Learnings from the rapid online transition of a real-world project task-based engineering course

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***Abstract*—This Innovative Practice Full Paper presents the results and learnings from a rapid and forced transition to online teaching of a campus-based and practical lab exercise intense course in robot engineering. Founded in previous pedagogical development work, we continued with activating and varied teaching methods connected through integrated project tasks. The online transition is evaluated from student course evaluations, examination results and the teachers' experiences from ten campus course occasions and four online course occasions during ten years. The paper focuses specifically on the combination of an innovative online lecturing format and fully virtual robot lab exercises. Our aim is to present learnings of interest for the engineering education community. The results highlight a successful and appreciated online course transition, with possibly improved student learning. In particular the pre-recorded video lectures were praised, the virtual labs was similarly appreciated as campus labs and it was demonstrated that online robot programming can be performed virtually, while practical lab exercises and study visits were still missed.**

Keywords—engineering education, project organized learning, online teaching, virtual lab exercises, video lectures

I. Introduction

The engineering profession is constantly developing and so must the engineering education. While the education historically has shifted towards theoretical knowledge and analytical skills, we are currently in a phase where effective updated learning methods are established in the literature and new teaching technologies are implemented [1-2]. Modern engineering also requires team working, creativity, practical ingenuity, life-long learning, agility and sustainability [3-9]. This is especially important in the context of the grand challenges in engineering [6-7]. Varied and inductive learning activities with focus on activity, authenticity, open-endings and collaboration are highlighted in the literature as effective teaching methods to include such skills [7-15]. In the field of robotics, real-world projects and lab exercises are identified as particularly effective in this teaching [16-17]. Robotics is also pointed out as effective for engagement in STEAM education [18]. From this theoretical framework, a new course structure with integrated, open-ended project tasks based on real-world applications was earlier developed at Uppsala University and implemented on a course in automation and robot engineering. This course was highly appreciated by the students and the results from this pedagogical development strongly indicate benefits to the students' learning [19].

In the beginning of the Covid-19 pandemic, it was rapidly decided to move all teaching online. Indeed challenging for most education institutions [20-22], and possible even more so for an engineering course based on real-life projects, physical lab exercises and student activation. Rather than just moving all teaching activities to live online meetings, we preferred a holistic approach with the students' learning in focus, treating the forced situation as an opportunity for pedagogical development. Video lecturing and virtual lab exercises were early identified as important tools in our online course transition. Video lectures can be used to promote a more student-centered pedagogy or flipped classroom, allowing more effective teaching with focus on active learning activities [23-25]. It is however a multifaceted tool. Lange and Costley [26] have examined common problems with online video lectures through literature review and a study on students taking online courses. Their results showed that quality issues were most common, followed by intelligibility, pace and diversity. Important factors highlighted in their work for achieving effective videos include visual and audio clarity, production values, esthetics, updated content, variable speaker rate and variation in the content. Other work have stressed the importance for video lectures to include interactive and embodying learning activities [27] and extra content to relief the students from study tedium [28]. Virtual programming was already used in our campus course, and such solutions are known as effective alternatives to practical robot labs in terms of resources, flexibility and student learning [29-31]. Remote industrial robot labs is yet another step closer to practical hands-on experience in online teaching, but require more hardware and preparation time [32].

Our transition to online teaching is outlined and evaluated in this paper. Four online course occasions are analyzed and compared to ten campus course occasions through student and teacher evaluations, and examination results. The aim of the paper is to present general online teaching learnings believed to be of interest for the engineering education community. Focus is on the combination of our two main contributions regarding innovative practice: innovative video lectures and fully virtual lab exercises. In Section II the method used to evaluate the online transition is outlined, while the implementation is described in detail in Section III. Results from this implementation are presented and compared to the campus course in Section IV, and then discussed in Section V. Conclusions are given in Section VI.

II. Method

The start point and reference work of this paper was the innovative engineering course structure previously developed at Uppsala University. First implementation of this course structure was in 2012 at campus on a five credits first cycle course on automation and robot engineering for the Bachelor Program in Mechanical Engineering (ME), where the course has been given once per year since. The results from the six occasions until 2017 are previously published, including a comparison to the traditional course version given 2011 [19].

While being somewhat adjusted and updated during the years, the course ran with the same overall structure and teaching activities until 2019. From 2018 the course was given twice per year now also for the Bachelor Program in Electrical Engineering (EE). The average number of students during the ten campus-based course occasions during 2012-2019 was 41, with range 25-54. In 2020 a thorough remodeling of the course was forced due to the pandemic outbreak and at the same time the Bachelor Program in Biomedical Engineering (BME) was also included in the course. The average number of students during the four online based course occasions during 2020-2021 was 46, with range 31-64. Two to three teachers were involved in all occasions, with the same course responsible (main teacher) and teacher assistant during 2012-2021.

In analyzing the emerged online course structure, we summarized extensive student course evaluations, teacher feedback and examination results collected during 2012-2021. Key student ratings from the course evaluations were averaged and compared between the campus and online course versions, including statistical variance analysis to determine significant rating differences between the course versions. Bartlett's and Lavene's test were used to determine the variance homogeneity, followed by the Tukey's HSD test to evaluate the significance of the difference when applicable. Relevant and representative free-text comments were also highlighted from the online course evaluations. Teacher feedback came from the teachers and from the course reports. The examination results were also averaged and compared.

III. Implementation

In this section, we give a summarized background of the campus course and a detailed description of the online course.

A. Campus Course Structure

The original version of the developed course was fully based on campus teaching activities and study visits. Our ambition was to achieve effective learning correlating with the requirements put on a modern engineer, through activating and varied teaching methods connecting theory to practice using real-world open-ended group project tasks. Three different assembly tasks – taken from our research on robotized production methods [33-35] – were used as student project tasks around which the course was structured. Project groups were formed with ideally four students collaborating to develop own robotized solution to one of the assembly tasks. Particular focus in the course and projects was on connecting theory to practice, with up to four different lab exercises, two study visits and one practical guest lecture from the industry. Course theory was presented during ten hall lectures. Examination was performed through lab exercises, seminars, hand-in reports and a final written examination. Minor changes during the years were mainly further developments of the lab exercises, updating course theory according to recent progress in the subject field, adjustments to ensure relevance as the course was given for all three ME, EE and BME Programs, and the introduction of optional online theory quizzes in 2019. A complete list of the course learning outcomes and a detailed illustration of the campus course structure with couplings between learning outcomes, learning activities and examination can be found in [19].

All course activities were planned to match the students' progress with their project tasks. To achieve authenticity, the project work was organized to match a professional work-life project process: (i) The process started from provided specifications and objectives on the chosen project task. (ii) From this information the students theoretically designed their own automated assembly solutions and presented their results in a simplified pre-study. Creativity and innovation were encouraged in this phase. (iii) Since it is not possible to let the students construct their own solutions, we continued with a full day practical lab exercise using the full-scale project task demonstrators developed within our research. Collaboration and ingenuity were encouraged to solve the robot programming, no step-by-step instructions were provided. (iv) Finally the students performed a very simplified commissioning by repeating the same lab exercise in the virtual robot programming and simulation software ABB Robotstudio, including an evaluation in virtual reality during the later courses. The students also completed their pre-study reports with regards to connectivity and safety equipment. In parallel with the project work we included a coupled case seminar on sustainable industrial development as well.

B. Online Course Structure

In shifting to online teaching in 2020, we carefully kept our research-based theoretical foundation with focus on student activation, varied teaching methods and integrated project tasks. With minimal preparation time, fixed course learning outcomes and concern for the students' situation, we also needed to be innovative in practice and think outside the traditional teaching box. Most effort was put into developing a new online course platform, recording video lectures and moving all lab exercises to simulation software. The main pedagogical developments were the innovative designs of online lectures and virtual lab exercises.

The online course followed the same project-based overall structure as the previous campus course, see Fig. 1. With exception of the cancelled guest lecture – relying on safety equipment demonstration – the previous lecture planning and theoretical content were kept, but as described in detail below in Subsection 1 the lecturing format was completely reworked. Study visits were not possible, instead an online training module from the industrial robot manufacturer Universal Robots was used for industrial relevance and training. The project work was kept, but seminars and student group work were moved to live online sessions using Zoom. Equipment demonstrations for the project tasks were recorded in our lab facilities and published on the online course platform. Physical lab exercises were replaced with extended virtual simulation lab exercises as described in detail below in Subsection 2. As the new simulation lab exercises become more comprehensive and time consuming, the second hand-in project report was removed during the later online course occasions. The final written examination on the course theory was moved online to the fully digitalized system Inspera Assessment. The examination was there divided into two parts, where the first part consisted of simpler auto-corrected questions and the second part required more comprehensive responses in text and figure. During the first three online courses the examination was performed remote with Zoom supervision, before it was possible to move to an examination hall. Extra effort was put on examining understanding rather than memorization and thereby prevent plagiarism, while striving for a continued constant examination level.

With a new course structure based on online teaching activities, it was necessary to develop a compatible and clear course platform. This was achieved within the Canvas Learning Management System used at Uppsala University. This course platform comprised all course material – videos, online lecture recordings, handouts, quizzes, study questions, instructions, submissions, live online meetings and evaluations – with a clear overview and easy navigation. Separate pages collected all material for different activities such as a lecture, assignment, seminar or lab exercise. All such pages were easily navigated to from the main course page.

Course Part I

L1: Introduction	*Course introduction, Zoom*	
Project work class I	*Introduction project tasks, Zoom*	F
L2: Technology	*Video and quiz*	A,C
L3: Positioning	*Video and quiz*	A
L4: Equipment	*Video and quiz*	B
Summary session I	*Summary and interaction L2-4, Zoom*	A-C
L5: Projecting	*Video and quiz*	F
Project work class II	*Supervision pre-study, Zoom*	A-C,F
Project seminar I	*Project group pre-study, report + presentation, Zoom*	A-C,F

Course Part II

L6: Programming	*Video and quiz*	A,F
L7: Sustainability	*Video and quiz*	E
Summary session II	*Summary and interaction L5-7, Zoom*	A,E,F
Case seminar	*Sustainability exercise, Zoom*	E
Online training	*Diploma Universal Robots*	A-D,F
Lab exercise class I	*Introduction lab exercises, Zoom*	A-D,F
Lab exercise class II	*Supervision onlineprogramming, Zoom*	A-D,F
Lab examination I	*Individual examination online programming, Zoom*	A-D,F

Course Part III

L8: Control & safety	*Video and quiz*	A,C
L9: Offline tools	*Video and quiz*	D
Summary session III	*Summary and interaction L8-9, Zoom*	A,C,D
Lab exercise class III	*Supervision offline programming, Zoom*	A-D,F
Lab examination II	*Individual examination offline programming, Zoom*	A-D,F
Project work class III	*Supervision project evaluation*	A-D,F
Project seminar II	*Project group work evaluation, presentation, Zoom*	A-D,F

Course Part IV

Summary session IV	*Summary and interaction L2-9, Zoom*	A-F
Witten examination	*Online digital examination, Inspera Assessment*	A-D
Course evaluation	*Extensive online end course evaluation*	A-F

Fig. 1. An overview of the presented new online course structure with examination activities marked with bold text and reference to the connected learning outcomes as presented in [19] given in the right column. L1-9 are short for Lecture 1-9.

1) Online Lectures

The lectures were from the beginning identified as central in the online shift, as digital lecturing cancel much of the natural interaction and activation while also leaving less room for formative adaption to the student group. One clear example was that we no longer could bring a small table robot for hands-on demonstration to the lectures. Our experience from the campus lectures on the other hand was that much time was used to mainly introducing the theory for the students. Interactive activities such as quizzes and group discussions could thus mainly be used for initial processing. Deeper understanding and synthesizing were left to the project work and self-studies. Furthermore, live lecturing is always affected by the context such as student group, feedback, hall environment and lecturer engagement. It is therefore unavoidable with variations in clarity and focus of the presentation.

From those observations, a new lecturing format based on video lectures was developed for the online course. All eight theory lectures were recorded separately in advance by the lecturer. Each lecture was then connected to online quizzes, where the students could repeat and practice the theory quickly before moving on to more comprehensive study questions. Lecture handouts, references to the course literature and links to extra material were published together with the videos, quizzes and study questions in lecture specific pages on the course learning platform. During the course, the students were asked to start on their own with the videos and online quizzes, as preparation for scheduled online lecture summary sessions where the theory was further processed together in class. Focus in those sessions were on active learning with questions, discussions and quiz exercises through Socrative. Thereafter the students could return to the material and practice on the study questions as preferred.

The video lectures were recorded in a simple setup using a green-screen, construction lightening and a hands-free microphone. Recordings were taken with a laptop computer through Zoom, where still images and virtual simulations could be applied as background. Basic editing using iMove included auto-tuning of video and audio, cutting for effective and clear presentation, adding picture-in-picture or video-in-picture effects, standard transitions, zooming and annotations. All lecture material were carefully worked through, updated and planned for online presentation before the recordings. This included writing manuscripts and dividing the material in sub-sections. PowerPoint presentations were used as a base for the lectures, but much effort was put into keeping the presentations clear and to regularly vary the teaching. The variations could consist of the lecturer talking or embodying theory, using a small toy robot model as a simple prop, demonstrations through virtual robot simulations, whiteboard sketching, live animations and annotating in the lecture notes, short videos demonstrating relevant practical applications, and step-by-step calculation exercise examples. A simple augmented reality lecturing method was also developed, by applying a robot simulation to the green-screen and thereby enable interaction with the lecturer. To promote student activation when watching the videos, reflection questions were regularly asked during the lectures. We also included a video instruction on how to craft a simple coordinate system model using three straws and a small polystyrene ball. This prop was frequently used in the video lectures and we encouraged the students to use it as well. Relieving and humoristic content were sometimes used, for example a concluding robot dance with the lecturer accompanied by robot inspired music and clips from different video lectures.

The lecture videos were published in shorter parts to facilitate navigation within each lecture and with respect to the human attention span. Each lecture consisted of 5-8 videos and included both a short initial lecture introduction and a short concluding lecture summary. The average video length was about 10 min, with 92 % being between 2-20 min. All video recordings were uploaded as unlisted YouTube videos and embedded at the course online platform, for a clear overview and to provide adjustable playback speed. Example screenshots from the video lectures are shown in Fig. 2.

2) *Virtual Lab Exercises*

The most critical part of the online transition was the lab exercises. Practical labs were an essential part of the previous campus course and the project tasks, as well as the course element earlier being most appreciated by the students. Furthermore, online robot programming – a term referring to direct interaction with an industrial robot most often using a hand-held control panel – is specifically mentioned in learning outcome (F) in the course syllabus [19]: *On completion of the course, the student should be able to implement and present a basic automation task with an industrial robot, including pilot study, online and offline programming and evaluation of the results, based on a given specification.*

Due to the rapidness of the online transition, it was not possible to develop remote lab exercises. Instead we decided to build on and extend the simulation lab exercise in ABB Robotstudio from the campus course. This previous lab exercise was however more modestly positive rated by the students and also performed fully at campus. It was appreciated by the students as a complement to practical labs, but also limited both from a technical barrier to master the software and from bugs in the robot station models.

Since the online course depended on fully remote teaching, the students now needed to install the software on their own computers. Students encountering hardware obstacles were encouraged to collaborate with a classmate over Zoom. In exceptional cases we also allowed single students working spread out at campus computers. A clear advantage with more extensive simulation lab was that it gave the students more time to get familiar with and independently explore robot programming and kinematics in the virtual environment. In practice the new virtual lab exercise was divided into two sub-tasks. Three class activities and two examination activities were scheduled, but the students were supposed to put in more work in between. To facilitate the software installation, video tutorials were recorded and shared on the course platform together with written instructions. At the first class activity we could thus focus on introducing the simulation environment and the two lab exercise tasks, but time was also dedicated for installation support if needed.

The first developed virtual lab exercise task focused on online robot programming. Here we used a simpler robot application taken from one of our physical lab facilities: An industrial robot picking cylinders from a conveyor and sorting them after size in different containers. The students were asked to prepare by watching a short external video tutorial on virtual online programming in ABB Robotstudio as well as the video lecture where the programming language was introduced. Video recordings demonstrating the physical equipment, a digital copy of the unprogrammed robot cell and a simplified programming manual were also shared on the course platform. As extra material we referred to the software documentation, and to ABB's online forums and YouTube channel. From this material the students worked independently on solving the given task against clear objectives, using only the built-in virtual control panel. Task specific supervision was concentrated to the second class activity and student collaboration was allowed, but all students

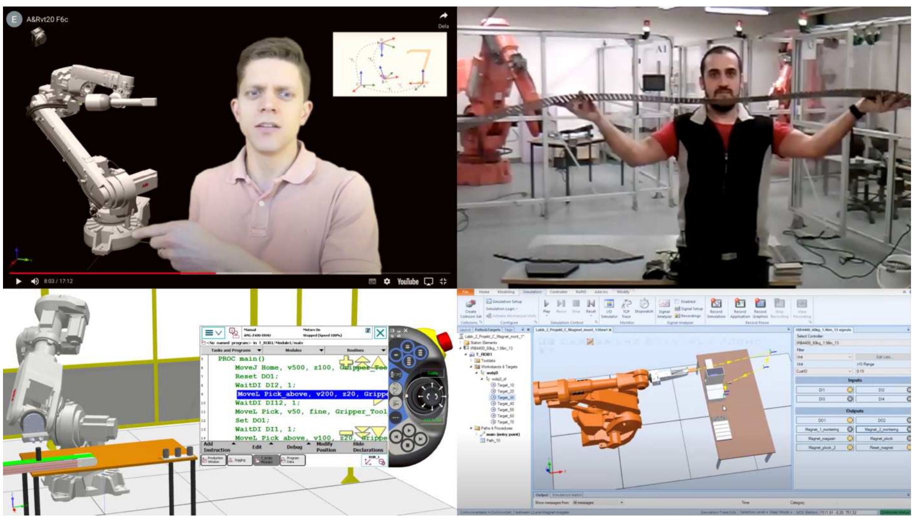

Fig. 2. Screenshots examples of different teaching activities from the new online course: Visualization of robot coordinate systems and kinematics using simple augmented reality during a video lecture (top left), physical demonstration of components during a project work class (top right), the online robot programming lab exercise task (bottom left) and the offline programming and simulation lab exercise task (bottom right).

were required to program and master their own solutions. Examination of the lab task was held individually during the first examination activity in 15 min slots using screen sharing over Zoom.

The second developed lab exercise task focused on offline robot programming, simulation. Here we used an extended version of the simulation task from the campus course, where the students worked with more complicated assemblies taken from their project tasks. In a pedagogical context we strived for a more open design with different possible solutions and more advanced programming. Beyond completing the first lab exercise, the student prepared for the second task by watching a short external video tutorial on virtual offline programming and simulation in ABB Robotstudio. Unprogrammed digital copies of our physical robot cells and video recordings demonstrating the simulated robot stations were also shared on the course platform. From this material the students again worked independently against clear objectives, now programming through the offline simulation interface, which enable a deeper focus on robot kinematics. Task specific supervision, collaboration and examination were performed as for the first lab task.

IV. Results

The rapid course transition into online teaching was overall met with understanding from the students. All extra effort from the teachers on adapting the pedagogics to online teaching and learning was much appreciated. The teachers received many positive comments on our online transition during the courses. From the teachers perspective the students' understanding of the situation was particularly high until the last investigated course occasion in the autumn 2021. The situation was then that our department kept the restrictions requiring fully online teaching while other departments returned to campus teaching. This was – as could be observed in the end course evaluation – clearly frustrating for some students who had looked much forward to the practical lab exercises in our course. Averaged ratings of the most relevant evaluation statements from all student end course evaluations – divided between and summarized for the campus and online course versions – are presented in Table I. In Fig. 3 and 4 selected evaluation statements are presented per year as well. It can be noticed that the ratings were effected from when the course was introduced to the EE Program in 2018. Average results are therefore included separately for the campus period 2018-2019 in Table I, since those student groups as well as the course structure were more similar to the online course period. It is also clear that the ratings dropped somewhat the autumn 2021. The average response rate was 61 % with 230 answers for all ten campus course occasions during 2012-2019, 55 % with 64 answers for the four campus course occasions during 2018-2019 and 60 % with 111 answers for the four online course occasions during 2020-2021. Replies to the evaluation statements were given on a Likert scale from 1 to 5, where 1 was the most negative, lowest or least agreement rating and 5 was the most positive, highest or most agreement rating. MI: 2012a-2020a (year two), 2021b (year three). EI: 2018b-2020b (year three), 2021a (year two). MTI 2020a-2021a (year two).

The student participation in the course was high for the full investigated period. In 2012-2019 almost every participating student (99 %) passed all the examination on lab exercises, seminars and hand-in reports and 86 % of the students passed the final written examination on the first occasion, whereof 37 % with a higher grade. Corresponding examination results from 2020-2021 were 95 % passing the lab exercises, seminars, hand-in report and online training and 81 % passing the final written examination on the first occasion, whereof 43 % with a higher grade. It is however noticed that also the final written examination results were effected when the EE Program was introduced to the course in 2018. This correlate with the teachers' perceptions of variations between the student groups during the courses. Therefore the final written examination results were also summarized separately for the four campus course occasions during 2018-2019. For those course occasions in average 81 % of the students passed the final written examination on the first occasion, whereof 25 % with a higher grade.

The optional free-text replies from the online course student evaluations reflected the ongoing online transition process during the pandemic to some extent. For example the expectations on online teaching were generally lower in the beginning and included many constructive suggestions, while tiredness of the pandemic restrictions were more common later on. Overall the commenting students were very pleased with the online course, lifting it as a positive model for online teaching and praising mainly the engagement of the teachers and the video lectures, but missing the opportunity for practical lab exercises. The relieving robot dance was commented specifically as appreciated during an overall challenging study situation. A few students wrote that video lectures require too much discipline and are less motivating than live lectures. Virtual lab exercises were in general commented as good during the circumstances, but some students still considered the software being too complex or complained about bugs and lack of instructions. Suggestions on what to keep from online teaching as we can return to campus varied somewhat, but the absolute majority wanted to keep the video lectures in some way and to get back to practical lab exercises. Corresponding free-text student replies from the campus-based course can be found in [19]. Some relevant and representative student replies from the online course occasions, with focus on the online transition, lectures and lab exercises, are presented below with the authors' translation from Swedish:

` Very well adapted from being a course relying much on lab exercises and projects in physical environment, probably thanks to big efforts from teachers/course responsible! ´

` Overall a very good course. This is absolutely the course with the best structure at my whole Program so far. [Third year student] ´

` Recorded video lectures have been incredibly good, nice to being able to go back and watch when you have not understood something. […] Good with live Zoom lectures that rehearse the content of the recorded. ´

` Would gladly have worked more practical with robots (both online and offline), but to be remote I thought that it went ok with two labs in Robotstudio, you got the basics. ´

`I think that the whole structure for remote should be kept [after the pandemic] but lab exercises can be at campus. […] [The lecturer] should have much credit for having created a course that educate in a modern way with different types of learning methods. ´

` [After the pandemic] use the same videos as complement to physical teaching ´

From the teachers' perspective, moving the course to online teaching in 2020 was a disruptive change. It required much work, but at the same time initiated fruitful pedagogical development perceived as stimulating and successful. On the other hand, while online tools such as Zoom were very helpful, the face-to-face interaction was still missed both in a pedagogical and in a social context. Recording video lectures was a good practice, helping the lecturer to become more aware on tempo and content. Using pre-recorded videos was to some extent a relief for the lecturer, allowing more interaction and flexibility during the live lecture summary sessions since all theory introduction was already covered in the videos. It was thus possible to focus on higher level teaching during the live sessions, including concepts that require more processing and thereby early avoid costly misconceptions. The lecture summary sessions were perceived to be most effective for students coming well prepared, but valuable also with limited preparation. It was supposed that most students watched the videos beforehand, but no quantative evaluation was made. The virtual lab exercises required a similar amount of total teaching time compared to the campus course labs. More time was spent on software support and individual examination, and the students focused more on the examination compared to the previous practical labs where an exploring mode often was more prominent. On the other hand, the online preparation relieved the teachers from repeating simpler instructions and thus allowed higher level supervision. The need for support as well as the student curiosity differed between the students during the virtual lab occasions, with slightly more students not passing compared to the campus simulation labs. Overall the teachers missed the face-to-face interaction and higher curiosity during practical lab exercises, but appreciated extended and less instruction-intense simulation labs.

TABLE I. SUMMARIZED AVERAGED STUDENT COURSE EVALUATION RESULTS FROM THE CAMPUS COURSE DURING 2012-2019 AND 2018-2019, AND FOR THE ONLINE COURSE DURING 2020-2021.

Evaluation statement		Average results		
		2012-2019	***2018-2019***	***2020-2021***
Q1[a]	General opinion on the course	4.5	4.2	4.3
Q2[a,c]	Opinion on the course workload requirement	2.9	2.8	3.3
Q3[a,c]	Opinion on the course difficulty level	2.9	2.8	3.2
Q4	Opinion on the communication with the teachers	4.6	4.4	4.5
Q5[a]	Opinion on personal course learning outcome fulfilment	4.5	4.4	4.4
Q6[b,c]	The lectures were valuable	4.2	4.0	4.5
Q6a	- *Hall lectures*	*4.2*	*4.0*	-
Q6b	- *Video lectures*	-	-	*4.7*
Q6c	- *Online lecture summary sessions*	-	-	*4.4*
Q7[b]	The lab exercises were valuable[b]	4.4	4.4	4.2
Q7a	- *Practical lab exercises*	*4.7*	*4.7*	-
Q7b	- *Simulation lab exercises*	*3.9*	*3.9*	*4.2*
Q8	The online quizzes were valuable	4.4	4.4	4.3
Q9[b,c]	The seminars were valuable	4.1	3.9	3.6
Q10	The hand-in assignments were valuable	4.1	4.0	3.8
Q11	The online training was valuable	-	-	3.9
Q12	The study visits and guest lecture were valuable	3.9	4.4	-
Q13[b,c]	Working with project tasks was valuable	4.3	4.2	3.9
Q14	The teaching activities were well coupled to each other	4.5	4.3	4.4
Q15	Opinion on the opportunity to be actively involved during the course	4.6	4.6	4.3
Q16	Evaluation of personal effort/engagement	4.3	4.1	4.2
Q17	Satisfaction with personal effort on the course	4.1	4.2	4.1

a. Evaluation statements presented per year in Fig. 3.

b. Evaluation statements presented per year in Fig. 4.

c. Evaluation statements analyzed in Fig. 5.

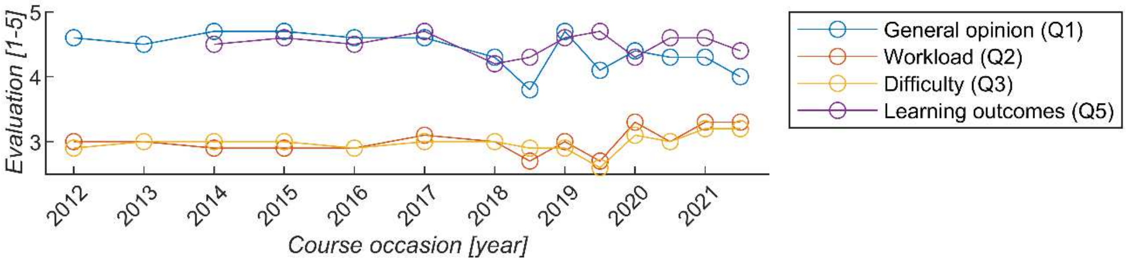

Fig. 3. Selected average student course evaluations results per year for the ten campus-based course occasions during 2012-2019 and the four online based course occasions during 2020-2021, with focus on overall course evaluation statements from Table I.

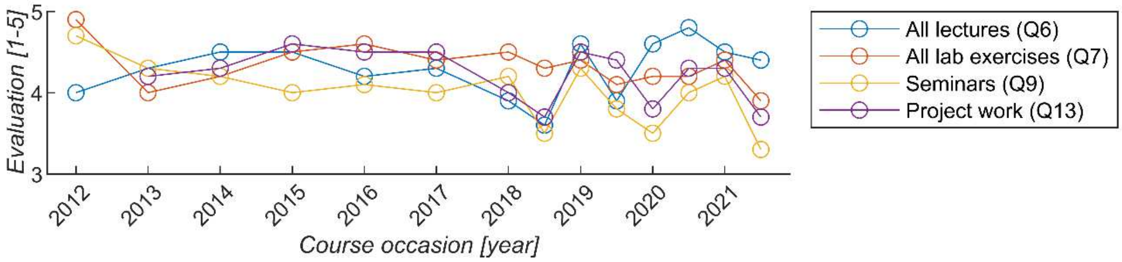

Fig. 4. Selected average student course evaluations results per year for the ten campus-based course occasions during 2012-2019 and the four online based course occasions during 2020-2021, with focus on learning activity specific evaluation statements from Table I.

V. Discussion

In this section the results from the online teaching transition are first discussed, with focus on the new lecture format and the developed virtual lab exercises. Thereafter we discuss general learnings from the online teaching transition and experience that can be of interest for the engineering education community, including suggestions on a further developed campus-based course version.

A. Online transition evaluation

The student course evaluations show that both the campus and the online courses were much appreciated by the students. While the campus course was ranked as one of the top ten most appreciated courses at the Department in a previous evaluation [19], the online course average rating would generate a position among the top 25 most appreciated of the same about 140 courses using the same reference data. An updated comparison was however not made during the pandemic, since this was a turbulent period with social restrictions differing between course occasions. The largest average rating differences (≥0.3) for the online course compared to the 2012-2019 campus course were higher ratings for the workload and lectures, and lower ratings for the seminars and project tasks. Through variance analysis ($p_{Bartlett}$ or $p_{Levene} > 0.05$, and $p_{Tukey} < 0.05$), the rating differences for lectures, seminars and project tasks were indicated to be statistically significant. Comparing to the 2018-2019 campus period instead, the largest rating differences for the online course were higher ratings for the workload, difficulty level and lectures. Variance analysis indicated the differences in difficulty level and lectures rating to be statistically significant. Online training was regarded as similarly valuable as the previous study visits and guest lecture when compared to the full 2012-2019 period, but clearly less valuable when compared to the 2018-2019 period. An important observation is that there was no larger, statistically significant student rating difference for the other evaluation statements between the campus course and the online course. This includes general course opinion, teacher communication, learning outcome fulfilment, lab exercises, student activation and satisfaction with personal effort. All ratings remained at high and acceptable levels. In particular the difficulty level and workload – with very little spreads in ratings – were still in the desired region. Since variance analysis was not robust for all evaluation statements with the limited Likert-scale resolution, we also present the most varying student rating responses in more detail in Fig. 5. To summarize, despite being a course with a previous high and appreciated focus on physical teaching activities, the new online course version was still very much appreciated by the students. In particular the online lectures were more appreciated than the campus lectures and overall the lab exercises were similarly high appreciated before and after the online transition.

The part of the new online course receiving the highest ratings and most positive comments was clearly the pre-recorded video lectures. It has thus been demonstrated that lectures can be successfully recorded and edited in a simple setup, provided the content is carefully planned with a varied and pedagogical approach. Due to the extent of the videos, the recordings were the most time-consuming development in the online transition. Preconditions for such recordings are an experienced lecturer, a mature lecture material and a possibility to re-using the material during multiple occasions.

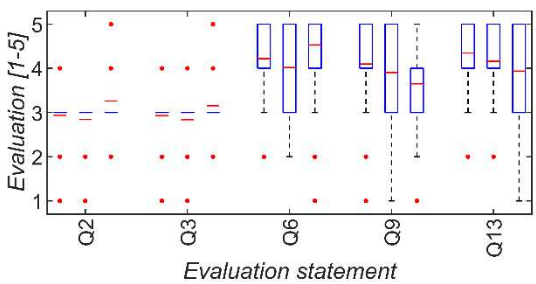

Fig. 5. A statistical visualization for the largest average rating differences between the students' responses in the course evaluations. For each statement, data is presented separatly for the time periods 2012-2019 (left), 2018-2019 (middle) and 2020-2021 (right). The blue boxess mark the data within the 25th and 75th percentiles, the red lines mark the average value and the red dots mark outliners.

Recording lectures can then be rewarding both on a personal and a pedagogical level, allowing the lecturer to spend time rather on active learning than on repeating and introducing the same material. Video lectures should however not be seen as a measure to simplify or reduce the teaching workload, as well planned interaction and processing sessions are now essential. Creating online quizzes and continuous updates of the video material is also preferred. This lecturing design puts higher pedagogical demands on the lecturer, whom should also consider the aggregated student workload. It is therefore necessary to keep focus on effective student learning and to explain the lecturing concept for the students. Despite the lack of face-to-face interaction, the online lecture summary sessions received higher ratings than the previous campus lectures. All together this argue strongly for the new developed lecturing format from the students' perspective. In the future it would be interesting to develop the lecture summary sessions further towards student-centered learning.

The part of the campus course being clearly most missed by the students was the practical lab exercises. Still the combined average ratings for all lab exercises were similar for the campus and online courses and the students' opinion on course learning outcome fulfilment was consistent. We have thus demonstrated that practical industrial robot lab exercises, including online robot programming, can be replaced with virtual simulation lab exercises. While it is not possible to fully replace all learnings from physical work – such as a touch for robot jogging or a sense for reasonable precision and mechanical velocities – in a simulation environment, virtual labs allow the students to examine robot programming and kinematics more freely and in deep. Two keys for succeeding with the simulation lab exercises were that the students prepared beforehand and that they had time to get familiar with the software rather than directly stressing towards objectives. Two possible explanations for the slightly lower lab exercise pass rate during the online course are the higher demand on remote study discipline and students being sick with Covid-19 symptoms. It can also be seen in the student course evaluations that a few students experienced the virtual lab exercises to be stressful and require too much work. In summary it can be argued that what was missed in practical experience was compensated for with more comprehensive simulations in the online course. Both lab designs are possible and can fulfil the course learning outcomes.

The final written examination pass ratio was rather consistent for the campus and online courses, in particular considering the period 2018-2021, while the ratio of students receiving a higher grade increased with the online course. Compensation for heterogeneous student groups and different Education Programs was to some extent achieved by covering several years, but another clear variation was the shift to digitalized examination during the online transition. Much effort was however put into preserving the requirement level, if anything the digital examination focused more on understanding and less on memorization. The increased risk for unidentified plagiarism during the remote digital examinations must also be taken into account, as there were reported cases rendering disciplinary measures. With several factors differing between the course occasions, it is not straightforward to put the examination results in a direct relation to the shift from campus to online teaching. However the overall picture, which is supported by the teachers' experiences, is that the online transition did not have a negative effect on but rather improved the students' learning.

B. *Online teaching learnings*

A general experience from our online teaching transition is that institutional support and student cooperation were crucial to succeed. During this time many students found themselves left to more self-studies and own responsibility, including periods of full isolation with disease symptoms. Thus teacher communication and engagement in the students' situation were essential. Measures that we found important to achieve a good study environment included: clear instructions and objectives; a clear online course platform; explicit efforts to adapt teaching activities from a pedagogical perspective; facilitating remote studies with elaborated online material; group work and examination rather than multiple hand-in assignments; effective communication; and sensitivity to and active request for student feedback. It was confirmed from the course evaluations that social or personal dimensions not necessarily relating directly to the course subject were important during the online course. This should not be underestimated, being an opportunity to lower the guard in an otherwise demanding context. A clear example from our course was the appreciated robot dance in the last video lecture.

Finally, it must be remembered that students are different and have different learning preferences. Some prefer remote self-studies, others prefer collaborative group learning and yet others learn best through practical exercises. It is thus not possible to fully satisfy all students. Perhaps the students' demands on our teaching has risen after a period of limitations, there are such indications. It is the strong belief of the authors that we should now make the best use of all our pedagogical developments and experiences from online teaching to improve our campus teaching, rather than simply falling back to the previous teaching situation. In our course this could be to keep the new lecturing format and preparation material for the virtual lab exercises, further developing active learning activities at campus, and taking back practical lab exercises and study visits. We strongly believe that our project organized learning and student-centered inspired teaching example can be useful also for other engineering courses.

VI. Conclusions

We have presented the thorough transition of a project task-centered engineering course, from being fully campus-based with a practical focus to fully online teaching with preserved varied and activating teaching methods connected to real-world project tasks. Most important from an innovative practice perspective were the developed combination of video lectures with connected interactive in-class sessions and the fully virtual robot lab exercises. The new online course format was much appreciated by the students, with specific praise to the new lecture format and particularly to the video lectures. Despite the lack of physical experiments, the new virtual lab exercise format was similarly appreciated as the previous campus based lab format. It was also demonstrated that online robot programming can be taught successfully in a virtual environment. The examination results indicate that the students' learning possibly benefited as a result of the pedagogical developments during the online transition.

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REFERENCES

[1] E.F. Crawley, J. Malmqvist, S. Östlund, D.R. Brodeur, and K. Edström, "Historical Accounts of Engineering Education,". In: Rethinking Engineering Education. Springer, Cham, 2014.

[2] J.E. Froyd, P.C. Wankat, K.A. Smith, "Five Major Shifts in 100 Years of Engineering Education", Proceedings of the IEEE: Special Centennial Issue, vol. 100, pp. 1344-1360, 2012.

[3] A. Ruargarcia, R.M. Felder, D.R. Woods, (2000). "The future of engineering education I. A vision for a new century," Chemical Engineering Education, vol. 34(1), pp. 16-25, 2000.

[4] A. Hanning, A.P. Abelsson, U. Lundqvist, M. Svanström, "Are we educating engineers for sustainability?" International Journal of Sustainability, vol. 13(3), pp. 305-320, 2012.

[5] E. De Graaf, W. Revensteijn, "Training complete engineers: global enterprise and engineering education," European Journal of Engineering Education, vol. 26(4), pp. 417-427, 2010.

[6] J.J. Duderstadt, "Engineering for a changing world: A roadmap to the future of engineering practice, research and education," Springer, New York, 2008.

[7] A Guerra, R. Ulseth, B. Johnson, A. Kolmos, "Engineering grand challenges and the attributes of the global engineer: a literature review," Proceedings of the 45th SEFI Annual Conference, pp. 1222-1235, Azores, Portugal, 2017.

[8] C. Zhou, "Fostering creative engineers: A key to face the complexity of engineering practice," European Journal of Engineering Education, vol. 37(4), pp. 343-353, 2012.

[9] K. Mohd-Yusof, S.A Helmi, F.A. Phang and S. Mohammad, "Future Directions in Engineering Education: Educating Engineers of the 21st Century", ASEAN Journal of Engineering Education, vol. 2(1), pp. 8-13, 2015.

[10] R.M. Felder, D.R. Woods, J.E. Stice, A. Ruargarcia, "The future of engineering education II. Teaching methods that work," Chemical Engineering Education, vol. 34(1), pp. 26-39, 2000.

[11] R.G. Hadgraft, A. Kolmos, "Emerging learning environments in engineering education," Australasian Journal of Engineering Education, vol. 25(1), pp. 3-16, 2020.

[12] M. Lombardi, "Authentic learning for the 21st century: An overview," Educase Learning Initiative, vol. 1, pp. 1-12, 2007.

[13] J.E. Mills, D.F. Treagust, "Engineering education: Is problem-based or project-based learning the answer?" Australasian Journal of Engineering Education, online publication, 2003-2004.

[14] J. Grimson, "Re-engineering the curriculum for the 21st century," European Journal of Engineering Education, vol. 27(1), pp. 31-37, 2002.

[15] K. Scager, J. Boonstra, T. Peeters, J. Vulperhorst, F. Wiegant, "Collaborative Learning in Higher Education: Evoking Positive Interdependence," CBE – Life Sciences Education, vol. 15(4):69, 2017.

[16] N. Barakat, "Balanced integration of theory and applications in teaching robotics," International Journal of Mechanical Engineering Education, vol. 30(1), pp. 1-19, 2011.

[17] J.M. Esposito, "The state of robotics education: Proposed goals for positively transforming robotics education at postsecondary institutions," IEEE Robotics & Automation Magazine, vol. 24(3) pp. 157-164, 2017.

[18] M.À. Conde, F.J. Rodríguez-Sedano, C. Fernández-Llamas, et.al., "Fostering STEAM through challenge-based learning, robotics, and physical devices: A systematic mapping literature review," Computer Applications in Engineering Education, vol. 29(1), pp. 46-65, 2021.

[19] E. Hultman, M. Leijon, "Integration of real-world project tasks in a course on automation and robot engineering," Proceedings of the 10th IEEE Global Engineering Education Conference, pp. 107-114, Dubai, UAE, 2019.

[20] S. Dhawan, "Online learning: a panacea in the time of COVID-19 crisis," Journal of Education Technology Systems, vol. 49(1), pp. 5-22, 2020.

[21] O.B. Adedoyin, E. Soykan, "Covid-19 pandemic and online learning: the challenges and opportunities," Interactive Learning Environments, vol. 2(1), pp. 1-13, 2020.

[22] J. Grodotzki, S. Upadhya, A.E. Tekkaya, "Engineering education amid a global pandemic," Advances in Industrial and Manufacturing Engineering, vol. 3:100058, 2021.

[23] D.S. Knowlton, "A theoretical framework for the online classroom: A defense and delineation of a student-centered pedagogy," New Directions for Teaching & Learning, vol. 2000(84) pp. 5-14, 2002.

[24] J. Bishop, M.A. Verleger, "The flipped classroom: A survey of the research,", Proceedings of the ASEE Annual Conference & Exposition, Atlanta, Georgia, 2013.

[25] M. Ronchetti, "Using video lectures to make teaching more interactive," International Journal of Emerging Technology in Learning, vol. 5(2) pp. 45-48, 2010.

[26] C. Lange, J. Costley, "Improving online video lectures: learning challenges created by media," International Journal of Educational Technology in Higher Education, vol. 17:16, 2020.

[27] I-C Hung, Kinshuk, N-S Chen, "Embodied interactive video lectures for improving learning comprehension and retention," Computer & Education, vol. 117, pp. 116-131, 2018.

[28] H.D. Brecht, "Learning from online video lectures," Journal of Information Technology Education: Innovation in Practice, vol. 11, pp. 227-250, 2012.

[29] P. Abreu, M.R. Barbosa, A.M. Lopes, "Robotics virtual lab based on off-line robot programming software," Proceedings of the 2nd Experiment@ International Conference, pp. 109-113, Coimbra, Portugal, 2013.

[30] C. Li, L. Fu, L. Wang, "Innovate engineering education by using virtual laboratory platform based industrial robot," Proceedings of the 30th Chinese Control and Decision Conference, pp. 3467-3472, Shenyang, China, 2018.

[31] M. Mikhail, V. Duong, D. Podgorski, "The new solution for robotics education," Proceedings of the 3rd International Conference on Electrical, Communication, and Computer Engineering, pp. 1-6, Kuala Lumpur, Malaysia, 2021.

[32] A. Rukangu, A. Tuttle, K. Johnsen, "Virtual reality for remote controlled robotics in engineering education," Proceedings of the IEEE Conference on Virtual Reality and 3D User Interfaces Abstracts and Workshops, pp. 751-752, Lisbon, Portugal, 2021.

[33] E. Hultman, M. Linder, M. Leijon, "Robotized stacking of the Uppsala University wave energy generator stator," Proceedings of the 33rd International Conference on Ocean, Off-shore and Arctic Engineering, San Fransisco, USA, 2014.

[34] E. Hultman, D. Salar, M. Leijon, "Robotized surface mounting of permanent magnets," Machines, vol. 2, pp. 219-232, 2014.

[35] T. Kamf, J. Abrahamsson, "Self-sensing electromagnets for robotic tooling systems: Combining sensors and actuators," Machines, vol. 4(3):16, 2016.