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The Impact of the COVID-19 Pandemic in 2020 on the Quality of STEM Higher Education

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Pandemic COVID-19 has forced universities around the world to go online virtually overnight. This has been a major challenge, especially for study programmes in STEM areas (Science, Technology, Engineering, Mathematics) where distance learning was not previously preferred. This was mainly due to a large proportion of the experimental laboratory work done by students, which could reach up to half of all contact hours. While the lectures were utilized practically immediately after lockdown using video conferencing systems, the implementation of the practical study contents posed a greater challenge. This paper presents specific adaptations for certain activities in the university education of chemical engineering that had to be implemented quickly, such as laboratory and computer exercises, students' final theses and dissertations, internships, knowledge examination and evaluation. We highlight the most critical activities and most urgent solutions that were initiated. Various measures taken against the spread of the coronavirus had to take into account many uncertainties about the duration of the pandemic to ensure that students acquire the desired competences and skills in time without being physically present in the laboratories. Particular attention is paid to examinations, especially calculus tests, which are difficult to apply remotely. First evaluations show that the adapted learning process has been carried out effectively, but the big unknown is how successfully the students will pass the exams and how the lessons will be conducted in next academic year.

1. Introduction

It is typical of higher education in the fields of STEM (Science, Technology, Engineering, Mathematics) that, in addition to theoretical lectures, practical knowledge is an essential complement, including computational problems, laboratory experiments, project assignments, the use of computer programs, etc. In recent years, many multimedia approaches and tools for more efficient and higher quality teaching have been developed to improve engineering education (Klemeš et al., 2013). STEM education is still teacher-oriented in many institutions, but new approaches are slowly penetrating this area, e.g. reverse learning in transport phenomena (Valero et al., 2019), the production of videos and virtual laboratory notes in the field of polymers (Blanco et al., 2017), cartoon agents and 3D visualizations for learning crystal structures in engineering (Dalacosta and Pavlatou, 2020). Individual disciplines, such as chemical engineering, are increasingly interdisciplinary, students are closer to the internet than to textbooks, they are skilled in the use of a variety of electronic devices, computer programs and teaching aids (Davis, 2020). Platforms with different materials have been developed to complement other teaching methods for learning chemical engineering, such as interactive videos, simulators, virtual laboratories, etc. (Granjo and Rasteiro, 2018). The project CHARMING, 2018-2022, developed immersive technologies for teaching chemistry and chemical engineering using virtual and augmented reality. Davila-Guzman et al. (2019) have shown that the use of STEM videos increases students' autonomy in their studies and improves their learning outcomes. When the pandemic COVID-19 broke out, higher education institutions had to quickly switch their educational activities from lecture rooms and laboratories to video conferencing systems and shift to distance learning. Study programs that have not yet implemented student-centred teaching approaches on a large scale and have not prepared multimedia materials and distance assessment methods have faced a number of challenges. This paper discusses the main issues and projections concerning the impact of the corona crisis on the performance indicators of studies.

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2. Characteristics of three-cycle education of chemical engineering

The three-level education of chemical engineering includes a first university degree lasting usually 3 or 4 y, a second master's degree lasting 2 or 1 y and a doctoral degree lasting 3 or 4 y.

First level. The first level 3-year syllabus of chemical engineering at the University of Maribor contains a total of 33 study units, including 4 elective subjects and a final thesis. Among the offered elective courses is also industrial project, which the student usually completes in the company. An integral part of the syllabus is the final diploma work, which the student carries out individually under the guidance of a mentor and includes experimental work in the laboratory and/or the use of engineering methods and computers. Diploma thesis is often carried out in collaboration with companies, institutes and other organizations.

The knowledge assessment in each subject consists of several forms and methods, the most common ones being a written examination with solving calculation exercises, modelling or programming exercises, theory test, which can be written or oral, writing reports on laboratory or computer exercises, written tests on laboratory or computer exercises, oral defense of seminar papers, etc. In recent years, the share of written tests has been increasing and the share of oral defenses has been declining. The number of contact hours is on average 740 per year, of which 56 % are lectures and 44 % are various exercises (laboratory, computer, seminar). In addition to contact hours, students perform an average of 1,060 h/y of individual work. Lectures are largely conducted in a frontal manner in lecture halls using projections. The solving of computational examples is also demonstrated, for which a traditional green board is often used.

Second level. In the second cycle, in-depth chemical-engineering and process system engineering courses prevails. The first group includes e.g. stagewise processes, reaction and bioreaction engineering, bioseparations. The second group includes process design, process synthesis, process dynamics and optimization, process development, project preparation, etc. The objects are interconnected and upgraded. In the first semester, students begin to work on project assignment, which they continue in the second semester with simulation, heat integration and optimization, and upgrade with the design of process equipment, detailed economic analysis and safety and environmental impact assessment. There is a total of 16 study units in the study program, of which two are elective courses, and a master's thesis and compulsory training in industry, which lasts about one month. The scope and quality of the master's thesis significantly exceeds the diploma thesis at the first level, and some masters' students also participate in the publication of scientific articles. The number of contact hours is on average 455 per year, of which 49 % are various exercises (laboratory, computer, seminar). In addition to contact hours, students perform an average of 1,345 h of independent work per year.

Third level. The doctoral study program has recently been extended from 3 to 4 y and is entirely research-oriented. Students choose 4 subjects, plus two units covering methods of scientific research work and different soft skills. The remaining time is devoted to scientific research, writing articles and conference papers, preparing a doctoral dissertation theme, writing and defending a dissertation. Doctoral students must publish at least two original scientific papers in journals with impact factor. Most students significantly exceed this number.

At the first level, the transition of students from the first to the second year is between 25 % and 30 %, while in higher years it is between 85 % and sometimes even 100 %. It is obvious that the main selection is made in the first year; many students need longer time to advance to their second year. The reasons are in lowering the level of difficulty of primary and secondary education, where students are increasingly taught to solve problems using certain patterns while not acquiring a deep understanding. Students are also not accustomed to full-time and in-depth study, they are in constant interactions on social networks, which distracts their attention and lowers concentration.

3. Adaptations of the study process due to the COVID-19

Before the coronavirus pandemic, teachers generally did not provide distance learning. This is partly because it is possible to have more direct contact with students in lecture halls, and partly because much of the curriculum is carried out in laboratories and computer classrooms as practical exercises that students must perform themselves. The social aspect is also important, as physical presence promotes cooperation and intergenerational assistance among students. Nevertheless, some educational activities began to be carried out online practically immediately after the coronavirus lockdown, which came three weeks after the start of the summer semester. Various teaching methods required minor or major adjustments, which were made on an ongoing basis due to the great uncertainty about the duration of the epidemic and the closure of the faculty. In the following, the adjustments of the main forms of the chemical engineering study process are described.

3.1 Lectures

After the closure of the faculty, the Teaching Support Centre at the University of Maribor immediately provided instructions to students and teachers on how to use the licensed video conferencing tool. The distance lectures started almost immediately, following the same schedule as before the pandemic. Before lockdown, many teachers regularly used a green board in the classroom in addition to the slide projections to illustrate various derivations and calculations. The students followed the implementation and the individual steps better than if they would just read the derivation on the slide. The switch to online teaching required additional equipment, such as pen tablets and additional cameras, whose supply was soon exhausted. Some teachers provided the students with scanned solutions of computational examples, which they explained in video calls. The students mostly attended online lectures, only occasionally they reported weak internet connections, underperforming or busy home computers, as these were also used by other family members. The faculty offered them some laptops to borrow. Some teachers reported that they were disturbed by the feeling of giving a lecture to themselves and that there were no contacts and responses from the students. It proved to be very important that the activities took place according to the same schedule as before the epidemic, as this introduced a certain order, stability and calm for students and professors, which was especially valuable in the first weeks of the epidemic, when insecurity and stress were very high. Even after the university authorities had given permission for the gradual return to the faculty, it was decided to keep the lectures online until the end of the semester.

3.2 Computer and seminar exercises

Computer and seminar exercises include elements of programming, computing, modelling, process simulation, design, optimisation, etc., with students using different computer programs. This type of activity was effectively conducted online. System operators arranged temporary remote access to faculty computers for students. The assistants introduced the problem and described the course of work at the beginning of the session using a video conferencing system, and then the students solved the problems on their own computers. If troubles occurred, they could show their program code to the assistant at any time via screen sharing, and the assistant provided them advice on how to fix the problem. For more difficult problems, students handed over control to the assistant, who could directly intervene in the student's code and fix the problem. Students wrote written reports of the exercises and submitted them to the online learning environment. As in the lectures, the computer and seminar exercises were carried out completely online.

3.3 Laboratory exercises

Laboratory exercises were a great challenge during the lockdown. During the first weeks of the pandemic, it was expected that students and teachers would be able to return to the faculty relatively soon and conduct laboratory exercises on site. Nevertheless, the technical staff, following the instructions of the lecturers, started preparations for the possible implementation of remote laboratory exercises practically immediately after the lockdown. In the first half of April (about a month after closing) it became clear that the presence of students at the Faculty would be impossible for a longer time. Lecturers were asked to define those laboratory exercises that students would have to perform in the laboratory themselves, otherwise the learning outcomes and competences of the study program could not be guaranteed. The lecturers determined about 10 % of these most urgent exercises according to the total number of laboratory exercises in the summer semester. The relatively low percentage can be explained by the fact that for some competences in lower years it has been estimated that students can acquire them later in higher years. However, in some subjects, e.g. organic chemistry, this proportion was up to 50 %.

Due to the uncertainty about the duration of the epidemic, teachers were asked to tackle the virtual execution of all laboratory exercises. The laboratory technicians carried out the experiments in the laboratory and transmitted them to the students via video conference at a certain time. Some teachers recorded the experiments, equipped them with an audio explanation and made them available to the students so that they could study them independently at any time. The students wrote the exercise reports in the same way they would do them in the laboratory. After May 18, the university authorities granted permission to the faculties to open up to the most urgent educational activities that were not carried out. Protocols were written for the return of students to the faculty, which required smaller groups of students to kept a social distance of 1.5 to 2 m, the use of face masks, entering the faculty only when accompanied by an employee, etc. Students performed the missing lab exercises in a concentrated manner over the day or several consecutive days to minimize their arrival at the faculty and meetings with other students.

3.4 Final theses

The preparation of students' final theses, i.e. diploma and masters' theses, was also a challenge during lockdown, and innovative ways of carrying them out had to be found. If this were not possible, an entire generation of graduates could be dropped out, and in the worst-case scenario there would be a very low enrolment in higher-level study programs. At the beginning of the pandemic, the students of the last years were in the phase of preparing and submitting the themes of their theses. During the first weeks of the lockdown, students were advised to read the literature at home, collect relevant articles and review the state-of-the-art. When it became clear that an early return to the laboratories would not be possible, guidelines were provided to mentors and students to find ways to replace experimental laboratory work with other forms that could be done from home. Final works, that did not involve a lot of laboratory work, were carried out under the new conditions without any problems and no major adjustments were necessary. Students used available computer programs, time-limited remote access to the programs on the faculty's computers, and met with mentors regularly for video conferencing.

Students whose final thesis included laboratory work were advised to prepare a design of experiments, algorithms for execution, flow charts, graphical presentations, some calculations, simulations, analysis, synthesis and visualization of information obtained from literature, etc. If necessary, a large part of the graduates, especially in the first cycle, would completely replace laboratory methods with other types of experimental work. The aim was to enable as many students as possible to complete their studies in a quality way. However, in the second half of May, as the Faculty gradually began to open up to the most urgent forms of educational activities, the mentors urged the students to start conducting laboratory experiments, albeit in an adapted manner and to a limited extent. A detailed schedule for laboratory work of each student and precise safety protocols were established. The defence of the final theses began online shortly after the lockdown and will continue to be conducted in the same manner for some time. Traditional graduation ceremonies, in which students and their close relatives usually participate, are not planned in the near future.

3.5 Students internships and projects

The practical training is an optional course at the first level and compulsory at the second level. Students conduct internships in companies. During the epidemic, some students had to abandon it, and even after the measures were released, some companies refused to take students back for a traineeship. Gradually, employers began to reopen their doors to students and it is expected that students will be able to do internships and industrial projects over the summer. The Faculty was ready to offer alternative methods to students who were unable to do an internship due to the epidemic, either by offering students alternative electives online or by carrying out various forms of project work in their home environment under the online guidance of a tutor.

For many years, the Faculty has been carrying out student projects which are supported by the European Social Fund. These projects involve students, mentors of the Faculty and mentors from external economic or non-economic organizations. The projects aim to strengthen the students' competences in order to find innovative solutions in different areas. Projects that involve laboratory work were suspended at lockdown. Projects involving types of activities other than laboratory work continued with the work and regular meetings via a video conferencing system. For example, in a project to promote chemical engineering among pupils, students prepared media presentations of attractive topics for young people, conducted an online survey, wrote a script for promotional videos, drew animations, etc. After the gradual opening of the Faculty, these projects were also activated, as they are carried out in small groups. The students carried out both planned laboratory experiments and video recordings in the laboratories.

3.6 Examinations

With the implementation of the Bologna system of studies, ongoing knowledge tests were introduced in most courses of study. These include two or three partial tests, which are recognized as a final examination if passed successfully. Newer generations of students prefer the ongoing examinations because less material has to be absorbed for each partial test. The university authorities have recommended that knowledge tests during the lockdown should be conducted mostly orally via video calls. For the written tests, it was recommended that students write down their answers in a document that they submit in the online learning environment. For the arithmetic tests, students should solve exercises on a sheet of paper which they take a photograph and submit to the online learning environment. In the field of science and engineering, these methods are not the most appropriate, as the most common method of testing knowledge is solving computational exercises, for which online electronic tests are not the most appropriate method. There are often very large groups of students (even 100 or more), which makes it difficult to ensure effective control in a video conferencing system. There is also the problem of unauthorized cooperation between students, which is practically impossible to control. There are also challenges regarding the protection of personal data in the context of the GDPR Directive.

For these reasons, most of the ongoing tests were stopped during the epidemic lockdown, only a small part of the checks was carried out, such as group defences of seminar works. Immediately after the opening of the Faculty for the most urgent activities, some tests were organized before the examination period, especially in more demanding courses in the lower years. The lecturers prepared the students for these tests beforehand via a video conferencing system, so that the students were given tasks that were solved in a certain time, and then the photographed solutions were shown to the lecturer, who reviewed them and gave feedback to the students. Some teachers would recognize grades of these online exercises with a small percentage in the student's final grade. However, teachers also observed some evidence of concerning behaviour even in this activity; for example, some students wrote the letter "t" in the arithmetic expression instead of "+", which could be a sign of unauthorized cooperation and plagiarism among students. The first results of the test, which covers the entire half-year curriculum in mathematics, show that the students' performance was slightly worse than under normal conditions when they took three partial tests. The problem also lies in the fact that students now have to take many missing tests in a short period of time, which can affect their performance. At this point it is difficult to predict the overall performance of students within this academic year.

3.7 Doctoral students

Doctoral studies are largely conducted as an independent study, which includes a large part of the scientific research work, in which students are guided by their mentors. Faculty lockdown due to the epidemic did not have as great an impact on the implementation of the doctoral students' activities as it did for the first and second cycle students. During the lockdown, doctoral students carried out a number of activities, such as independent study for exams, reviewing literature and reading articles written by other authors, writing their own articles and conference papers, modelling, programming and running computer programs, writing dissertations, etc. They were in contact with their mentors all the time via a video conferencing system.

4. The impact of the crisis on the performance and quality of studies

The corona crisis in 2020 is most likely to have the greatest impact on student performance in passing exams. The study period for the corona generation will almost certainly be extended, the question is by how much. Last year, the average duration of studies at the first level was 3.9 y. Almost 70 % of the students completed their studies in 3 y plus an additional year granted to them by the government. At the second level, the average duration of studies was 2.9 y. Over a period of three years (2 y + one additional year) almost 80 % completed their master’s degree.

It can be predicted that the transition of the students to a higher year will decrease, as the students will not meet the prescribed conditions for enrolment. The Faculty carried out all the activities prescribed by the curriculum, but several months of physical absence of the students, the presence of uncertainty and stress due to the crisis and the absence of ongoing tests give reason to fear that the students will not be as ready for the exam period as they would normally be. The state authorities allow students who have been unable to meet their prescribed obligations due to exceptional circumstances to benefit from an extended student status for a further year. It is expected that many students will take advantage of this. As mentioned before, the Faculty conducts the main selection among students in the first year at the first level, so that a large proportion of students repeat the first year. Due to the corona crisis, the selection may have to be spread over several years to ensure a steady flow of students from the lower to the higher years.

The effects of the corona crisis on the quality of education will be felt over time, but it is predictable that this unexpected impulse has forced us to introduce distance learning, which will have several positive effects even after the corona. To name but a few: lectures that would be cancelled due to short or even long (e.g. sabbatical leave) absence of teachers, and it would be difficult to organize alternative dates because of student and lecture hall occupancy, could be replaced by distance learning even after the corona crisis. This could also be a short-term solution to bridge space problems that many faculties face in older premises. The recording of laboratory exercises could help students to better prepare for the exercises. Consideration should also be given to preparing recordings of interpretations of the most difficult derivations, theorems and proofs so that students will be able to view them several times in a peaceful environment. The records may also be useful to students who are ill for a long time, to those students who are top athletes and are often absent, or to students on mobility abroad.

5. Projections for the second half of 2020

The latest data show that the pandemic is easing with the arrival of summer. But what can we expect in autumn when the new academic year begins? Perhaps effective vaccine will not be ready soon and the pandemic will come and go in waves for some time in the future, and we will have to get used to switching between face-to-face teaching in lecture halls and laboratories and completely remote teaching by video calls. But even at the lowest point of the pandemic, it is unlikely that a large number of students could sit close together in lecture halls, as has been the case in the past. The spatial and staffing capacities do not allow faculties to hold lectures separately for numerous smaller groups of students. It will be necessary to create innovative ways of holding lectures and practical exercises that allow for social distance. For example, it will be possible for half of the students to come to the faculty for a week in order to follow the lectures live in a lecture hall and the other half of the students to follow the lectures at home via a video conferencing system. The other half of the students would be present at the faculty next week. This would at least partially maintain social contacts between students and professors.

Conducting laboratory exercises will also be a challenge, as some specialized laboratories are relatively small. A possible solution is that one group of students will only perform a part of the exercises in the laboratory, which will also be recorded, while another group of students will follow these exercises by videos. The second part of the exercises would be performed by another group of students and the recordings would be shared with the colleagues of the first group. Since it is not clear when the second wave is expected, it might be useful to start the laboratory exercises in autumn at the beginning of the new academic year and to postpone the lectures, which are easier to conduct online, until winter.

During this summer it will be necessary to purchase the necessary equipment such as cameras, microphones and pen tablets and to strengthen wireless internet in lecture halls and laboratories. It will be necessary to find ways to ensure that socially disadvantaged students are also equipped with good computers. Perhaps successful chemical and pharmaceutical companies could support good students by donating equipment that will enable them to study successfully in adapted conditions. In this way, companies could attract good candidates for future employment.

6. Conclusion

There is no doubt that the COVID-19 pandemic has hit many higher education institutions quite unprepared for online teaching and assessment. The ability and creativity of university teachers and staff to develop approaches quickly and innovatively to implementing the distance learning process has been demonstrated. In the coming months it will be necessary to strengthen the technical equipment for distance learning and to increase the confidence of all parties involved in student-centred teaching methods. It is possible that students' performance in passing exams, transition to higher years and in the duration of their studies will deteriorate. Scientific outputs may also decrease. Nevertheless, the corona pandemic has also had positive effects, such as the introduction of advanced communication tools for distance learning, which could continue to be used after the epidemic, even for non-traditional students. The new situation could also foster the transition to student-centred learning, in particular by introducing even more computer-based topics into chemistry and chemical engineering curricula and thoroughly developing simulation tools for experiential immersive learning. Virtual labs could be very useful in the STEM education, where expensive laboratory equipment is used that takes up a lot of space and quickly becomes obsolete. Students need to strengthen academic integrity and build self-confidence to participate in online knowledge tests in a fair and non-fraudulent manner.

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