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Remote Concurrent Engineering from the customer's perspective

C. Bach, C. Drobny, T. Schmiel, M. Tajmar

Professorship for Space Systems, Institute of Aerospace Engineering, Faculty of Mechanical Engineering, TU Dresden

Abstract

Concurrent Engineering ist ein Ansatz zur Entwicklung komplexer Systeme, der durch eine direkte Kommunikation zwischen den beteiligten Disziplinen gekennzeichnet ist. Diese Interaktion zu erlernen und zu verstehen, welche Informationen zwischen den Disziplinen kommuniziert werden müssen, gehören zu den zentralen Lernzielen der Lehrveranstaltung „Entwurf von Raumfahrzeugen“. Die Studierenden vertreten darin unterschiedliche Disziplinen und arbeiten eine Missionsstudie aus, die von den Lehrenden in Auftrag gegeben wird. Die Lehrenden nehmen somit in der Rolle der Kunden am Entwicklungsprozess teil. Aufgrund der mit der COVID-19-Pandemie einhergehenden Einschränkungen musste die Lehrveranstaltung in ein virtuelles Format übertragen werden. Daraus ergab sich die zentrale didaktische Herausforderung, die Struktur und gewählten Methoden so anzupassen, dass die Missionsstudie, die auf ein Zusammenarbeiten aller Beteiligten angewiesen ist, dennoch durchgeführt werden konnte. Dieser Beitrag erörtert, wie dies durch eine Mischung aus synchroner und asynchroner Lehre erreicht wurde, wie das Lernerlebnis der Studierenden dabei ausfiel und welche Schlussfolgerungen sich für die Weiterentwicklung der Lehrveranstaltung für postpandemische Zeiten ergeben haben.

Concurrent engineering is an approach to the development of complex systems that is characterized by direct communication between the disciplines involved. Learning this interaction and understanding what information needs to be communicated between disciplines are among the central learning objectives of the course "Spacecraft Design". In this course, the students represent different disciplines and work out a mission study that is commissioned by the instructors. The instructors thus participate in the development process in the role of customers. Due to the constraints associated with the COVID-19 pandemic, the course had to be transferred to a virtual format. This resulted in the key didactic challenge of adapting the structure and chosen methods so that the mission study, which relies on all participants working together, could still be conducted. This paper discusses how this was achieved through a mixture of synchronous and asynchronous teaching, how the students' learning experience turned out, and what conclusions emerged for the further development of the course for post-pandemic times.

*Corresponding author: christian.bach1@tu-dresden.de This article was originally submitted in German.

1. Introduction

The design of space missions and their systems is a complex task, even in the preliminary design and concept phase. All technical disciplines and sub-disciplines are interconnected to some degree, and none of them can be neglected in the development of the entire mission. Classical, i.e. sequential or centralised, development approaches require a large number of iterations and have a low resistance to errors. Concurrent engineering (CE) was developed to avoid these very disadvantages and to shorten development times for highly complex systems while maximising the probabilities of success. [1]

This development approach, which has meanwhile assumed a central role in the space domain and is just as relevant for similar systems in other industries, is taught to the students of the Aerospace Engineering specialisation of the Mechanical Engineering degree programme in the course "Spacecraft Design". The central element of this course is a CE workshop, in which the teachers take on the role of customers and give the student teams a design study assignment.

This paper discusses the virtualisation of teaching this course as a result of the restrictions associated with the COVID-19 pandemic and the experiences gained thereby. First, section 2 discusses the context and framework. Section 3 presents an overview of the CE approach and Section 4 presents the CE software Valispace used in the course. Section 5 describes the learning objectives of the course. Section 6 discusses the didactic challenges, whose solutions are presented in Section 7. Section 8 reflects on the course of the semester, while the conduct of the examination is discussed separately in Section 9. Section 10 provides a comprehensive insight into the conducted teaching evaluation and draws a conclusion. The following section 11 presents possibilities for improvement. This contribution is summarised in section 12, which also contains an outlook on the further development of the course.

2. Context and framework conditions

The course "Spacecraft Design" is embedded in the specialisation module Space Systems Engineering of the diploma programme Mechanical Engineering, specialisation Aerospace Engineering, and regularly takes place in the 9th semester. This course is one of two courses of the aforementioned module and is usually completed by a written examination of 90 minutes as specified by the module description.

The students have already acquired detailed knowledge of the design of space systems in courses such as "Energy Systems for Spacecraft" or "Space Propulsion". The course chronologically and thematically forms the conclusion of their courses before the diploma thesis. However, some students exchange the 9th semester with the 7th semester, which is reserved for internships. These students lack all the knowledge from the 8th semester. In addition, there are a few students from other disciplines (e.g. from business administration and management or exchange programmes such as ERASMUS+) who do not necessarily pursue this specialisation. Occasionally, students from lower and higher semesters also participate, as can be seen in Figure 1. This results in a heterogeneous group of participants.

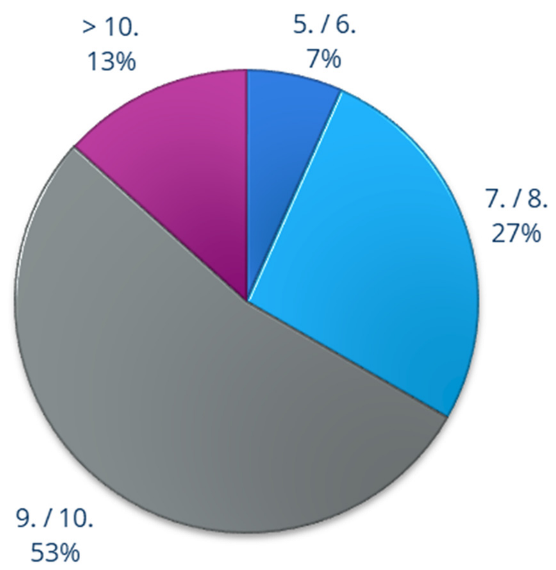

Fig. 1: Distribution of participants by study semester

The number of students is usually between 30 and 40, in the present semester there were 32. As can be seen in Figure 2, based on an evaluation carried out in the present semester (see Section 10), the large majority of participants are male students. According to their own statements, all participants were pursuing a degree. However, the reasons for participating in the course differed. For most participants, the selection was based on interest in the content (see Figure 3).

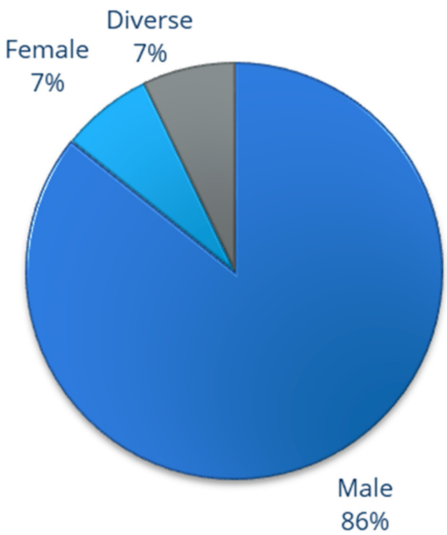

Fig. 2: Distribution of participants by gender

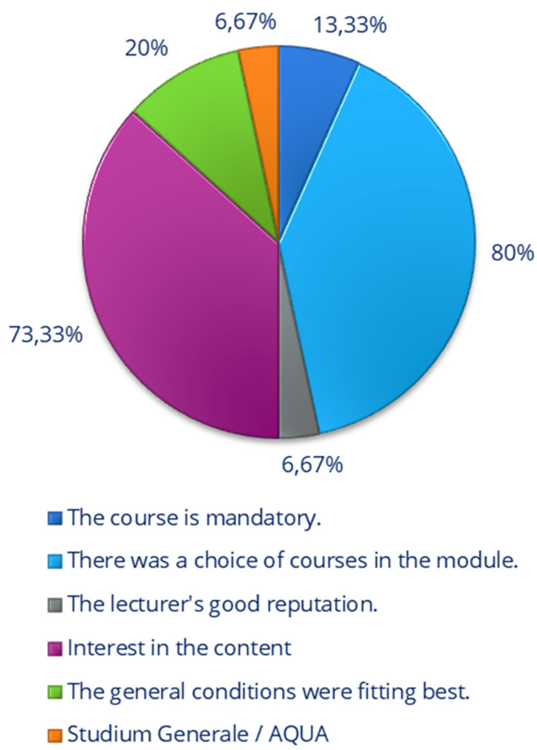

Fig. 3: Motivation of participants in the course (multiple answers were possible)

3. Concurrent engineering (CE)

Space missions and their technological components are extraordinarily complex systems, characterised by the close interaction of various disciplines. The development of such missions is characterised by high effort, often extreme requirements and low fault tolerance.

As a counter-design to classical development approaches, which for example are sequential (i.e. all disciplines work on the design one after the other) or centralised (i.e. all disciplines work in parallel, but all communication is directed through a central interface, usually the system engineer), Concurrent Engineering (CE) has been developed in order to meet the needs of the different stakeholders. It is characterised by a collaborative, cooperative, collective and simultaneous development environment. This means that all disciplines work in parallel and together on the mission and exchange information with each other. This includes, in particular, the customers / clients, as a central goal of CE is to increase customer satisfaction. [2]

To enable CE, several elements are needed. Besides the central multidisciplinary team, these include a hardware and software infrastructure (see section 4) that enables the integration of a design model, as well as a defined process. The latter is divided into installation, preparation, study and follow-up phases. In the study phase, the actual elaboration takes place, which in turn is subdivided into alternating design sessions and individual work. [3]

The present course covers all phases, with the main part falling on the study phase. While the course was previously structured mainly as a closed design session (i.e. all students were on site at the institution), a restructuring is taking place in the present semester. In this process, the individual work is moved to the self-study phase and only the design sessions are conducted synchronously with the teachers, who represent the clients (see section 7).

4. Valispace software

During the course, the web-based software Valispace of the German-Portuguese start-up with the same name was used. Valispace is a software support for the joint and simultaneous development of a design or system by a multidisciplinary team.

The central idea of Valispace is the development of the design in a central database (Single Source of Truth). Users access the database and are able to read, store and link information. Every change that any user makes in the database is passed on to all other users in real time. The great advantage of such a system is that all users have access to the current data at all times. This eliminates the need to exchange documents that only reflect a temporary design status.

The design itself is built up in Valispace in a directory tree (product tree) via the hierarchical linking of individual components. In addition to the directory tree, which is the heart of the design, there are a number of other functions. Particularly noteworthy is the implementation of a requirement manager. This allows the automatic checking of the current design against defined boundary conditions. In addition, test procedures can be stored. Moreover, Valispace supports numerous extensions that can significantly simplify development in an interdisciplinary team. Examples include a complete unit calculation and the temporal development of the individual parameters over the course of the design. Above that, there are functions for time management (Gantt chart) of the project, the possibility of implementing simulations (or complex calculations) by means of an Octave GUI as well as the creation of documentation with automatically derived tables and diagrams. Furthermore, Valispace also allows direct communication with other participants in the study via various commentary and discussion functions.

Although the full range of functions is by no means used in the course, Valispace is an important support in the efficient implementation of the CE process with students. For example, the browser-based implementation allows participants to access the current design from anywhere and expand it with their corresponding work. Working with a "single source of truth" also supports the fundamental aspects of CE. The clear structure of the software enables students to use it effectively during the course, even without prior knowledge.

5. Learning objectives

The overall learning objectives of the course can be summarised as follows:

1. By establishing criteria, weighting them and performing a trade-off, students can comparatively evaluate concepts for space missions to find the solution approach with the highest probability of success.
2. By practically applying and combining the knowledge gained in the previous courses, students will be able to conceptualise space missions to develop an overall system to solve a specific engineering problem.
3. By getting to know their characteristics as well as advantages and disadvantages, the students know different strategies and models for the development of technical systems and are able to classify and assess them in order to apply them in a targeted and justified manner.

The essential expansion of these learning objectives in the winter semester 2020 / 2021 results from the shift of the class into the digital space:

- By learning about and applying different collaboration tools, students can use digital collaboration opportunities to solve a development task that they cannot do alone.
- By exploiting different tools of virtual collaboration, students will be able to contrast and develop concepts of interplanetary space missions using the concurrent engineering model to circumvent the limitations of direct interaction.

The students must first learn about and experience possibilities of virtual cooperation in order to then be able to apply them in a targeted manner. Although this is aimed at pragmatically circumventing contact restrictions in the present semester, it is intended to show them more generally, how they can efficiently achieve their goals even under adverse conditions.

6. Didactic challenges

Up to now, the course was held as a block course on three complete days shortly before the end of the lecture period. The three days were spread over a period of eight days - Friday, as well as Friday and Saturday in the following week. At the beginning of the course, the characteristics as well as advantages and disadvantages of design processes were taught. Special focus was put on concurrent engineering (see section 3). In addition, the most important basic knowledge was briefly refreshed and an introduction to the software Valispace (see section 4) was given.

The remaining time is used to carry out a concurrent engineering process for the conceptual design of a space system (e.g. a Mars probe or a Moon rover). For this purpose, a mission objective is issued by the teachers and the role of the customer / client is assumed. The mission is first discussed by the students and initial solution concepts are postulated, which are then evaluated. We / the students divide themselves into different roles / disciplines. Each discipline develops the corresponding subsystem (e.g. for energy supply or communication) or carries out the tasks belonging to the corresponding role (e.g. cost or risk analysis).

The concurrent engineering process is characterised by the fact that all subsystems are developed in parallel. Since all subsystems and roles are interdependent, the process is characterised by an extremely high need for communication. This is precisely the main learning objective: the students should have understood how the individual subsystems, which they already know from other courses, are connected to each other, i.e. which interfaces there are and which inputs and outputs have to be transmitted. The students have a large PC pool at their disposal for this purpose and can constantly exchange information while detailing their subsystems.

However, due to the restrictions resulting from the COVID-19 pandemic, the course could not be conducted in attendance in the present semester. Nevertheless, all students had to be reached and motivated throughout the course, as all students depend on each other. The particular didactic challenge is therefore to transfer the previous format to the virtual space in such a way that the learning objectives can be achieved. This is particularly difficult, because the core of the course lies in the interaction between the students (and teachers).

7. Didactic approach

Only the introduction (approx. 15% of the course) could be digitised relatively easily. For this, screencasts were already made available at the beginning of the semester and a live consultation was held to conclude the introductory part.

The rest of the course had to be restructured completely. Our approach was to stretch the course over the entire semester. The actual task processing was then to be carried out in self-study, if possible in small groups. Students and teachers met virtually at regular intervals (every 2 to 3 weeks) to present progress and exchange.

In order to keep the organisation manageable and to offer each person the opportunity to contribute, the course was divided into 2 groups, which worked on the design task in parallel to and independently of each other. The group division and role assignment required special attention and was realised via an enrolment tool in the course on the OPAL learning platform. This was intended to give all participants equal opportunities to secure the discipline they preferred. Final inhomogeneities in the distribution of roles within and between the teams were balanced out in the subsequent live consultation (e.g. the occupation of one central role instead of the double occupation of another). In previous years, we experimented with the distribution of roles. In some cases it was predetermined, which partly forces students out of their comfort zone, but can also lead to some demotivation. In some cases, students were able to choose the roles, although compromises had to be found for roles that were particularly in demand. Enrolment via an online tool largely circumvents these difficulties and is the fairest variant of role assignment to date.

The size of the teams was 16 participants each. This is considered a very good group size, as on the one hand, all essential roles can be covered and on the other hand, the communication effort within the team remains manageable.

It should be noted that not all 15 existing roles were filled, as some roles are considered essential (e.g. Team Leader), while others can be replaced in case of doubt or carried by the other participants (e.g. "Integration, Assembly and Verification"). As in previous years, it was important to double up on particularly critical roles (e.g. energy supply) in order to create a certain redundancy. In principle, this would be desirable for all roles, but larger teams would make implementation much more difficult.

While the sizes of the two teams were identical, the distribution of roles in the two teams showed slight variations. This was again due to the fact that roles, which were not considered essential, could be assigned according to the inclinations of the participants (e.g. only team A had a simulation engineer). On the one hand, this of course makes a direct comparison of the results achieved by the two teams difficult, but on the other hand, it allows the effects of different role assignments to be examined. The latter has the advantage that the significance of the (non-)participation of individual roles can be visualised to the students.

The video conferencing tool GoToMeeting was used for communication with the course tutors. Between the appointments, an exchange platform also had to be provided for the students. This was possible via the Valispace software, which was used anyway to centralise all the data. In addition, the OPAL course was provided with various elements (e.g. a forum).

The development task was subdivided by several milestones in order to be able to motivate the students to work continuously throughout the semester. These milestones corresponded to the iteration stages of the design or its detailing and were represented by the live consultations, in which the current status was presented to the clients / teachers. This enabled us to uncover communication or other problems in the self-learning phases and to ensure the active participation of all involved. In addition, this process not only gave us insight into the progress of both teams, but also ensured that any lack of consistency in the work became visible to us as well as the students.

The live consultations with the individual teams were conducted independently of each other. The main reasons for this were, on the one hand, to limit the time required of the participants and, on the other hand, not to give an advantage to the team presenting last. This means that the teams were not informed about each other's progress. However, it is possible that the students also exchanged information with each other across teams. This cannot be prevented and can even be beneficial if, for example, a role of one team is stuck and asks the corresponding role representatives of the other team for advice. This was supported by the provision of an overview of the team compositions by those responsible for the course.

8. Reflection on the process

It should be noted that, as expected, the preparation of the course in this semester required far more effort than was otherwise necessary. However, this effort was worthwhile because the careful planning could be fully implemented. In addition, the actual implementation during the semester took place with a reasonable amount of effort.

Particularly noteworthy is the consistently high level of student engagement. This led to a scope and level of detail of the results that is significantly higher than those of the previous years. This is not entirely surprising, since the students also had a much longer period of time to work on the design task and this was also used effectively, for example through weekly team meetings.

However, it remains unclear to what extent this is due to external circumstances. While the course offers an opportunity for active involvement that is clearly above the usual level, it stands to reason that limited social interaction opportunities have further increased the students' motivation to work in teams.

An interesting aspect resulted from the division of the participants into two parts. This made it possible to respond to the individual wishes of the teams and to slightly adapt the approach. This illustrated that relatively small differences in implementation can have an impact. For example, Team A's bi-weekly consultations with teachers / clients were purely for status presentation and discussion via GoToMeeting. Team B, on the other hand, asked for the customer meetings every fortnight to be combined with the weekly team meetings via Discord. From the teachers' point of view, the originally planned approach as carried out with Team A worked better, as the team was forced to coordinate precisely in advance and to come to a coherent state. This allowed more time to discuss the design and the development process.

9. Conduct of the examination

According to the module description of the examination regulations, the assessment for the course consists of a written exam of 90 minutes in length. However, due to the restrictions associated with the pandemic in this semester, it was requested that the examinations either be conducted digitally or that alternative forms of examination be sought. Since the students were supposed to present their approach and obtained results at the end anyway, it was obvious to include this in the examination performance. However, only 180 minutes were available for the final presentations including discussion for 32 students, so that no reliable assessment of individual performance could be made on the basis of the presentations alone. For this reason, the students were required to submit a final report, the main text of which was to be between 1500 and 3000 words.

The main focus of this final report was on the process. Thus, not only information on the data exchange and the final state of the design study was required, but also self-reflective elements on the individual progress and problems encountered in the development / learning process.

The examination performance was very well received and mastered by almost all students. For Team B alone, a total of 271 pages of reports were submitted. The quality of the presentations and reports was very good. With one exception, the grades were in the range of 1.0 to 1.3. In both teams, the average was 1.2.

Figure 4 shows a small section of the final result, a rendering of the lunar lander developed by Team A.

Fig. 4: CAD rendering of the lunar lander developed by one of the two teams.

10. Teaching evaluation

In order to obtain feedback from students on their learning experiences, they were encouraged to openly communicate feedback already at the beginning of the semester and at regular intervals thereafter. However, this request was almost not complied with. In addition, a teaching evaluation provided by the Faculty of Mechanical Engineering was implemented in the OPAL course towards the end of the semester. Although this also does not provide an anonymous opportunity for feedback due to the direct user assignment, 15 of the 32 students participated in the evaluation. This section summarises the main results of the evaluation.

On a positive note, the vast majority of students (93%) were able to understand the objectives of the course (see Figure 5), all participants were able to recognise a common thread in the structure of the course (see Figure 6) as well as the direct practical relevance (see Figure 7), and 80% of the students found the pace of the course to be optimal (see Figure 8).

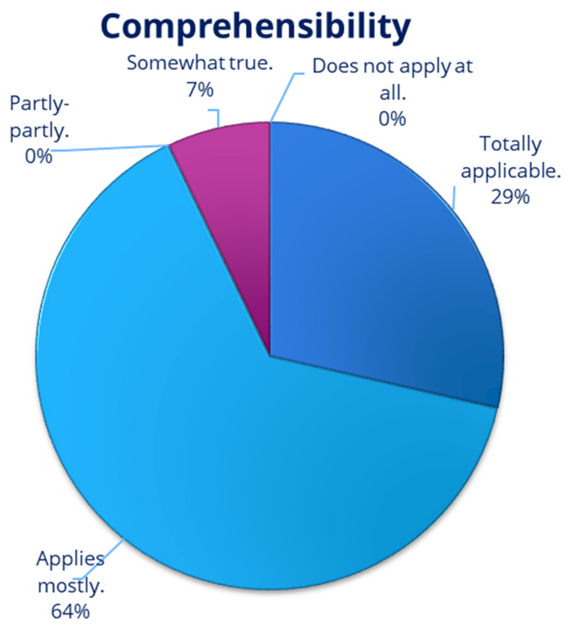

Fig. 5: Answers to the statement "The teacher presents the objectives of the course in a comprehensible way".

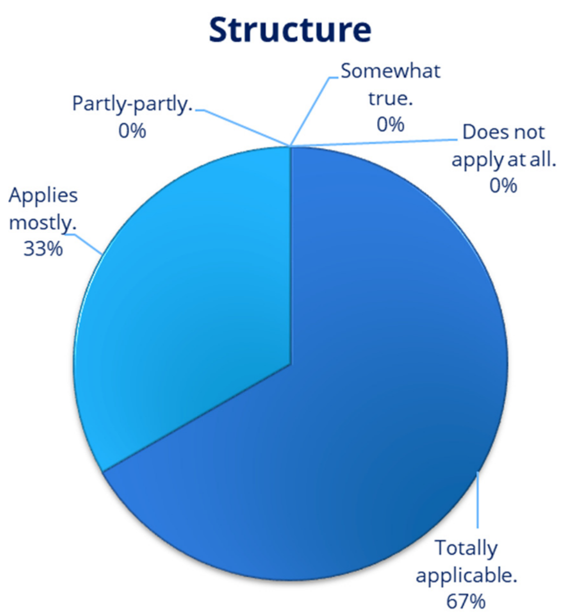

Fig. 6: Answers to the statement "The teacher structures the event. There is a recognisable thread."

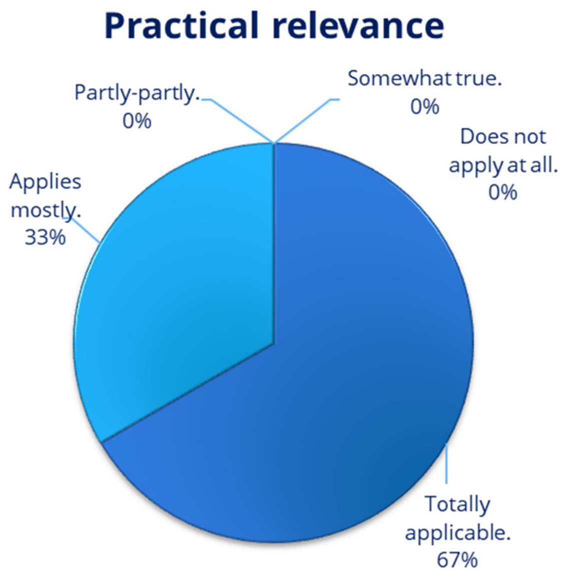

Fig. 7: Answers to the statement "The teacher establishes a link between theory and practice / applications".

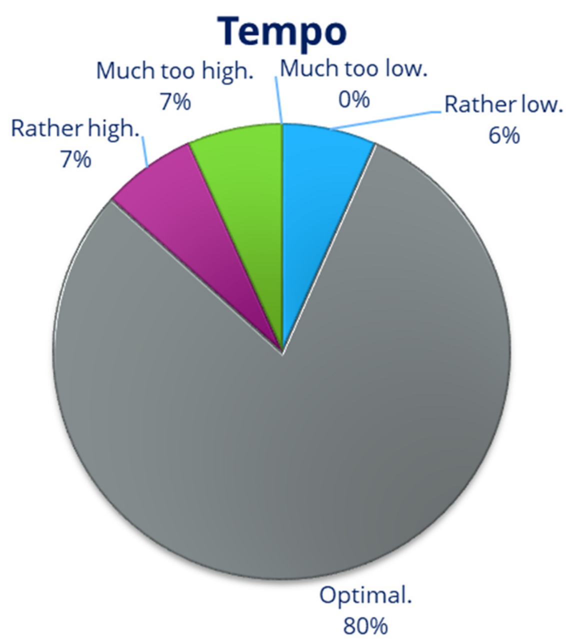

Fig. 8: Answers to the statement "The pace of the event is:. "

In addition, all participants found that the teachers were available for questions (see Figure 9) and 79% of the students stated that the teachers were able to make complicated issues understandable. This shows that the didactic concept of the redesigned course worked.

A similarly convincing picture emerges with regard to the media used to conduct the course. Two thirds of the participants stated that the work materials provided were helpful (see Figure 11). It should be noted here, that the 13% of participants who stated that there were no working materials, although e.g. information on individual roles and literature recommendations were communicated, distort the result somewhat. The presentation media used, i.e. in this case the screencasts and associated slides provided, were also rated as helpful by a 79% majority (see Figure 12).

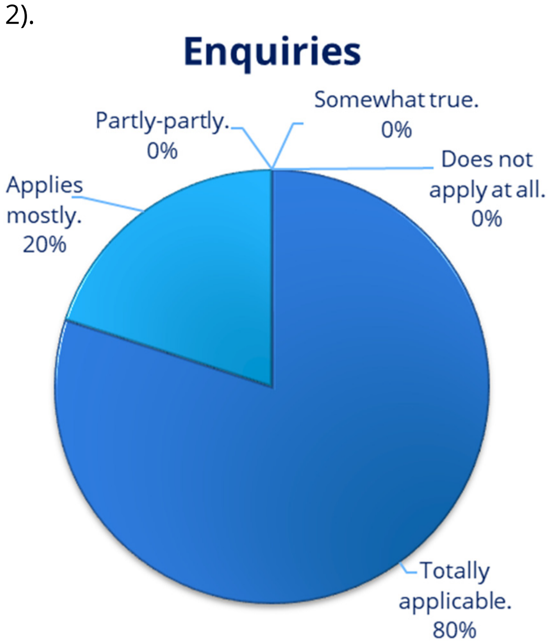

Fig. 9: Answers to the statement "The teacher is available for questions".

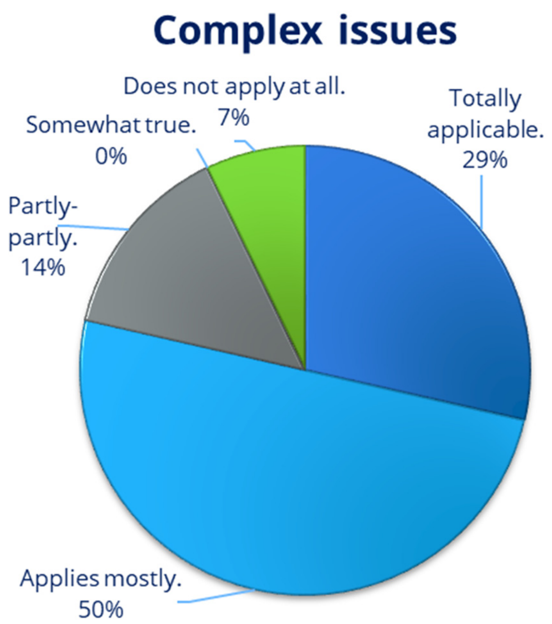

Fig. 10: Answers to the statement "The teacher can make complicated issues understandable".

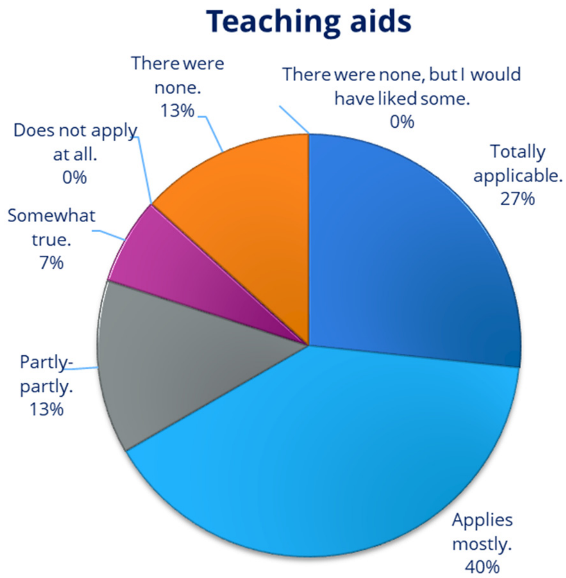

Fig. 11: Answers to the statement "I find the work materials provided helpful (e.g. handouts, scripts, references). "

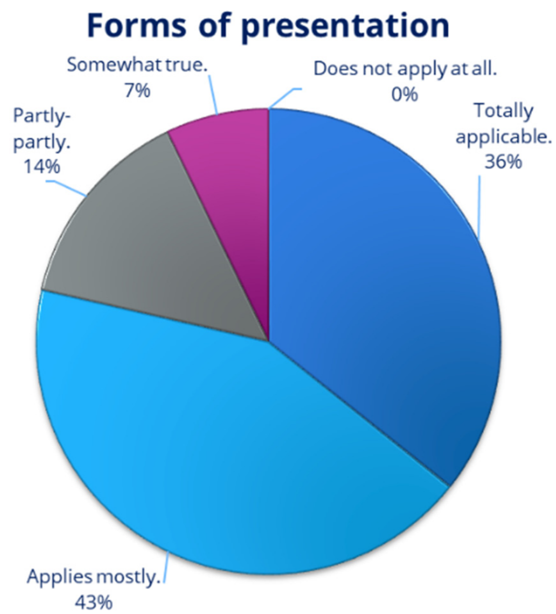

Fig. 12: Answers to the statement "I find the presentation media used helpful (e.g. presentation, slides, visual objects). "

Furthermore, all participants rated Discord positively for the course (see Figure 13). This platform was not specified, but chosen by the students themselves for their exchange. It is therefore worth considering to deliberately integrate this platform into the course or at least recommending it to future participants, but ultimately leaving the decision up to them.

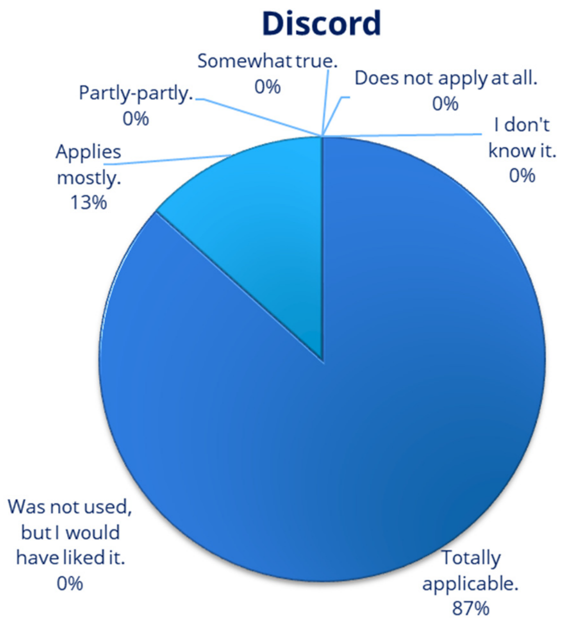

Fig. 13: Answers to the statement "I find the Discord communication tool helpful in teaching".

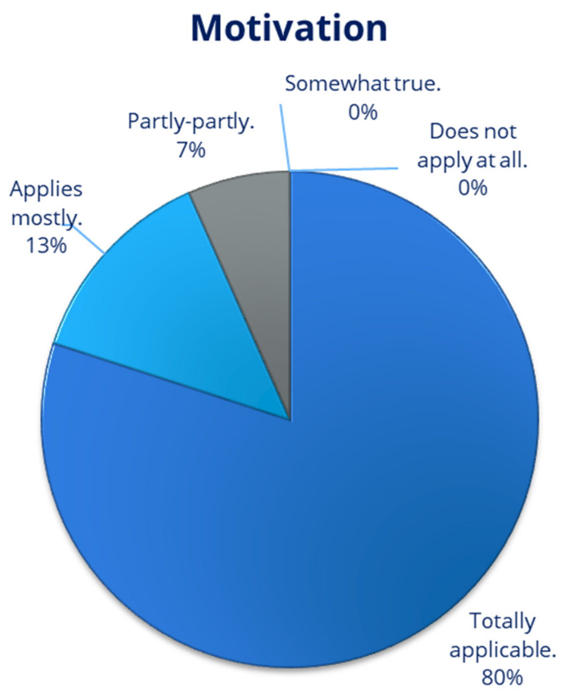

Fig. 14: Answers to the statement "The event motivates to deal with the contents on ones own".

The evaluation also paints a positive picture of the transformed course in the areas of motivation, learning experience and transferability into practice. Thus, 93% of the participants stated that they were motivated by the course to deal with the contents themselves (see Figure 14). An equally high percentage stated that they had learned a lot from the course (see Figure 15) and felt able to apply the knowledge they had learned in practice (see Figure 16). The latter point in particular is crucial, as the course places special emphasis on better preparing students who are about to complete their studies for everyday working life. It is therefore hardly surprising that 87% of the students stated that they were satisfied with the course overall (see Figure 17).

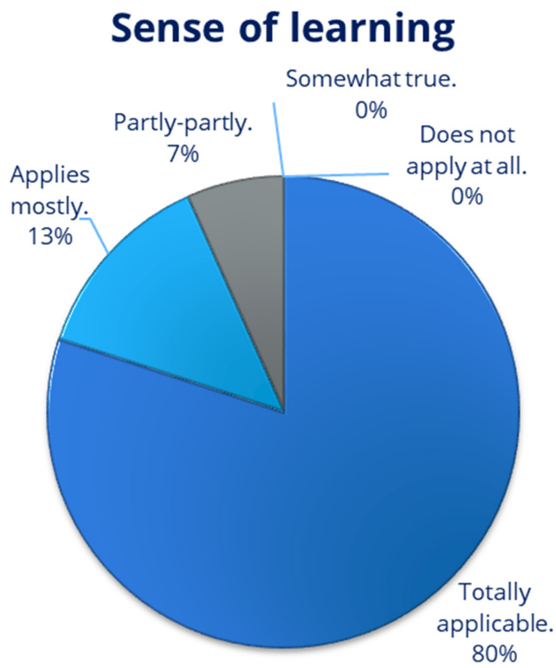

Fig. 15: Answers to the statement "I learned a lot from the event".

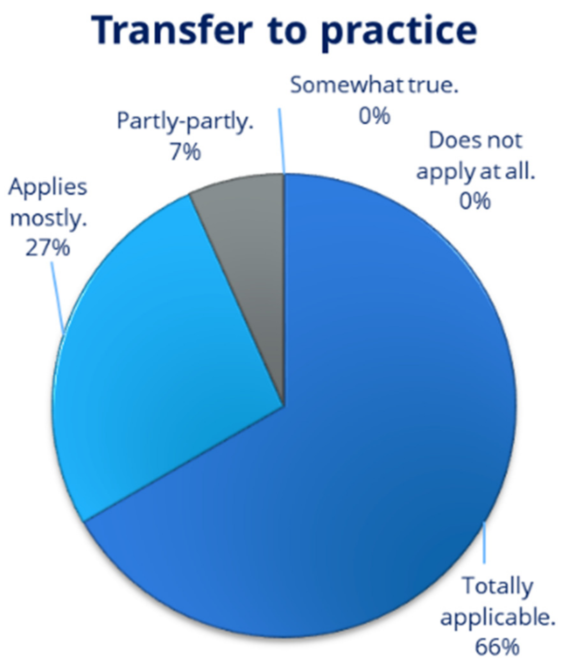

Fig. 16: Answers to the statement "I feel able to apply the knowledge learned in the course in practice.“

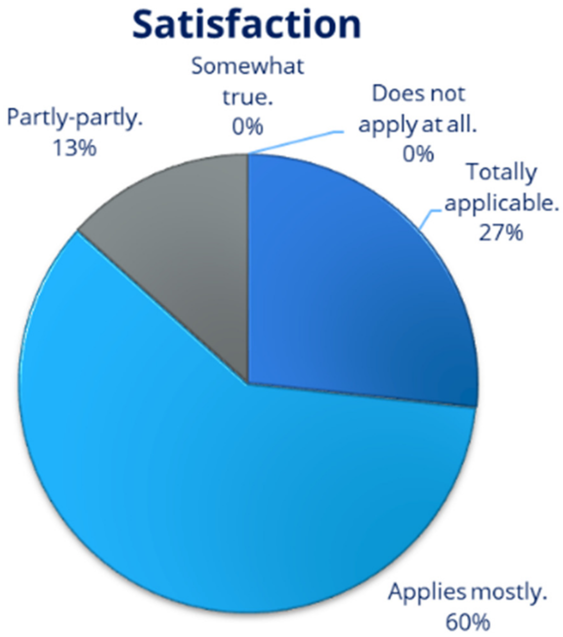

Fig. 17: Answers to the statement "Overall, I am satisfied with the course".

A somewhat more differentiated picture emerges with regard to the amount of material (see Figure 18). Although two thirds of the participants stated that the amount of material in the course was optimal, the remaining third felt that the amount of material was too high. Accordingly, no one felt that the amount of material was too low.

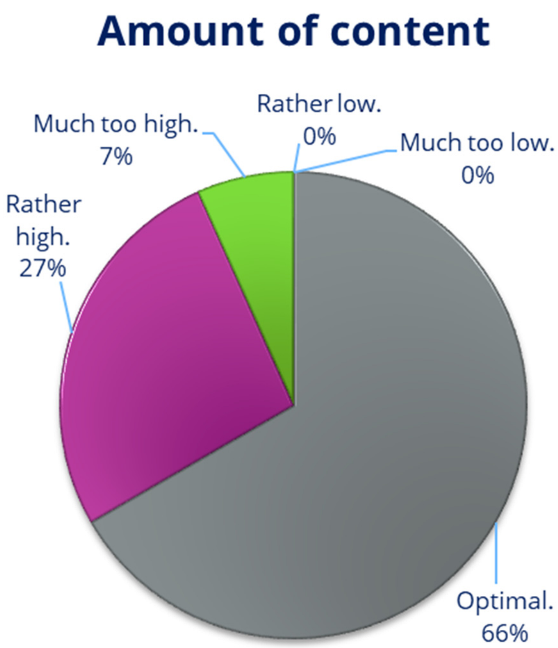

Fig. 18: Answers to the statement "The amount of material in the course is:“

This corresponds with the feedback on the amount of preparation and follow-up work (see Figure 19). Here, 87% of the students stated that they regularly prepared for and followed up on the course. This is clearly the intention due to the chosen structure with fixed milestones. However, this is accompanied by the fact that the workload was perceived as above average, at least subjectively. Thus, 93% of the students confirmed that the workload was higher than in other courses (see Fig. 20).

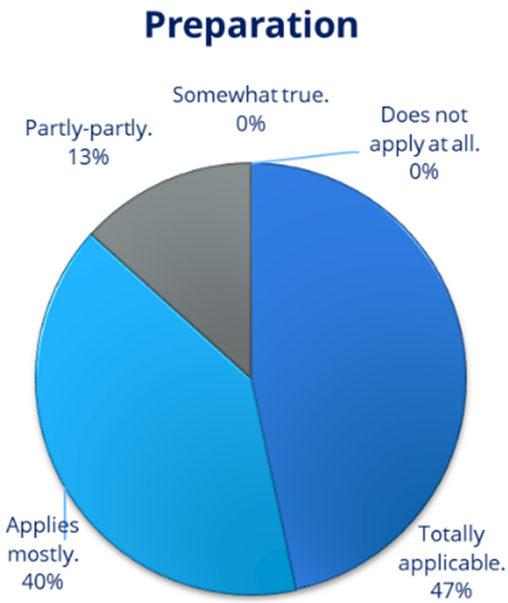

Fig. 19: Answers to the statement "I regularly prepare the event before and after".

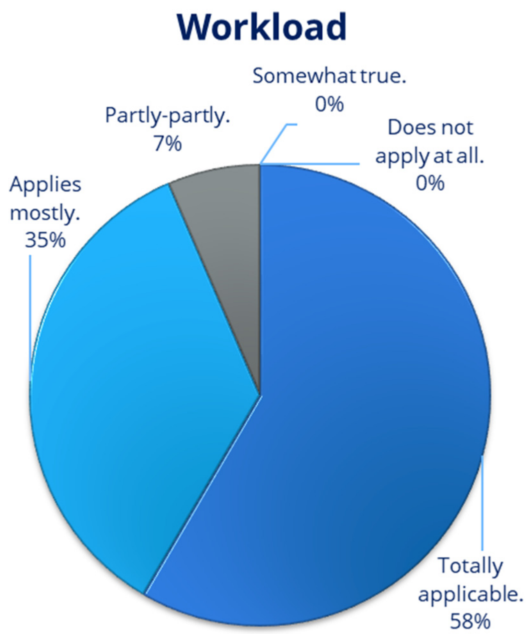

Fig. 20: Answers to the statement "My workload is high compared to other courses".

Figure 21 shows that this refers more to the amount of work than to the difficulty of the material, as 93% of the participants stated that the difficulty of the material was optimal. A further 7% tended to find it too low. Thus, the perceived high effort could be reduced by dropping one of the three iteration cycles. This would also eliminate a live consultation, which the students would not have to prepare and follow up accordingly. In this case, the effects on learning outcomes would have to be evaluated as precisely as possible.

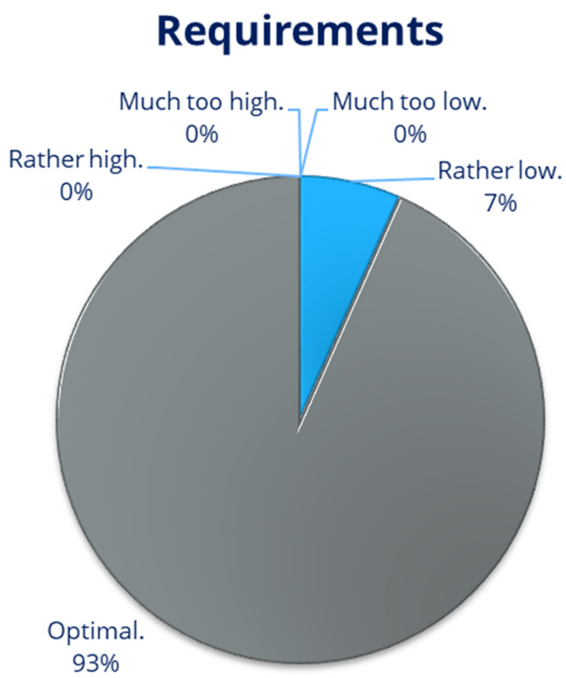

Fig. 21: Answers to the statement "The requirements are / the severity of the substance is:"

Overall, it can be said that the conversion of the course to a virtual format was a complete success. In fact, we were even more satisfied with the teaching-learning outcome than after the face-to-face events of the previous years. This includes the examination performance, which in the alternative format of final presentation and report is much closer to the professional reality of an engineer than a written exam.

11. Opportunities for improvement

However, the students' feedback also shows that there is still room for improvement. It turned out that the schedule of the course, which is very different from other courses in the aerospace engineering specialisation, did not become clear to everyone. In addition, not everyone was able to cope well with his or her role from the beginning. These points could be remedied relatively easily, for example, by explaining the tasks of the individual roles more clearly during the introductory session.

Another point is the utilised software, Valispace, which was rated positively throughout, but could not be fully utilised due to its limited performance (especially with regard to long times for synchronisation and calculation of data). A separate evaluation was carried out on this, which will be the subject of a future publication.

A disadvantage inherent in the applied approach is the limited insight into student learning during the semester. It is true that the consultations every two to three weeks, in which all students are expected to point out problems as well as their progress, provide a basis. Nevertheless, the perception of learning difficulties is more direct in face-to-face events and feedback loops can be kept shorter.

13 Summary and outlook

In the context of the course "Design of Space Systems" of the specialisation aerospace engineering of the diploma course mechanical engineering of the TU Dresden, a concurrent engineering workshop on the conception of a space mission was successfully transferred into a virtual format. The core of the restructuring, which became necessary due to the restrictions associated with the COVID-19 pandemic, was the stretching of the course, which had previously been held as a block course over three days, to cover the entire semester. The portfolio of utilised methods included screencasts to teach the basics at the beginning of the course, shifting the actual elaboration to self-study, and regular live consultations with short presentations by the students. This mixture of synchronous and asynchronous elements, together with the change of the assessment from a written exam to a combination of final presentation and report, led to the success of the course in this semester, which was underlined by the conducted teaching evaluation.

At the same time, this first iteration revealed concrete approaches for further improvements. For example, the students noticed the high amount of work compared to other courses. This could be reduced in the future by omitting an iteration stage in the detailing of the mission design or shortening it. In addition, the introduction to the course can be expanded, e.g. through dedicated short presentations with concrete example scenarios for the introduction to the different roles. This is important in order not to lose students at the beginning. After all, the main challenge of reaching all students and enabling them to actively participate, so that the mission study carried out can be led to success in the sense of concurrent engineering, arises anew each time.

Since the virtual format has led to a very positive teaching-learning result overall, the approach suggests itself to develop a hybrid format in the future, which is based on the structure of the virtual approach, and thus partly asynchronous knowledge transfer, and links this with face-to-face events. However, it will probably not be possible to please all students, as the opinion on face-to-face and online teaching in Figure 22 shows.

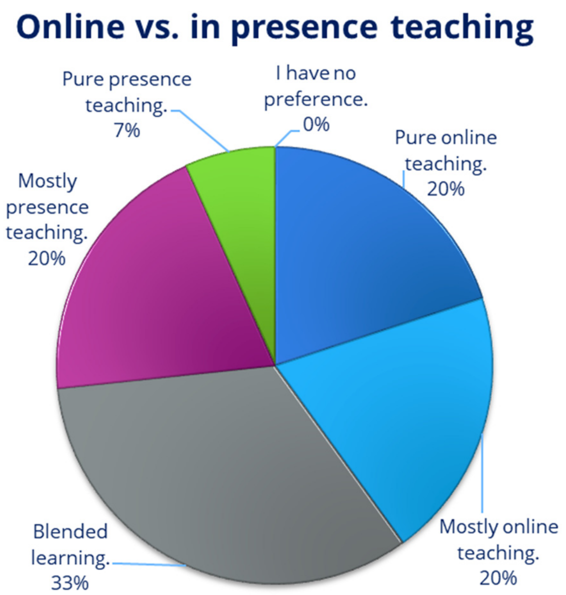

Fig. 22: Answers to the statement "In the context of teaching, I prefer the following forms of communication:"

Acknowledgement

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