Reflection on Design Teaching Before, During and After Pandemic

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Reem Roufail is a materials engineer that is interested in engineering teaching and applying new technologies to engage students in class. Reem believes that learning is a continuous process that does not end with earning a degree. This explains her willingness to explore different fields of engineering as opportunities to learn. She explored mechanical engineering, environmental engineering, petroleum engineering, systems design, and biomedical engineering in her career paths from an academic perspective. Recently she has successfully led and supported Biomedical engineering and Systems Design engineering programs at the University of Waterloo to apply the Canadian Engineering Accreditation Board (CEAB) graduate attribute and continuous improvement approach to the programs. That intrigued her to dig deeper into teaching-learning pedagogy. The abrupt changes that the pandemic brought to the education system, were a trigger for her to realize that change is coming to how we do things. However, before we jump into applying a change, we should understand the impact of the change from all stakeholders' perspectives.

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Abstract

The pandemic caught the world by surprise. Instructors at all levels had to quickly learn and adopt new tools for online course delivery. The adoption of new tools that could capture the unique features of design courses, which are primarily project based and open-ended, and require in class discussions, feedback and teamwork represented a major challenge in an online environment. It was not clear how the online environment would affect the perception of instructors and the performance of the students. The primary purpose of this paper was to investigate potential relationships between the perception of instructors of the impact of the course delivery on the student learning, namely the final course grades and student performance against expectations. The instructors' perceptions, collected in an anonymous survey, was examined, and compared to the performance of the students. Based on the observations, it appears that the effect of online teaching was course specific where some impact of the students' performance was observed. In this context, the potential benefits of an online delivery mode of design content require further investigation.

1. Introduction

The impact of the pandemic on teaching is examined around the world. UNESCO identified "severe" impact in Canada resulting from closure of in-person learning for elementary and high school children [1]. A survey from Statistics Canada in April-May 2020 reported that 92% of Canadian post secondary students had courses moved online [2]. The survey also reported that 5% of engineering students were unable to finish their courses due to impacts of the pandemic. The University of California, United States of America, conducted an extensive survey of engineering students in the Spring of 2020 to assess the impact of online learning through the pandemic. This study looked at access to internet, hardware, software, printer, computer, webcam, study space, instructors and student perceptions of their engagement, disconnection and fatigue [3]. They reported that 7.6 % of undergraduate student expected to delay graduation due to the pandemic. The national US survey of undergraduate students showed a significant reduction in course satisfaction with 19% of students extremely satisfied with their course compared to 51%pre-pandemic [4]. In this extensive survey, student motivation (42% of respondents) was identified as the most significant factor that contributed to course difficulties.

Remote learning was present long before the pandemic. Bourne et. al. [5] provide examples of online engineering programs and courses dating back to the early 1990s. They identified the development of meaningful laboratory experiences as one of the major hurdles to online engineering education. Park et. al. discussed the challenges associated with delivery of online lab courses in engineering programs, the core part of the undergraduate engineering curriculums and mandated for accredited programs [6], and reflected on the emotional toll of online learning during the pandemic for students. In the field of engineering, a well documented example of an 'hands-on' lab for fully remote learning is the research project ELLI, "Excellent Teaching and Learning in Engineering Science", launched by the German Federal Ministry of Education in partnership with three universities. The project was initiated in 2011 and remains operational. It consists of a tele-operative mechanical engineering 'hands-on' lab for fully remote learning,

where students experience the technology and its limitations [7]. A different example is the fully online ABET accredited B.S. Software Engineering program offered by Penn State University [8].

The impact of online and hybrid and back-to-normal classes based on grades for Engineering courses has been reported. Ramo et. al. [9] combined synchronous, asynchronous and blended delivery of a biomechanical course for the Biomedical Engineering program at Shantou University in China. The article details the tools used by two instructors located in different continents and two different time zones co-teaching the technical course. The students viewed the online transition and tools as useful and easy to adopt. The only challenge was to encourage students to participate in discussion, which was resolved by the professor explaining to the students the benefit behind the discussion approach. A paper by Hosseini et. al. [10] assessed the impact of the pandemic and the online delivery on the grades at Ontario Tech University, Canada. The authors considered the Canadian Engineering Accreditation Board (CEAB), Graduate Attributes (GA) 'Knowledge Base' and 'Problem Analysis' as a reference for students' performance. In the GA 'Knowledge Base', the cohort of students with online delivery achieved 20% higher grades than pre-pandemic. The authors attributed this to students having more opportunities to practice their knowledge than the pre-pandemic. In contrast, the student performance for the GA of 'Problem Analysis', was similar. This was unexpected as students were permitted multiple attempts at similar assessment and were expected to perform better. Hosseini et. al. concluded that the collected data were not conclusive, therefore, more analysis is needed to adopt online teaching tools effectively and meet the CEAB requirements for accreditation. A study by Seshasai et. al. [11] compared the effect of online pandemic versus in-person pre-pandemic cohort performances. In this paper, four courses were reviewed, one math, two engineering science, and one programming based course. Although individual assessments had grade fluctuations the final grades were quite consistent for almost all courses, both online and in-person. The authors shared the response of the students during the online delivery format during the pandemic who felt that their learning was devalued, and preferred hybrid learning over full virtual model. The survey was given to Canadian and Spanish students, and it showed that Canadian students declared that their social wellbeing declined, compared to their counter Spanish students who did not see a change in in their social wellbeing.

Students grades pre-pandemic (in-persion) and during pandemic (online delivery) in a mechanical engineering program were reported by Grodotzki et. al. [12]. For the course 'Forming Technology II', the students' performance was similar for both, pre-pandemic and during pandemic. To eliminate the potential effect of the cohort academic aptitudes, the same cohort was compared during pandemic (Forming Technology II) and pre-pandemic (Forming Technology I). It was observed that the cohort experienced 10% increase in second semester (Forming Technology II) offering. The authors noted this was normal for most cohorts, whether online or in person. The authors concluded that the online teaching was not in any way substandard, compared to the in-person conventional learning [12].

The objective of this paper is to examine the impact of pre-pandemic and back-to-normal delivery of teaching design in the Biomedical Engineering co-op Program at the University of Waterloo. Three types of data are considered. The first data set is the instructors' perceptions on the impact of shifting to online teaching through a survey that covered changes made to course content delivery method, types of student assessments, grade shift. The second data set is the students' overall course grades for multiple terms which included conventional in-person, fully online, hybrid and back to fully in person in design courses and engineering science courses that include

design concepts. The third data set is the students' design specific assessments as defined by the Canadian engineering accreditation board (CEAB) for the design graduate attribute.

2. Background

At the University of Waterloo in Canada, within less than 48 hours notice, all courses were mandated to operate exclusively online effective March 16, 2020. The sudden mandate meant instructors at all levels had to immediately learn and adopt tools that could allow online teaching. Engineering programs at the University of Waterloo operates all year-round with 3 terms a year, 4 months each (Fall, Winter, and Spring). The Biomedical Engineering (BME) program is a co-op program, in which students alternate between academic and work terms with a total of eight academic terms and six work terms (Table 1). The BME is a design-centered program curriculum divided in four years, each year with two terms, term A and term B, consisting of 40 core courses, 7 of which are design focused and another 7 of which are engineering science-based courses with integrated design components. Following the shift to online, instructors needed to modify their delivery and assessments, as traditional lecture, tutorial and in person exams were no longer feasible. As the pandemic restrictions eased, course delivery shifted to hybrid approach, where courses were required to offer 1-1.5 hrs/week in-person and remaining weekly hours were delivered online. This allowed a transition to in person teaching, exam assessments, teamwork for project…etc. Instructors were required to accommodate remote learning, mostly synchronously for students who could not return to partial in-person instruction. In summary, the return to in-person teaching occurred gradually and varied between departments, programs. and even between courses in the same program. For the BME program, back-to-normal occurred on February 7, 2022. Table 2 provides details of the BME program instructions methods from fully online to back to in-class delivery.

Table 1: BME academic and work term (WT) sequencing

Fall	Winter	Spring	Fall	Winter	Spring	Fall	Winter	Spring	Fall	Winter	Spring	Fall	Winter
1A	1B	WT	2A	WT	2B	WT	3A	WT	3B	WT	WT	4A	4B

Table 2: BME instruction method during COVID by term.

Term	Student cohort	Instruction method, mandates & safety precautions
Winter 2020	1B / 3A / 4B	- On March 16, 2020, the University moved to online learning. Instructors decide on method of teaching and assessments.
Spring 2020	2B	- All courses were held online and delivered through a mix of asynchronous and synchronous teaching materials, up to the instructor choice.
Fall 2020	1A / 2A / 3B / 4A	- All courses were held online and delivered through a mix of asynchronous and synchronous teaching materials.
Winter 2021	1B / 3A / 4B	- All courses were held online with the requirement for synchronous components. - One BME elective course was permitted to operate in person in a large classroom to maintain social distancing, masks were mandatory.
Spring 2021	2B	- All courses were held online with some synchronous components.
Fall 2021	1A / 2A / 3B / 4A	- Many courses were held with 1.5 hour in-person instruction. Instructors were required to provide an online option for all course materials for students that were unable to come to campus (travel restrictions, contracted COVID -19, symptoms, etc.) - BME cohorts were scheduled to have two half days on campus (one and half hour in-person per course) with no overlap between cohorts. BME in-person classroom capacity was maintained at half to one-third in each room. Details provided in Safety section. - The University mandated proof of vaccination, mask wearing, and COVID-19 screening policies for anyone accessing the campus (including students, faculty, and staff) using a campus Check-in App. Cleaning and sanitizing procedures for classrooms, bathrooms, and common areas were enhanced.
Winter 2022	1B / 3A / 4B	- Due to the Omicron variant, the University's plans to return to fully in-person were delayed until February 7, 2022. Policies for vaccination, masks, and daily COVID-19 screening remained in place. There were no restrictions on classroom capacity. Students were expected to come to campus. Exams were held in-person, with make-up dates to accommodate for students with COVID-19 symptoms.
Spring 2022	2B	- All courses were held in person, with no restrictions on classroom capacity or accommodations to provide course materials online. Masks were still mandatory for all in indoor spaces, however the vaccine policy and daily COVID-19 screening was removed. Mask mandate was dropped on July 01, 2022

3. Methods

Instructor Survey

In May 2021 and October 2021, an anonymous survey was distributed to instructors who taught during the pandemic, to collect their feedback of the impact of COVID on course delivery. The survey was four multiple choice questions. The objective of the survey was to collect instructors' reflection on the overall course delivery, engagement and grades for lectures, tutorials, and lab courses. There were 20 BME instructors that provided input representing about 80% of BME

instructors. As the survey was anonymous and focused on course delivery it was not possible to identify those responses for instructors teaching 'design' courses from those responses of instructors who teach other courses such as mathematics or engineering science. The survey had open ended reflection question, where they had the choice to comment on the modifications made to their course deliverables during the pandemic and the multiple choice questions, instructors were allowed to select all that applies.

Students' Course Performance

The students' performance measured as the final course grades for the seven design courses and the seven engineering science courses with design components was collected before and during the pandemic and upon back to normal. The final cohort grades for the seven design courses were aggregated and they focused solely on design concepts. The final cohort grades for the seven-engineering science course were aggregated and included design components.

Students' Graduate Attribute Design Performance

The Graduate Attribute (GA) design is one of the twelve mandated GA by the Canadian Engineering Accreditation Board (CEAB) for the accreditation of Engineering programs in Canada. GAs is to measure what students have developed over the course of their studies. Each GA is represented by a set of measurable indicators that describe the competency of the student. [13]. Courses are identified where students develop the GA design at three different levels, introductory, developing and applied. Programs develop their own assessments (e.g. assignment, exam, report) and collect The definition of the design GA given by CEAB, and the indicators as defined by the BME program are listed in Table 3.

Student assessment for the three indicators of the design GA were collected before and during the pandemic and back-to-normal for three design focused courses representing first year, second year and third year courses. GA focused data were collected from a specific assessment or a rubric section of an assessment.

Table 3: Design graduate attribute (GA) CEAB definition and indicators

CEAB - Definition	Indicator	
The ability to perform engineering design. Engineering design is a process of making informed decisions to creatively devise products, systems, components, or processes to meet specified goals based on engineering analysis and judgement. The process is often characterized as complex, open-ended, iterative, and multidisciplinary. Solutions incorporate natural sciences, mathematics, and engineering science, using systematic and current best practices to satisfy defined objectives within identified requirements, criteria and constraints. Constraints to be considered may include (but are not limited to): health and safety, sustainability, environmental, ethical, security, economic, aesthetics and human factors, feasibility and compliance with regulatory aspects, along with universal design issues such as societal, cultural and diversification facets. [13]	Des.a	**Identify** needs, design requirements, constraints, and specifications for complex, open-ended engineering problems
	Des.b	**Generate** and **refine** potential solutions to complex, open-ended design problems, considering safety, ethics, and applicable standards and regulations.
	Des.c	**Critically evaluate** and compare design choices

The achievement of the students for the design GA was grouped in four levels (exceeding, meeting, marginally meeting and below meeting expectations), expressed as grades (Table 4).

Table 4: Achievement level of student for the design GA

Achievement Level	Grades
Exceeding Expectations	≥85% - 100%
Meeting Expectations	≥70% - <85%
Marginal	≥60% - <70%
Below	<60%

Triangulation of the three sources of data is utilized to validate if teaching design has been impacted by moving to online teaching, compared to in-person. Qualitative data were collected from specific assessments' grades in design courses, overall students' performance (final grades) in engineering design and engineering science courses against qualitative data in the form of instructors' perspective that were surveyed.

4. Results

Instructors' Perspective

The perspective of instructors was obtained from the response of the twenty BME instructors to a survey, on the impact of the pandemic in their courses. The survey was distributed in 2021 while classes were in hybrid mode, back-to-normal had not yet occurred. Instructors were asked to identify the changes in their course compared to pre-pandemic. A decrease of content and the removal of hands-on activities were the most common cited impacts, Figure 1a. Instructors were also asked to describe modifications made to their assessments during the pandemic. The most common adjustments were additional time given for assessment (more than normal), a flexible 24 hour start window for assessments (necessary to accommodate students in other time zones), and additional project work given (to mitigate cheating). Half of the instructors, 10 respondents, perceived that grades were higher, 7 responded as no change in overall grades, and 3 responded as unknown and 1 responded that grades were lower than normal in-person offerings, Figure 1c. Due to the anonymity of the survey, it was not possible to distinguish the responses of those instructors delivering design courses from those that taught other courses. The survey also asked instructors to comment, if they perceived that courses grades were higher during online teaching. The two most frequent comments were, the increased allocated time to complete assessments, and potential academic integrity issues, Figure 1d. With the lack of access to academic integrity data, it is not possible to verify if this perception is justified.

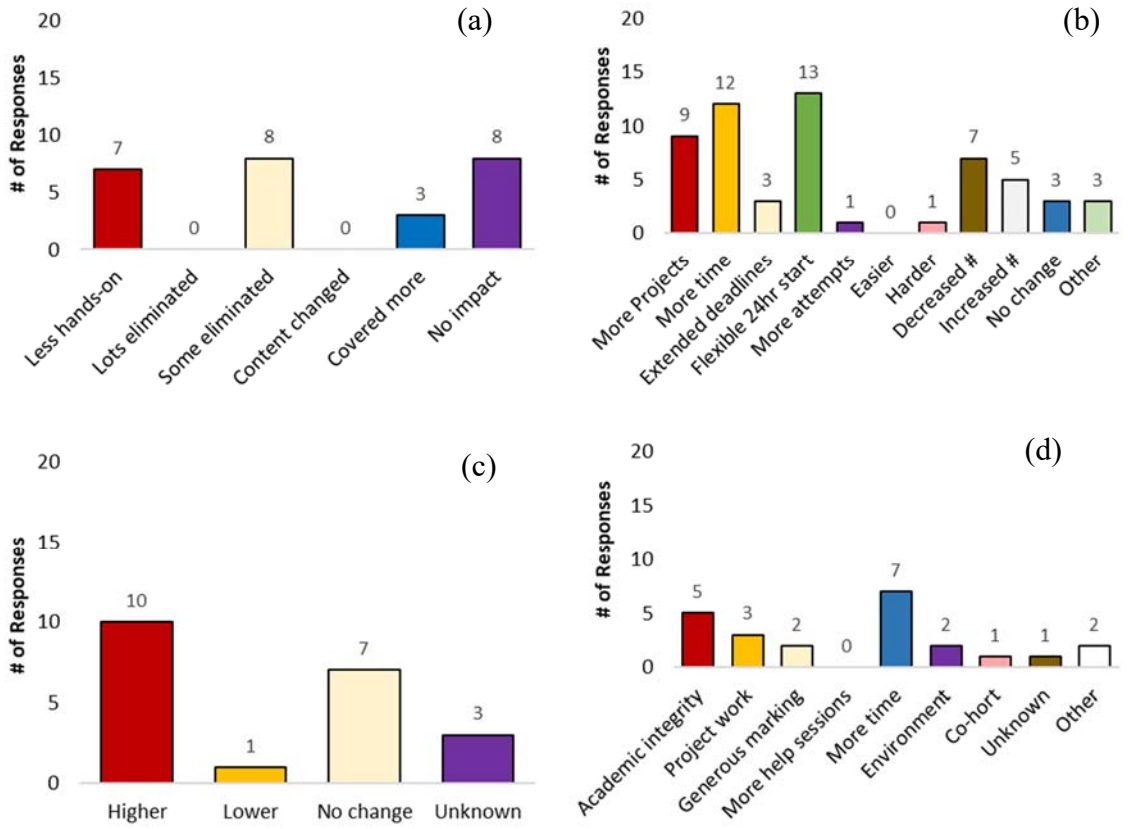

Figure 1: Instructor perceptions of the impacts of online delivery on their course (a) course content, (b) student assessments (c) student grades (d) perceived cause of perceived grade increase

Overall Student Performance

Final course grades were compared for each of the 7 design courses before, during and upon back-to-normal, Figure 2. Online and hybrid delivery are identified by the highlighted rectangles on the charts. The courses are identified by the level, 1A representing first year students to 4B representing 4th year students. Apart from 3A and 3B course during Fall and Winter terms, respectively, there was no significant change of cohort overall performance during the online pandemic teaching.

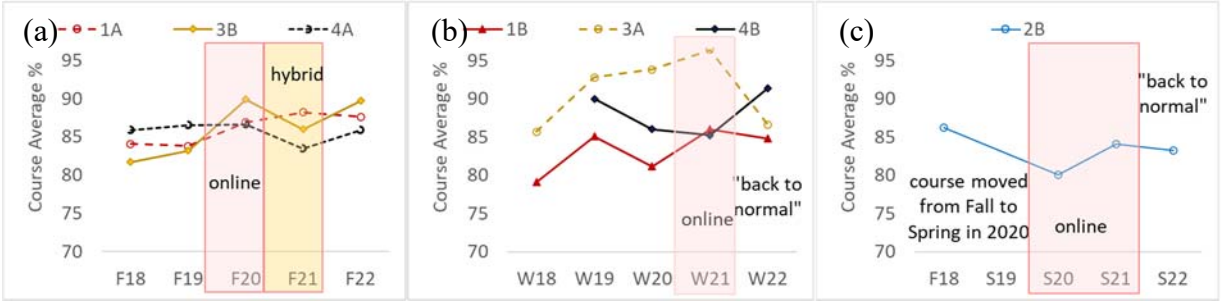

Figure 2: Final grade of BME design courses by term (a)Fall (F), (b)Winter (W), (c)Spring (S)

The final grades of the design focused course were compared to the final grades of courses with some elements of design, Figure 3. The courses are engineering science core courses. Differences in final grades due to the pandemic are observed with an immediate increase in grades during the pandemic with a gradual decrease as pandemic restrictions continued and further decrease upon back-to-normal. Final course grade increase during pandemic was observed for two different courses, for the same cohort (2B) in spring term.

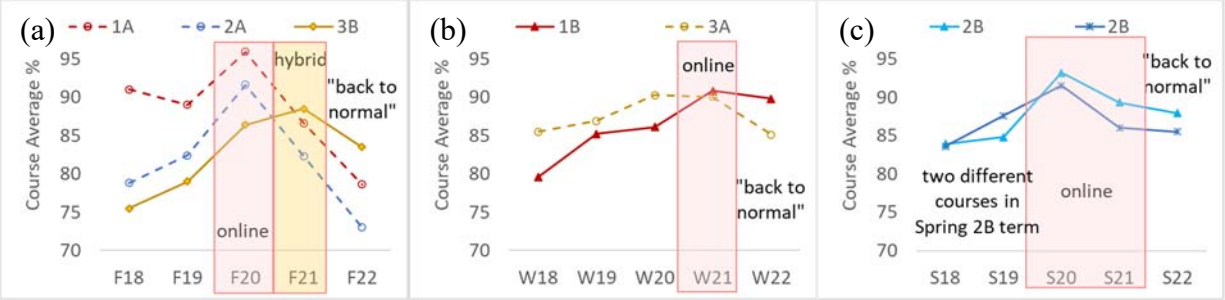

Figure 3: Final grade of BME engineering science courses with some design components by term (a) Fall (F), (b) Winter (W), (c) Spring (S)

The final course grades indicate differences according to course content. The final grades of the design focused courses remained relatively similar during the pandemic while the grades for the courses with design elements increased, particularly for the first online offering which may reflect the adaptation of the instructors to the new constraints of online teaching.

Design Graduate Attribute Assessment Data

The assessment data of the design graduate attribute collected in a first year, second year and third year design focused course will be reported in this section. It is to be noted that these selected courses represent a sample of the many courses in the BME curriculum that contain design components.

First year design course

The introductory first year design course was delivered by the same course instructor for the period presented in this paper. The performance of the students according to the expectation levels shown in Table 4 is presented in Figure 4 for each indicator of the design graduate attribute representing the three major steps of the design process (Table 3). The assessment consisted of a 'design showcase project'. All groups were given the same 'situation of concern', but each group was assigned one of six potential scenarios. Components of the project were graded, those grades were related to each of the design graduate attribute indicator (a, b, and c). Student performance was different according to indicator and in-person versus online offerings. In the needs assessment step of the design process (Indicator a) (Figure 4a), the relative number of student at the marginal level decreased in the online delivery compared to pre-pandemic while the relative number of students at the exceeding expectations level increased continuously from the online, to the hybrid and to the back to normal delivery mode. A different assessment profile was observed for the second and third steps of the design process, concept generation of possible solutions and critical evaluation of design choices (Indicators b, c), (Figure 4b, c). Data pre-pandemic were not available. In the online delivery, students were primarily meeting expectations. When students came back for hybrid teaching, which was partially online and partially in person, the relative

number of students who achieved meeting and exceeding expectations were nearly equally distributed, while in the back to normal in-person delivery, the relative number of students who achieved exceeding expectations increased slightly. This could reflect the benefits of in person environment for the ability to generate multiple potential solutions and the effect of students working together in person.

The potential relationship between the assessments of the design GA according to expectations levels and the final course grade of the 1A cohort (Figure 2) was investigated. There was a modest increase of the final course grade from 84% to 88% while the shift of students from 'meeting' to 'exceeding' was more substantial with 10-50% of the students shifting in to the 'exceeding' level even upon 'back to normal' delivery (Figure 4 a to c). Further investigation is required to better understand these observations.

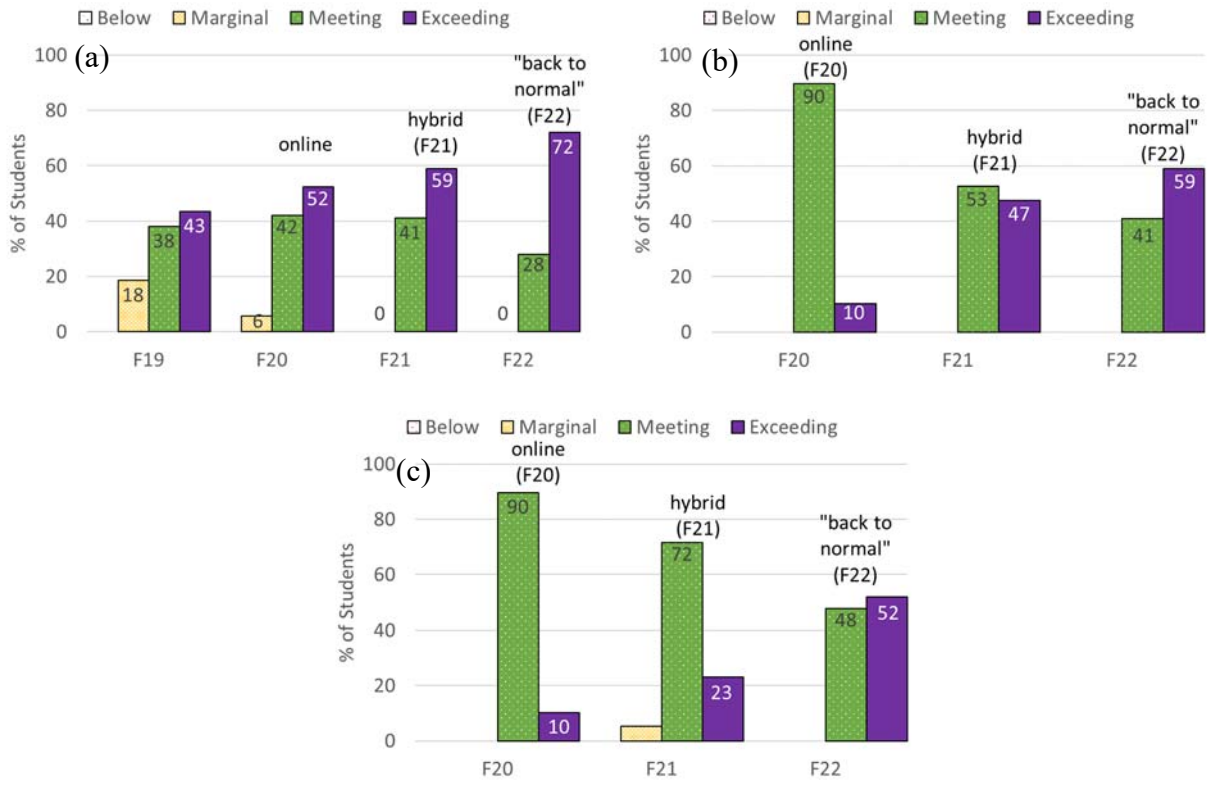

Figure 4: Student achievement level in first year design course (1A term) for each indicator of the design graduate attribute design. (a) Des.a. (b) Des.b. (c) Des.c.; F19 N=92; F20 N=107; F21 N=95; F22 =100

Second year design course

Figure 5 presents the student assessment level for a second year, 2B design course. This course had a different instructor in S22 term (returning to back to normal, in-person teaching). Students worked in groups and were given the same problem space and asked to create a component for a specific medical device with a defined problem. Groups had to design and build a prototype with

a maximum budget. The distribution of achievements levels for the assessment of the design section of the report for the critical evaluation and comparison of design choices (Des.c, Table 3) is presented in Figure 5. A significant increase in the relative number of students exceeding expectations, increased to 65% in S21 that was online, compared to 16% in F17 that was in-person. Upon back-to-normal delivery in S22, the exceeding expectations achievement level decreased to 43%, but remained well above pre-pandemic levels. The potential relationship between the assessment of the design GA according to expectations levels (Figure 5) and the final course grade of the 2B cohort (c) was investigated. Consistent student final course grade with a +/- 6%, which is within the typical average fluctuations across cohorts was observed which is different than the profile of the achievement levels of the design graduate attributes.

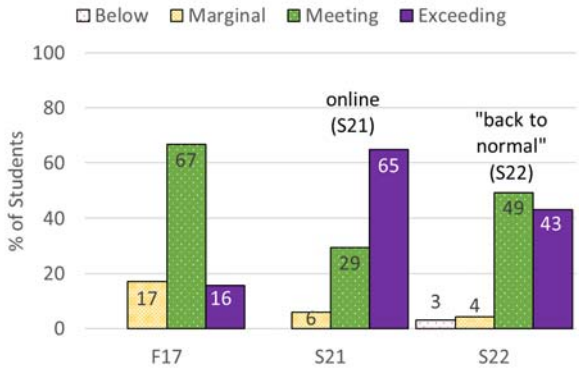

Figure 5: Student achievement level in second year design course (2B term) of the design graduate attribute indicator c (Des.c); F17 N=51; S21 N= 85; S22 N=97

Third year design course

Third year BME students (3B) start working on their capstone course (pre-capstone), which will be completed in their fourth year, by identifying the problem space and researching for information prior to the start of their 4th year. The course had the same instructor for all three terms (S18, S21, S22). The students' assessment level of the final report is shown in Figure 6. for the needs assessment (indicator a) and concept generation (indicator b). There was a significant increase in the relative number of students at exceeding expectations for the needs assessment component (indicator a) during the online offering (F20), which went back to a lower distribution during hybrid and back to normal offering (Figure 6a) while the concept generation component (indicator b), showed a similar distribution of expectations levels across all types of offerings, Figure 6b.

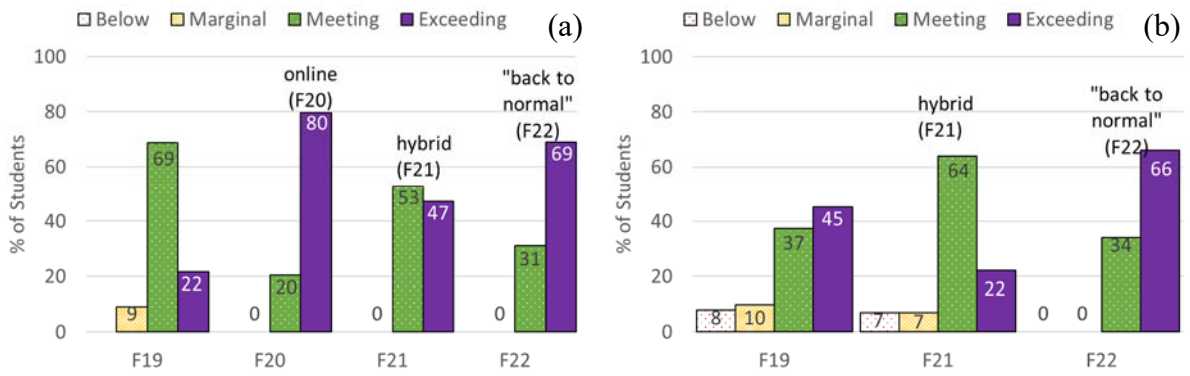

Figure 6: Student achievement level in an third year design course (3B term) for the indicators of the design graduate attribute. (a) Des.a (b) Des.b; F19 N=51, F20 N=59, F21 N=72, F22 N=71

The lack of trend for the student expectations levels for the indicators of the design graduate attribute for the 3B design course is different than what was observed for the final course grade (Figure 2a) of the 3B class where the final course grade remained relatively constant during the pandemic (+6%).

5. Discussion

The primary purpose of this paper was to investigate potential relationships between the perception of instructors on the impact of the course delivery on the student learning, the final course grades, and student performance against expectations level for three specific steps of the design process. The instructor perception collected from anonymous survey conducted in 2021 while hybrid course delivery was offered indicate that 47% of the instructors perceived that grade increased during the pandemic, while 33% perceived that grades did not change. This perception is not supported by the final grades of design focused courses which indicates minor increase (1A and 3B course) and minor decrease (2B course) from pre-pandemic to online and negligible changes when transitioning back to normal course delivery. The minor increase in grades were considered within the normal range of grade fluctuation between cohorts.

Differences according to delivery mode are more pronounced when looking at the distribution of the student achievement levels for each of the indicator (step of the design process) for the design graduate attribute obtained from the grades of specific assessments. Differences appear to be course specific. In the first-year design course, where the assessment was based on common situation of concern with groups investigating distinct scenarios, the relative number of students in the exceeding expectations level increased when transitioning from hybrid to back to normal delivery. In the second-year design course, based on a common problem space with groups having to create a component for a specific medical device with a defined problem, a different expectations level profile was observed with the relative number of students in the exceeding expectations level decreased when transitioning from hybrid to back to normal delivery. A similar decrease in the relative number of students in the exceeding expectations level when transitioning from hybrid to back to normal delivery was also observed in the third-year engineering design course, where students were asked to identify their own problem space and locate sources of information on this selected topic.

Engineering science-based courses, on the other hand, the online teaching showed a consistent increase in overall grades, up to 10%, Figure 3. Engineering science courses assessments are conventional, which would include individual assignments, quizzes, tests…etc. and possibly a term project. It is anticipated that students' need for in-person support, such as office hours might have impacted the students, compared to groups work and project-based courses. However, the design graduate attribute assessment of the engineering science course showed an increase in meeting and exceeding expectations, but data are inconclusive since the type of assessments have changed over the years.

The use of the final course grade and grades for targeted assessments of the design process support the instructor perceptions that there were impacts on grades and individual assessments from the pandemic, however, the impact varies by assessment and course type. Further work should examine the type of assessment and how teamwork and group interactions have occurred in design activities and courses during online, hybrid and back to normal course delivery.

The connection between students' performance in specific design assessment, relative to their overall performance in the course and instructors' perspective needs a systematic data collection to verify the presented observations, which is beyond the scope of this paper.

6. Conclusions

The pandemic was an overwhelming transition for both instructors and students. To better understand the effect of the pandemic for instructors and students, we have compared the responses of instructors collected in an anonymous survey to assessment results for three indicators of the design graduate attribute in three design focused courses. Nearly half of the instructors felt that course grades increased during the pandemic. This perception was not supported by the final grades of design focused courses where minor changes from pre-pandemic to online and negligible changes were observed when transitioning back to normal course delivery. Differences were observed for the distribution of the student achievement levels for each of the indicator (step of the design process) for the design graduate attribute obtained from the grades of specific assessments. These differences are course specific and would require further examination of the type of assessment and how teamwork occurred in the various delivery modes. An additional year of data will be required to understand and define back to normal delivery.

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