their camera creates a more in-class feeling for the teachers.
• Weekly interactive sessions should be maintained so that the students and teachers stay in rhythm throughout the semester.
• Proper teaching equipment and hardware on both sides must be ensured. Insufficient sound quality or choppy audio transmission during live sessions can be frustrating and annoying.
• Teachers should keep the long-term benefits in mind during the time-consuming transition to digital teaching. Over time, digital teaching can actually save time and include more direct interaction with the students compared to traditional teaching approaches.

What kind of digital tools and teaching methods are best suited for a digital semester?

• The flipped-classroom approach should be employed. Pre-recorded lecture videos can be distributed via the LMS and during the lecture hours, Q&A sessions can be performed using VCS. Students value the benefit of watching a lecture multiple times, at their own pace and in intervals, enabling them to come up with meaningful questions regarding a subject. If possible, provide a download option for the videos additional to the streaming option.
• Try to avoid live online lectures. There are hardly any benefits over pre-recorded lectures. On the other hand, unstable internet connections, different time zones and other aspects render live online lectures significantly less suitable for digital semesters.
• Make use of interactive and collaborative tools wherever possible. Students are more likely to get engaged if they feel they can participate or better, be part of the session.
• For answering questions, use live Q&A sessions rather than written forms of communication.
• If possible, address as many learning types as possible. For instance, one could use gamification-based unlocking of new content, where, if desired, a student could complete the entire course in week one of the semester. Others might choose not to use such options and wait until the content is unlocked automatically according to the given schedule of the course.
• Conduct lectures from laboratories. It gives the students a feeling of being on campus and theoretical aspects can be directly linked with their application. For actual lab courses, one can rely on virtual, remote or human-remote laboratories. The latter one is easy to implement and highly valued by students.
• Lastly, do not be afraid of new technology. Many tools can improve the overall teaching and learning experience. Look for courses about digital online teaching which are typically provided by the IT and/or didactics department. They help to lower the barrier.

How is it possible to track the current learning status throughout and at the end of the semester?

• Combine objective and subjective ways of assessment.
• That means, use, for instance, weekly online quizzes to assess the understanding of each subject. Broader assignments throughout the semester can combine multiple aspects and can give better insights about the overall, more general learning status.
• Such assignments could be about computer simulations, calculations or technical drawings. Performing the tasks in teams might offer benefits, especially on the social front. Students can use a modern way of video submissions instead of lengthy reports to present their results. The application-oriented tasks should be at best based on a problem-based or scenario-based concept.
• On the subjective side, keep track of the questions which the students ask during Q&A sessions. The questions themselves offer valuable information about potential misconceptions or a lack of understanding.
• Multiple-choice or similar type of exam questions are suitable for online assessments. Bear in mind that such questions typically can only serve for assessing lower taxonomy levels of understanding.
• If possible, use classical, written exams with free-text answers to better address high taxonomy levels. The benefit here is the possibility to ask for calculations, drawings and diagrams all in one exam.

Overall, paraphrasing one of the teachers, it can be concluded that:

• digital teaching is indeed feasible.
• digital teaching still has a long way to go and requires a lot of effort to be implemented to the benefit of students and teachers alike.
• as of now, digital teaching is not the same as traditional in-class teaching. Therefore, the two should not be compared directly. Digital teaching offers new possibilities and, if implemented correctly, yields the same learning outcomes as conventional teaching.

10. Outlook

There is always room to improve. Being in charge of a lecture also means being responsible for the student’s success. Therefore, the style of teaching should constantly adapt to the students and their way of learning, so that with each generation of students, the best learning outcomes are achieved. With digital teaching methods and tools, such changes are often easier to implement because the technology evolves faster than traditional learning environments. Based on the findings from this first digital semester, which are presented in this paper, in the following section, potential next steps are derived to further improve the quality of teaching. The final goal is to have smarter and more competent students at the end of a course through the purposeful use of novel digital teaching tools and methods.

One such example, where future students can benefit from the current ones, is that with the use of a written or video-based FAQ. The approach is to transcribe the current Q&A sessions and condense the most important questions that were asked by the students. Thorough answers should be generated for those questions, especially if the spontaneous answer by the teacher during the Q&A session was not satisfactory enough. Combined questions and answers can be uploaded to the next semester’s LMS page of the same course. One approach to make the best use out of such a database is that upon uploading a video, the corresponding questions are uploaded as well. On viewing the questions from previous generations, the current students can then try to answer those questions themselves, further fostering their understanding of the subject. Shortly before the Q&A sessions of the video, the answers would be uploaded as well, so that the students only ask their remaining questions in the Q&A sessions. Those questions contribute again to the further growth of the FAQ.

Especially in engineering sciences, showing real-world examples or performing simple yet powerful in-situ experiments are very common
during in-class teaching. This aspect is arguably one of the biggest advantages of in-class teaching. However, digital teaching technology can also help transfer these demonstrations to the digital world. In-situ experiments, for instance, could be pre-recorded in front of a green screen from multiple points of view. With 3D camera software, these views can be stitched together so that students can observe the experiment from multiple angles. This enables the students to digitally walk around the experiment as they could do in the actual classroom. On a similar line, physical objects, like demonstrators, can be digitized using a 3D-scanner and the resulting 3D object file can be uploaded along with the video. Alternatively, to 3D-scanning, CAD files and simulations, which first need to be converted to a common 3D object file format, can be used to enhance the learning experience.

Running such digital environments is usually done on computers. However, bringing such content to mobile devices, running on Android or iOS, assists the shift to mobile learning. The students can then also study certain aspects without having to access their personal computers or laptops. Such applications are useful if specific aspects are sought to be highlighted. The disadvantage of such endeavors is that the creation of such apps take a lot of time and requires a certain skill-set. With the evolution of what-you-see-is-what-you-get software environments, creating such apps might, to a certain extent, not require any coding skills these days. With such tools, however, the educational depth of the apps is limited. In general, mobile applications are a suitable enabling of educational games. It was shown in (Wellsers et al., 2019) for gamification and scenario-based learning that such educational games are especially beneficial for undergrad students. Quests and tasks, at best derived from real-world examples or applications, can be included in learning apps so that students can either study the related topic more in-depth or also work collaboratively to solve the given problems. The present study has confirmed the importance of gamification elements to keep motivation high among students.

But improving the learning environment for students should not be the only aspect that is in focus in the future, it must also be on improving the teaching environment from the side of the universities. The lack of support during the shift to digital teaching is something many educators mentioned. Therefore, universities must increase the effort to supply the hard- and software needed but, moreover, educate the educators about how to use such tools. They should not be left alone with their struggle to make this transition. High-quality instructional videos are the favored way of doing this. Another benefit for the universities is that they can maintain a certain level of teaching quality if they properly support their teachers. In times, when there is an externally driven upheaval in the approach to teaching, supporting the teachers with additional teaching assistants is also a viable option.

An important thing to understand when using novel, digital technology to enhance the learning experience is that at the core of each course, there is still the actual content of the topic. If the content itself is not of a high quality, the best digital technologies will not help to improve the learning outcomes of the students. Here, the recognition and support from the universities’ side, as stated in the above paragraph, encourage educators to not just implement every new technology there is, but to also focus on the continuous improvement of the core content, for instance, by means of proper scripts that support the digital media and tools. Alternatively, one can use digital tools to upgrade existing scripts and thus improve the learning experience. A great example of such an approach was done by Ostermeyer and Olearczyk (2021) using the software generally known as Blackboard Collaborate. As an add-on to the existing well-established script for fundamentals of mechanics, the mobile app can be by the students to display additional augmented reality material, such as graphs, videos or 2D- and 3D-Animation. Such technologies can motivate educators to not simply digitize their courses but also rethink the general structure and content of it. The combination of high quality content, enhanced by modern digital teaching technologies is the ultimate goal that should be aspired by all parties involved, the students, educators and universities.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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References

Adnan, M., Anwar, K., 2020. Online learning amid the COVID-19 pandemic: students’ perspectives. J. Pedagog. Social. Psychol. 2 (1), 45–51. https://doi.org/10.3390/jpsj.2020061309.
Anderson, L.W., Sontak, L.A., Bloom, B.S., 1994. In: Bloom’s Taxonomy: a Forty-Year Retrospective. Chicago NSESE. https://www.worldcat.org/title/blooms-taxonomy-a-forty-year-retrospective-oclc/30420566.
Asgari, S., Trajkovic, J., Rahman, M., Zhang, W., Lo, R.C., Sciontino, A., 2020. An observational study of engineering online education during the COVID-19 pandemic. http://arxiv.org/abs/2010.01427.
Barber, W., King, S., 2016. The relationship between an online synchronous learning environment and knowledge acquisition skills and traits: the blackboard collaborate experience. Electron. J. e Learn. 14 (4), 235.
Bishop, J.L., Verleger, M.A., 2013. The flipped classroom: a survey of the research. In: ASEEE Annual Conference and Exposition, Conference Proceedings. https://doi.org/10.18260/1-2–2251.
Bourne, J., Harris, D., Mayadas, F., 2019. Online engineering education: learning anywhere, anytime. Online Learn. 9 (1) https://doi.org/10.24059/olj.v9i1.1800.
Brull, S., Finlayson, S., 2016. Importance of gamification in increasing learning. J. Cont. Educ. Nurs. 47 (8), 372–375. https://doi.org/10.1097/JCN.0000000000000109.
Castelli, F.R., Sarvary, M.A., 2021. Why students do not turn on their video cameras during online classes and an equitable and inclusive plan to encourage them to do so. Ecol. Evol. 11 (8), 3565–3576. https://doi.org/10.1002/ece3.7123.
Colwell, C., Scanlan, E., Cooper, M., 2002. Using remote laboratories to extend access to science and engineering. Comput. Educ. 38 (1–3), 65–76. https://doi.org/10.1016/0360-1315(00)0077X.
Dhawan, S., 2020. Online learning: a panacea in the time of COVID-19 crisis. J. Educ. Technol. Syst. 49 (1), 5–22. https://doi.org/10.1177/0044111320934008.
Grodotzki, J., Olearczyk, J., 2021. Hybride lernskripte in der Ingenieurslehre mittels ELLI 2 - Excellent Teaching and Learning. Procedia Manuf. 26, 1349–1355. https://doi.org/10.1016/j.promfg.2018.07.126.
Harper, B., 2018. Technology and teacher–student interactions: a review of empirical research. J. Res. Technol. Educ. 50 (3), 214–225. https://doi.org/10.1080/10494820.2018.145096.
Hemanth, L.K., 2020. Changing trends of social interaction during the pandemic and its effects on mental health – a student’s perspective. Asian J. Educ. Soc. Stud. (1), 7–14. https://doi.org/10.9734/ajess/2020/v9i330247.
Holzweiss, P.C., Joyner, S.A., Fuller, M.B., Henderson, S., Young, R., 2014. Online education: a panacea in the time of COVID-19 crisis. J. Educ. Technol. Syst. 49 (1), 5–22. https://doi.org/10.1177/0044111320934008.
Hemanth, L.K., 2020. Changing trends of social interaction during the pandemic and its effects on mental health – a student’s perspective. Asian J. Educ. Soc. Stud. (1), 7–14. https://doi.org/10.9734/ajess/2020/v9i330247.
Holzweiss, P.C., Joyner, S.A., Fuller, M.B., Henderson, S., Young, R., 2014. Online graduate students’ perceptions of best learning experiences. Dist. Educ. 35 (3), 311–323. https://doi.org/10.1080/015878919.2015.955262.
Kleinenschmit, G., Strenger, N., Petermann, M., Freich, S., Grodotzki, J., Selvaggio, A., Tekkaya, A.E., 2020. Remote laboratories in engineering education – deriving guidelines for their implementation and operation. In: Proceedings of the 48th Annual Conference of European Society for Engineering Education (SEFI) Online, pp. 251–259.
Lee-Post, A., Hapke, H., 2017. Online learning integrity approaches: current practices and future solutions. Online Learn. J. 21 (1), 135–145. https://doi.org/10.24059/olj.v21i1.843.
Lima, R.M., Anderson, P.H., Saalman, E., 2017. Active learning in engineering education: a (re)introduction. Eur. J. Eng. Educ. 42 (1), 1–4. https://doi.org/10.1080/03075698.2017.1332897.
McDonald, B., Boud, D., 2003. The impact of self-assessment on achievement: the effects of self-assessment training on performance in external examinations. Assess. Educ. Princ. Pol. Pract. 10 (2), 209–220. https://doi.org/10.1080/03075698.2003.1254161.
Mills, E.J., Treagust, F.D., 2003. Engineering education - is problem-based or project-based learning the answer? Austral. J. Eng. Educ. 3, 1324–5821. http://www.aaee.asn.au/journal/2003/mills_treagust03.pdf.
Ostermeyer, G., Olearczyk, J., 2021. Hybride lernskripte in der Ingenieurslehre mittels mobile augmented reality in der Ingenieurslehre mittels mobile augmented reality. In: DUZ. https://doi.org/10.36197/DUZOPEN.022.
Park, J.J., Park, M., Jackson, K., Vanhoy, G., 2020. Remote engineering education under COVID-19 pandemic environment, international journal of multidisciplinary perspectives in higher education, 2020. Int. J. Multidiscip. Perspect. Higher Educ. 160–166.

Petress, K.C., 2004. The Benefits of Group Study, vol. 587. Education, 2004-Jun-22. Education. https://eric.ed.gov/?id=EJ705764.

Richter, G., Raban, D.R., Rafaeli, S., 2015. Studying gamification: the effect of rewards and incentives on motivation. In: Gamification in Education and Business. Springer International Publishing, pp. 21–46. https://doi.org/10.1007/978-3-319-10208-5_2.

Selvaggio, A., Upadhya, S., Grodotzki, J., Erman Tekkaya, A., 2020. Development of a remote compression test lab for engineering education. In: Lecture Notes in Networks and Systems, vol. 80. https://doi.org/10.1007/978-3-030-23162-0_45.

Steffe, L.P., Gale, J.E., 1998. In: Constructivism in Education. Lawrence Erlbaum Associates, Inc. https://psycnet.apa.org/record/1995-97082-000.

UNESCO, 2020. Education: from disruption to recovery. https://en.unesco.org/covid19/educationresponse.

Vivolo, J., 2016. Understanding and combating resistance to online learning. Sci. Prog. 99 (4), 399–412. https://doi.org/10.3184/003685016X14773090197742.

Welbers, K., Konijn, E.A., Burgers, C., de Vaate, A.B., Eden, A., Brugman, B.C., 2019. Gamification as a tool for engaging student learning: a field experiment with a gamified app. E-Learn. Digit. Media 16 (2), 92-109. https://doi.org/10.1177/2042753018818342.