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Challenges and Opportunities for Higher Engineering Education During the COVID-19 Pandemic*

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The pandemic caused by COVID-19 had a profound impact on engineering education challenging both educators and students to innovatively continue the learning process and unveiling many of the issues hindering education systems' resilience. To explore the challenges to engineering education which were imposed by the COVID-19 pandemic, responses to the challenges, and the underlying reasons. The hypothesis is that these challenges overlaps with challenges to sudden change of instruction to become remote while belonging to four categories: Access and compatibility, Remote and hybrid assessment, Lab and experiential learning delivery, and interpersonal relations and support societies. The goal is to use the outcomes to propose themes for consideration in building a sustainable and resilient engineering education system.

Students' responses to a questionnaire were analyzed utilizing quantitative and qualitative tools. 124 engineering students volunteered to participate in the questionnaire. Results were coded and categorized to allow studying their interrelations. Challenges to engineering education caused by the COVID-19 pandemic were found to belong to three categories (performance, adaptation, and accessibility-and-compatibility). These categories are interrelated in a significant moderate positive correlation. Also, socio-economic status of students, life experiences and maturity levels, as well as availability of resources by location or other means, play a significant role in improving students' adaptation to rapid changes in the education process, and consequently affects their academic performance. Education systems aiming at becoming resilient can start by improved infrastructure and training programs related to advanced technology as well as enhancing levels of equity of access for their students.

Keywords: learning environment; engineering education during the pandemic; resilient education systems

1. Introduction

Unprecedented challenges at a global scale were brought to engineering education by the COVID-19 pandemic in year 2020. Higher education institutions were forced to change their modes of operation very quickly to accommodate social distancing through remote education, distance learning, or limited face-to-face instruction with extensive safety measures related to social distancing, in different format. Although remote education has been around for a while with proven advantages such as time flexibility and reduced physical constraints, it was not satisfying for many programs such as those having hands-on components, and it was not for every student in terms of individualized learning styles [1, 2]. Moreover, the challenge was not limited to this part, but extended to the idea of forcing a rapid change to modes of instruction without any preparation or training time by the students or instructors. This was evident even in evolving technology where platforms serving the few online education and communication operations had to suddenly increase capacity by orders of magnitude to accommodate this change [3]. With this change came new challenges, issues, and opportunities which have not been experienced or addressed before. These challenges cover many areas from technology upgrade, training, and adaptation to proper instructional delivery and from individualized learning styles to socio economic differentials and levels of equity [4, 5].

At the top of the challenges list is the educational platform used widely during the COVID-19 pandemic, which is digital learning. As was mentioned, digital learning has existed in higher education institutions for several years but rapid transition of most educational institutions to full digital learning as they scrambled to respond to the COVID-19 pandemic required adaptation to innovative technologies [5, 6]. This change required a transformation process that would give higher education institutions the opportunity to positively implement digital technologies, particularly in light of known barriers to this process such as those reported by Kopp et al. where they argued that change, pace, technology, capabilities and financing are considered barriers to digital change in higher education institutions [7]. Feldman noted three challenges in digital transformation of instructional operations during the period of Covid-19 pandemic [8]:

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1. The performance of academic students will have a negative impact as a result of the pandemic related anxiety.
2. The performance of academic students may be affected by racial, economic, and resource differences.
3. Instructors are unable to conduct high quality online training.

From the learners' side, disconnections from the internet and the use of old technological devices by either instructors or students cause disruption or prevention of proper online learning [9]. Moreover, the socio-economic conditions of students greatly affect students' ability to acquire access to technology including the internet [10]. Demirbilek noted that some students in low socio-economic class would rely on free internet and computers provided by their school. When using information and communication technologies (ICT) and digital devices to attend or conduct classes, students and instructors with low digital competencies are liable to lag behind in online learning [11, 12]. Add to this the different kinds of distraction related to the study setting, such as being at home or in a public place, and the lack of a cohort or group to consult, the already existing level of challenges is bound to increase with remote learning. From the instructors' and the institutions' side, the COVID-19 pandemic caused assessments to be conducted mostly online, hence, limiting instructors' ability to supervise remote exams and making it impossible to prevent or control cheating [13]. In addition, a heavier workload has been reported when modifying courses to be conducted online by instructors and on ICT units of the academic institutions as a result of this rapid and sudden digital transformation process. Meanwhile, Researchers have contested compatibility of online learning with fields such as engineering, where hands-on practical experiences and team interactions are required as part of instructional activities [14]. Nevertheless, according to Adedoyin et al., online learning has benefits, such as opportunities, flexibility, interactivity, and self-pace [14–16].

This paper is inspired by actual experiences and changes observed in engineering education during the COVID-19 pandemic. It includes a study aimed at identifying the most critical or dominating challenges in engineering education resulting from the COVID-19 pandemic. Moreover, the study aims at surveying the responses by students regarding these challenges and relevant solutions, as well as the reasons behind these responses. The starting hypothesis forming the base of the study is that challenges to engineering education and learning during the COVID-19 pandemic significantly overlaps with challenges to sudden change in instruction modes to remote learning and education. These challenges reveal many unresolved issues stemming from one of mainly four categories: Access and compatibility, Remote and hybrid assessment, Lab and experiential learning delivery, and interpersonal relations and support societies.

Ultimately, challenges and corresponding responses and reasons will be utilized to establish the basis for potential solutions to similar problems at a systematic level. The goal is to use the outcomes as a roadmap to propose themes for consideration in building a sustainable and resilient engineering education system. The following sections include a description of the theoretical framework of the study and an explanation of the methodology followed to conduct the study. This is followed by a presentation of the results combined with a discussion of the findings. Finally, a conclusion summarizing the findings is provided which could benefit the formation of a resilient engineering education system.

2. Theoretical Framework

Before the COVID-19 pandemic, some students chose online learning in order to adjust work and family schedules, to avoid long traveling distances to the classroom, and out of interest in an expanded selection of courses offered through online courses available to them [17]. But for most students online or remote education was not the correct mode of instruction as it severed their direct relation with peers and instructors and eliminated their classroom experience which was critical to their learning styles. Moreover, hands-on experiences and master-apprentice relationships which constituted a significant element of learning in most STEM areas were removed from the learning process leaving graduates with an inferior degree and lacking necessary training to perform their jobs as expected.

Several studies around the world have investigated the effect of COVID-19 on academic performance of university students. For instance, Gonzalez et al. reported that because of COVID-19 pandemic confinement the autonomous learning performance of students in higher education improved causing a significant positive effect on their academic performance, which helped students to enhance their efficiency and learning strategies to a more continuous habit [18]. Another study found that in underdeveloped countries, online classes cannot produce desirable academic performance because most students cannot access the Internet [19]. It was also reported that during the COVID-19 pandemic, students faced other problems such as response time, lack of face-to-face interaction with the instructor, and absence of social interaction and communication among students. Nevertheless, some literature reports revealed that students were satisfied with the support provided by teaching staff and public relationships of their universities during COVID-19 pandemic. Meanwhile, inadequate computer skills and a higher workload prevented students from realizing their own improved academic performance in online learning during COVID-19 pandemic. Moreover, students with certain socio-demographic characteristics were significantly less satisfied with their academic performance [20].

3. Research Goal and Questions

This study aims at exploring the most critical or dominating challenges during the COVID-19 pandemic in engineering education among engineering students, as well as students' responses regarding corresponding measures taken to adapt to this situation. This will help in enhancing the understanding of reasons behind the various challenges, related responses, and students' perceptions. Therefore, the following questions were derived from the research goal:

During the COVID-19 pandemic:

- To what extent was engineering students' performance affected by access to resources and compatibility?
- To what extent did engineering students and instructors adapt to changes in modes of instruction and other life changes, and how did that affect their performance?
- What is the interrelation between the different categories of challenges and related responses during the COVID-19 pandemic?
- What were the most problematic or challenging issues when engineering students had to accommodate changes in their education process due to the COVID-19 pandemic?

4. Methodology

The methodology implemented to conduct this study included both quantitative and qualitative instruments. A questionnaire was designed to investigate and verify the starting hypothesis by directly asking students a variety of questions regarding their experience in engineering education during two semesters of the COVID-19 pandemic. Following are related details.

4.1 Participants

The total number of students who responded to the questionnaire was 124 engineering students from The University of Texas at Tyler (UT-Tyler). This includes 73 (59%) students from UT-Tyler-Main Campus (TYL) and 51 (41%) students from UT-Tyler-HEC (HEC). Demographics of the participating students are presented in Table 1. The ratio between male and female students was 4.2 (81% male and 19% female) in TYL which is close to national average, while the ratio between male and female students in HEC was 1.8 (65% male and 35% female), which is higher than national average of gender ratio in engineering programs and closer to international averages of the same ratio. Also, the HEC population includes more diversity compared to TYL population. Geographically, TYL campus is located in a relatively small rural city while HEC campus is located in the middle of an enormous major city.

In terms of academic distribution, Table 2 presents the departments of the participating students while Table 3 shows their distribution among the four classes of study (freshman, sophomore, junior, and senior). In addition, three graduate students responded and filled the questionnaire. It is to be noted that HEC campus hosts mostly junior and senior students who have completed their first two years of study in a different college, usually a

Table 1. Demographics of participating students responding to questionnaire of COVID-19 effect on the learning process

Demographic	TYL Campus	HEC Campus
White	60%	20%
Hispanic	26%	43%
African American	3%	6%
Asian	7%	27%
Other	4%	4%
Total	73 (59%)	51 (41%)
Male	81%	65%
Female	19%	35%

Table 2. Distribution by department of participating students responding to questionnaire of COVID-19 effect on the learning process

Department	TYL Campus	HEC Campus
Civil Engineering	18	13
Construction Management	15	0
Electrical Engineering	11	11
Mechanical Engineering	26	27

Table 3. Distribution by class of participating students responding to questionnaire of COVID-19 effect on the learning process

Class	TYL Campus	HEC Campus
Senior	14	28
Junior	33	22
Sophomore	14	1
Freshman	9	0
Graduates	3	0

community college, before transferring to UT-Tyler. The advantage of having majority respondents from upper classes is in the increased possibility that these students have been in college before the two semesters during the COVID-19 pandemic and therefore can make a comparison between the two different times.

Participants were also asked about the average size of the classes they were in as they have experienced changes in instruction modes due to the COVID-19 pandemic. Over 60% stated that they were in classes hosting between 15 and 30 students and another 30% stated that their classes hosted between 31 and 45 students.

4.2 Procedure

Both quantitative and qualitative methods were utilized in this study. Following the fall semester of the academic year 2020–2021, where COVID-19 has been around for at least two semesters, and during the first week of the spring semester of the same year, an anonymous questionnaire was distributed to students electronically where 124 engineering students (N = 124) filled out this self-reporting questionnaire. All answers were coded into three categories based on the research questions which are: performance, adaptation, and access-and-compatibility. As part of the quantitative analysis of the categorized answers, the correlation coefficient between answers in these three categories was calculated. The Kolmogorov–Smirnov test of normality (goodness of fit) showed that a normal distribution can be assumed for all variables ($p > 0.05$). Therefore, One-way MANOVA and Pearson correlation coefficient were calculated. In addition, two experts in engineering education coded the qualitative data (observations and open questionnaire question) and classified them into these categories using directed content analysis [21].

4.3 Instruments

The self-reporting questionnaire which was composed specifically for this research comprised of six questions (22 statements) and one open question. Table 4 presents all the items for which students' evaluation of their experience during the pandemic was requested in the questionnaire. Seven of the 22 statements referred to performance and motivation in the context of different modes of instruction, another set of seven state-

Table 4. Exploratory factor analysis of the 22 Items of the self-reporting questionnaire

Items	**Factor**						**Categories**
	1	2	3	4	5	6	**Performance**
Academic performance	**0.783**						
Fitting education with your other changing responsibilities	**0.755**						
Staying motivated to do well in the courses	**0.740**	0.309					
Your motivation to learn	**0.697**	0.323					
Level of distraction from course work	**0.636**	0.352			0.429		
Your performance on Quizzes and Exams	**0.566**	0.419	0.373				
Quality of online products (Audio, Video, Zoom, etc.)	0.487	0.365	**0.389**				**Access-and-compatibility**
Remote lectures	0.486	**0.709**					**Adaptation**
Remote quizzes and exams		**0.704**					
Remote labs		**0.681**				0.335	
Remote discussion / tutorial sessions / group meetings		**0.661**	0.525				
Quality of instruction	0.398	**0.636**		0.327			
Quality of your engagement	0.367	**0.611**					
Knowing where to get help with the course		**0.557**		0.429	0.313		
Ability to interact with other students			**0.687**	0.331			**Access-and-compatibility**
Availability of a quiet place to study	0.395		**0.678**				
Availability of connection to the internet	0.384		**0.677**				
Ability to interact and communicate with instructors and Tas		0.445	**0.658**	0.365			
Ability to do labs in person				**0.802**			**Adaptation**
Continuity of the educational process (teaching, learning, assessment)				**0.641**			
Study workload					**0.870**		**Performance**
Availability of digital equipment (phone/tablet/laptop/computer)						**0.933**	**Access-and-compatibility**

ments referred to adaptation to these mode changes, and the remaining eight statements referred to access-and-compatibility related to these modes. The open question was about most problematic or challenging issues when students had to accommodate changes in their education process due to the COVID-19 pandemic. The questionnaire was validated by two experts in engineering education. The internal consistency, or coefficient of reliability, of the 22 statements (Cronbach's $\alpha = 0.928$) was found to be excellent. A sample of the statements in the questionnaire is displayed in Appendix A. The 22 statements relating to changes in modes of instruction were factor analyzed using principal component analysis with Varimax (orthogonal) rotation to help verify their relation to principal factors [22].

The analysis yielded six factors explaining a total of 70.24% of the variance for the entire set of variables. As shown in Table 4, factor 1 was comprised of 7 items reported on a 5-point Likert scale that explained 42.67% of the variance with factor loadings from 0.566 to 0.783. Factor 2 was comprised of 7 items that explained 6.73% of the variance with factor loadings from 0.557 to 0.709. Factor 3 was comprised of 4 items that explained 5.86% of the variance with factor loadings from 0.389 to 0.678. These three factors correspond directly to the original categories derived from the research questions. Factor 4 was comprised of 2 items that explained 5.86% of the variance with factor loadings from 0.641 to 0.802. Also shown in Table 4 are factors 5 and 6 where each had only one item. Items related through factors 4, 5, and 6 were re-aligned by two engineering education experts with factors 1, 2 and 3.

Qualitative data from daily observations while conducting engineering education and from open questionnaire question were collected, coded and classified. Internal Review Board (IRB) approval to conduct the questionnaires for this study was requested and an exemption was granted explicitly on January 12, 2021 from the IRB committee at UT-Tyler.

4.4 Procedure and Results

Based on the authors' daily observations while conducting engineering education during the COVID-19 pandemic, as well as the literature summarized previously, a starting hypothesis was set to initiate this study which states that challenges to engineering education and learning during the COVID-19 pandemic significantly overlaps with challenges to sudden change in instruction modes to remote learning and education. These challenges reveal many unresolved issues stemming from one of mainly four categories as follows:

(1) Access and compatibility: in this category, socio-economic factors such as students' access to ICT resources, as well as other means and resources like a quiet place to study, while being free from extra life constraints and requirements such as family demands, which also have changed during the pandemic, are considered major influencing factors on the learning process, students' performance, and engineering education during the COVID-19 pandemic.
(2) Remote and hybrid assessment: in this category, changes in assessment methods forced by the COVID-19 pandemic situation are considered to have had the most influence among changes in the different parts of modes of instruction causing challenges in quality, motivation, and performance as well as equality and justice in the engineering education process.
(3) Lab and experiential learning delivery: in this category, focus is on a critically important element in a field like engineering which had to experience significant changes to adapt to the new situation bringing many questions to its flexibility and effectiveness as well as the effect of these changes in the quality of students' education and performance.
(4) Interpersonal relations and support societies: in this category remote learning is considered to have caused a loss of interpersonal relations as well as interactions with, and ability to form, support groups and societies, which are known to be critical to students' motivation and the educational process in general. This caused students' performance deterioration. Relations between students and instructors, or students and peers, were challenged when interaction modes became mostly through electronic devices causing a significant difficulty to learners, and sometimes to instructors, seen not just on performance, but also on the mental and psychological state of individuals.

These four components formulate the roots of the challenges facing the entire engineering education process as students and instructors try to adapt to rapid changes of the traditional education practices and modes of instruction. The level of adaptation by either students or instructors will ultimately influence students' motivation and performance as well as the quality of instruction and the quality of the students' learning. These influences and effects are not sequential but rather reciprocal generating a circular type of interaction such as the one seen where performance of a student influences motivation and motivation influences performance simultaneously. Therefore, detecting the root cause of challenges and verifying the hypothesis can be established by observing performance levels and adaptation levels as students' and instructors navigate through any changes to instruction modes, levels of accessibility and compatibility to implement these changes, and any other accommodations that were needed at the students' or instructors' side to adapt to changes.

Anonymous questionnaires were opened for all engineering students at UT-Tyler in the form of a Qualtrics® questionnaire. Students were invited to fill the questionnaires within a week period at the beginning of the spring semester of 2021. To extract all potential useful information from these results some sorting was attempted based on exiting factors of grouping which could also provide the reasons for certain answers. Consequently, students' answers were grouped from the questionnaires allowing calculation of the mean score *M* (ranging between 0 and 5) and the standard deviation *SD* for each group of students. The first grouping attempt was by splitting TYL campus and HEC campus students into two separate groups and comparing their results in relation to the three categories of focus from the research questions. As shown by Table 5, the descriptive statistics (*M*, *SD*) were calculated for all possible groups.

These statistics were used to conduct an independent samples T-test between the populations of the two campuses. The T-test revealed a significant difference in students' performance scores between the two campuses $t(122) = -2.73$, $p < 0.005$; a significant difference in students' adaptation scores to different aspects of instruction between the two campuses $t(122) = -4.29$, $p < 0.001$; and a significant difference in students' access-and-compatibility scores between the two campuses $t(122) = -2.39$, $p < 0.05$. Therefore, grouping the results based on campuses seemed like a logical choice to help answer the research questions and compare the results from these two groups for better understanding and insight. These observed differences in questionnaires' answers between the two campuses can be attributed to many factors. One major factor is campus location where the HEC campus is located in the middle of a significantly large city of CITY. This city has a population of almost nine Million. Consequently, access-and-compatibility are always available and choices of resources are in abundance. In comparison, TYL is located in a small city in a rural area with less access and choice of resources such as a limited internet provider. Another factor is the composition of student body in each campus. HEC students are more diverse in terms of ethnicity and are more mature with a relatively wider life experience and ability to adapt compared to students in TYL, as shown in Table 1. In addition, TYL students have a higher contingent of First Time in Any College Students (FITAIC) and include lower class students as shown by Table 3. This could explain the need for more levels of interaction with peers and instructors by the TYL population compared to the HEC population.

One potential factor causing the observed difference in answers between HEC and TYL groups could be intrinsic. This factor comes from the reciprocal nature of influence between performance, motivation, and access-and-compatibility. This factor is not easy to characterize as it slowly propagates, and negatively influences, back and forth between the three research categories of performance, adaptation, and access-and-compatibility. As a result, this factor causes students' resilience to erode slowly, which shows on performance. To explore this factor, a correlation coefficient analysis was carried out between these three categories of research. As shown in Table 6, results of the Pearson correlation coefficient between the three categories (performance, adaptation, and access-and-compatibility) indicate that there was a positive, moderate and significant association between the three categories among the TYL answers while a positive, high, and significant association was revealed between the three categories among the HEC answers.

This result is expected at different levels depending on the level of interaction between the different changes to the engineering education process which

Table 5. Descriptive statistics for students' answers grouped by campus and by department

		Performance		Adaptation		Access-and-compatibility	
Campus	N	*M*	*SD*	*M*	*SD*	*M*	*SD*
TYL Campus	73	2.62	0.75	2.53	0.74	3.03	0.57
HEC Campus	51	3.01	0.81	3.15	0.86	3.31	0.71
Civil Engineering & Construction Management (TYL)	34	2.52	0.68	2.40	0.79	2.98	0.65
Civil Engineering & Construction Management (HEC)	13	2.93	0.60	2.94	0.85	3.22	0.51
Electrical Engineering (TYL)	14	2.91	0.79	2.80	0.66	3.08	0.54
Electrical Engineering (HEC)	11	3.07	0.92	3.22	1.02	3.64	0.78

Table 6 Pearson's correlation coefficient between the three categories in focus

Categories	TYL Campus (N = 73)		HEC campus (N = 51)	
	r	p	r	p
Performance – adaptation	0.624	< 0.01	0.789	< 0.01
Performance – access-and-compatibility	0.560	< 0.01	0.801	< 0.01
Adaptation – access-and-compatibility	0.586	< 0.01	0.726	< 0.01

was experienced by these populations during the pandemic. The difference in perceptions between populations is dependent upon many elements residing in the composition of each student's frame of reference, past experiences, and ability to adapt to change. These elements cannot be completely decoupled causing interrelations and interdependencies to exist between the three categories in focus.

To test if there is a difference between the results from populations of different departments, data from Table 5 was used to conduct a one-way MANOVA test. The test revealed that no significant difference in students' scores exists between the engineering departments at TYL campus ($F(6, 136) = 0.80$, $p > 0.05$; Wilk's $\Lambda = 0.993$) and at HEC campus ($F(6, 92) = 1.52$, $p > 0.05$; Wilk's $\Lambda = 0.827$). Different engineering departments and disciplines have similar modes of instruction, bases of education, and techniques of delivery. Therefore, these results are highly expected within one university and even between different universities. These results supported the decision to group information based on campuses and use this as a platform for comparison while conducting further investigation of the answers.

Guided by the previous findings, students' direct answers were divided into groups based on their campus to facilitate further studying and exploration of findings. Fig. 1 shows students' perception of the effectiveness of remote instruction during the pandemic in HEC campus while Fig. 2 shows the same information from students in the TYL campus.

While both groups seem to agree that discussion groups and tutorials as well as quizzes and exams during remote instruction were relatively more effective, or as effective as they were before changes were introduced due to the pandemic, the group in TYL expresses a fairly lower evaluation of effectiveness of the different aspects of remote instruction compared to the HEC group. Another agreement between the two groups is when rating the effectiveness of remote instructions of labs and lectures. Labs were rated the least effective by both groups and lecture followed as the second least effective. Further exploration of questionnaire information might help explain the reasons for these ratings. Therefore, the following part of the answers to the questionnaire was investigated. In this part, students were asked to rate their satisfaction with the different aspects of their engineering education during the pandemic. A question including six statements was proposed for students' rating on a 5-point Likert scale requesting that they rate their level of satisfaction with the following different aspects of instruction in their engineering courses after COVID-19 started:

1. Quality of instruction.
2. Quality of their engagement.
3. Level of distraction from course work.

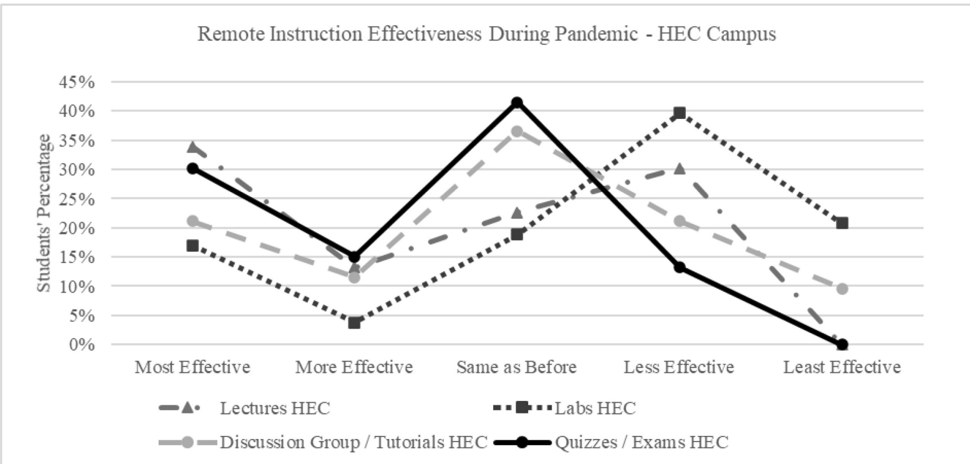

Fig. 1. Students' perception of the effectiveness of remote instruction during the pandemic, HEC campus.

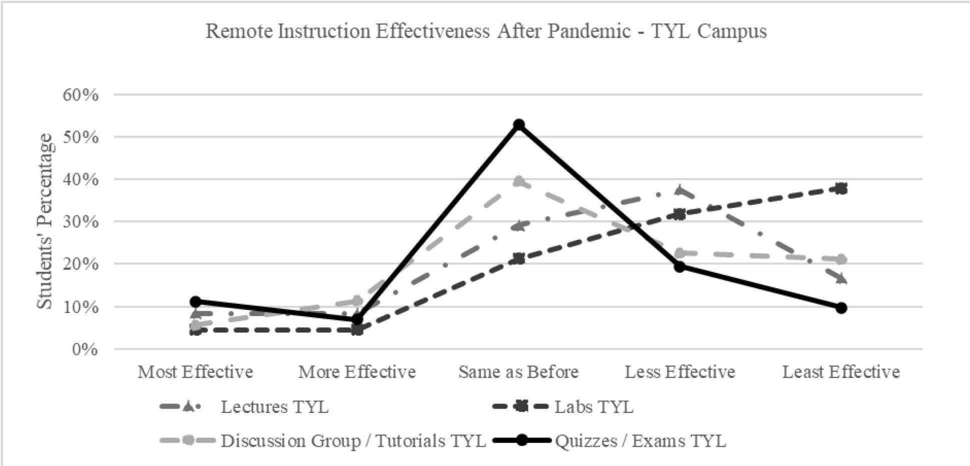

Fig. 2. Students' perception of the effectiveness of remote instruction during the pandemic, TYL campus.

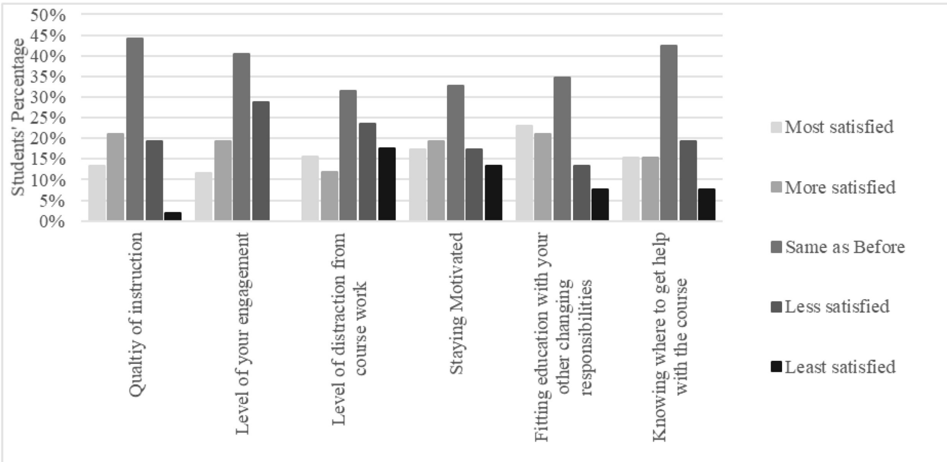

Fig. 3. Students' level of satisfaction with different aspects of their education during the pandemic – HEC campus.

4. Staying motivated to do well in courses.
5. Fitting education with their other changing responsibilities.
6. Knowing where to get help with the courses.

Fig. 3 shows the related information from the HEC campus, while Fig. 4 shows the related information from the TYL campus. Results from these figures show that HEC group satisfaction was relatively higher than that of the TYL group. In each statement of the question almost half the population in both sides expresses no change in their level of satisfaction compared to their experiences before the pandemic. The least satisfaction from the HEC group was with their level of engagement in the changing instruction modes and with the distraction from course work, while from the TYL group the least satisfaction was in staying motivated and with the distraction from course work as well as in fitting education with other changing responsibilities.

Remarkably, the most satisfaction expressed by the HEC group was in fitting education with other changing responsibilities, which is opposite to the response from TYL group. Such difference in answers is expected considering the wider life experiences and higher maturity levels of the HEC group which help in increasing their adaptability. This also confirms the relatively higher resilience notion of the HEC group compared to the TYL group. Comparing the level of satisfaction with staying-motivated to the levels of satisfaction with access to help, engagement, and distraction from course work, a directly proportional relationship can be detected between change in motivation and change in engagement as well as change of access to help. Meanwhile, an inversely proportional relation can be detected between change in motivation and change in the level of distraction from course work. This can be observed more clearly in the answers from the TYL group. This confirms the interrelation proven earlier and quantified in Table 6

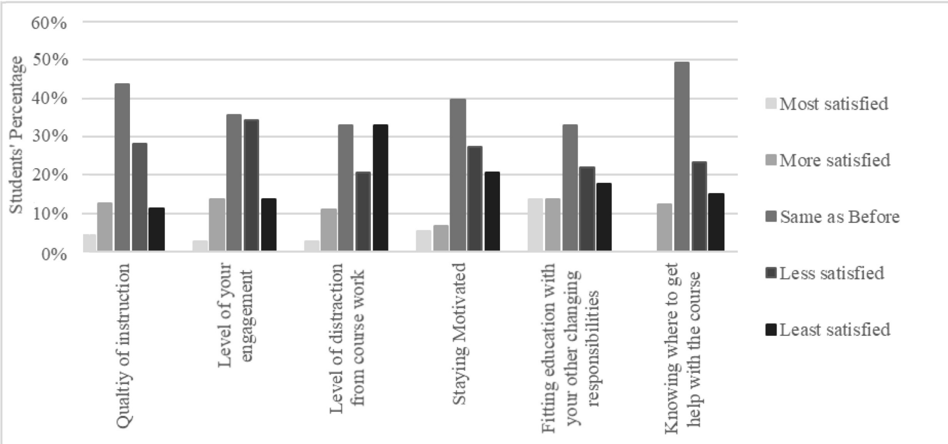

Fig. 4. Students' level of satisfaction with different aspects of their education during the pandemic – TYL campus.

between the three categories of performance, adaptation, and access-and-compatibility.

In a following part of the questionnaire, students were asked to provide their assessment of how changes in different elements related to their learning influenced their engineering education process and performance during the COVID-19 pandemic. These elements were:

1. Availability of connection to the internet.
2. Availability of digital equipment (computer, laptop, phone, tablet).
3. Availability of a quiet place to study.
4. Ability to interact and communicate with instructors and TAs.
5. Ability to interact with other students.
6. Performance on quizzes and exams.
7. Quality of online products (Zoom, Audio, Video, etc.).
8. Motivation to learn.
9. Ability to do labs in person.

Results from the HEC group are presented by Fig. 5 and results from the TYL group are presented by Fig. 6. A prominent assessment result that both groups agree on is the highly negative influence on learning that was experience due to students' inability to conduct lab work in person. In the HEC group over 45% of the population provided this assessment while in the TYL group almost 40% of the population agreed with this assessment. Also, both groups seem to agree, at different levels, on the influence of digital equipment availability, internet access, and availability of a quiet place to study on their learning. Almost half the population from both groups assessed the influence of having access to these three elements as being positive. However, the level of influence on learning by the ability to interact with peers seems to be significantly higher with the TYL group than the HEC group. Over 60% of the TYL group expressed negative influence on their learning due to the lack of peer interaction. With the HEC group this the negative influence was expressed by almost 40 % of the population. Also, the two groups exhibit

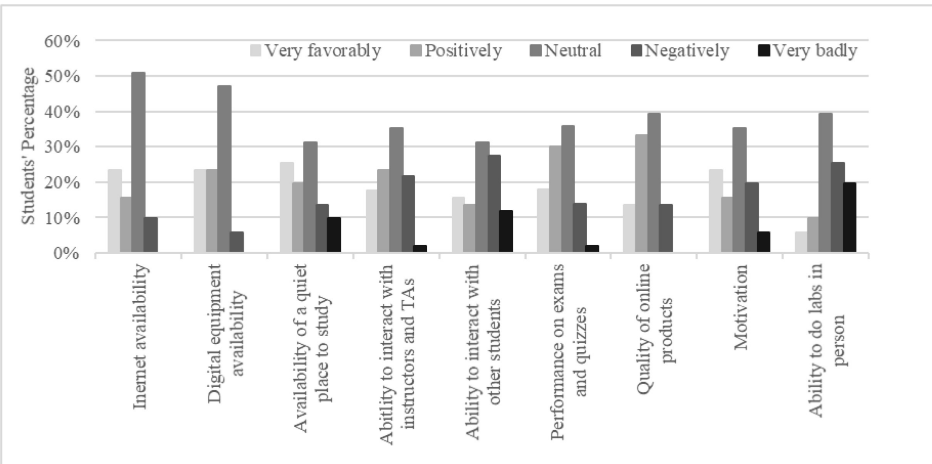

Fig. 5. Students' assessment of the influence of change in different elements on their learning during the pandemic – HEC campus.

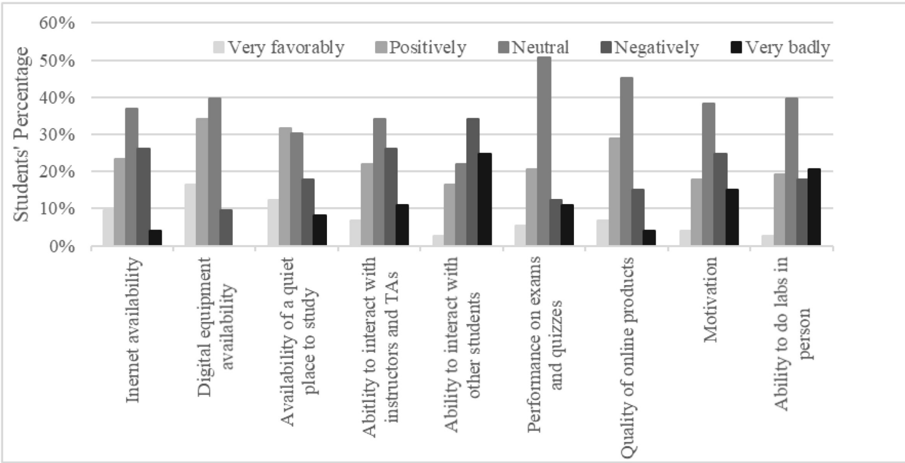

Fig. 6. Students' assessment of the influence of change in different elements on their learning during the pandemic – TYL campus.

remarkably different assessment levels of motivation-to-learn influence on learning where the TYL group shows a highly negative influence of motivation which is opposite to the HEC group.

The questionnaire had another question where students were asked to assess their academic performance during the pandemic in comparison to how it was before the pandemic. Fig. 7 shows the results from both campuses and a combined result as well. Combined answers from both campuses seem to show an equal distribution of the majority around expressing no change in performance. However, when separating the answers of HEC and TYL, the TYL group expresses more deterioration in performance compared to the HEC group. This indicates that the TYL group is more resistant to change or less adapting than the HEC group.

To uncover more results a qualitative instrument was employed by exploring the answers to the open-ended question in the questionnaire which required that students describe in their own words the most challenging issues they faced as they tried to accommodate changes to the education process due to the COVID-19 pandemic. These results were coded and categorized under the three researched categories as shown by Table 7. The first observation from this table confirms the interdependencies or interrelations between the three research categories (performance, adaptation, and access-and-compatibility) which was uncovered using quantitative analysis summarized in Table 6. As an example: a repeated complaint by students is that lack of interaction with instructors, teaching assistants, and mostly peers had a negative effect on their performance. Moreover, the same item was a reason for their reduced adaptability to the changes imposed by the pandemic. Along the same lines and because of the same reason, students did not have accessibility and did not achieve compatibility during the education process. Therefore, the lack of interaction established an interdependency between performance, adaptation, and access-and-compatibility.

When looking deeply into the answers by students in Table 6, it seems to fairly indicate that

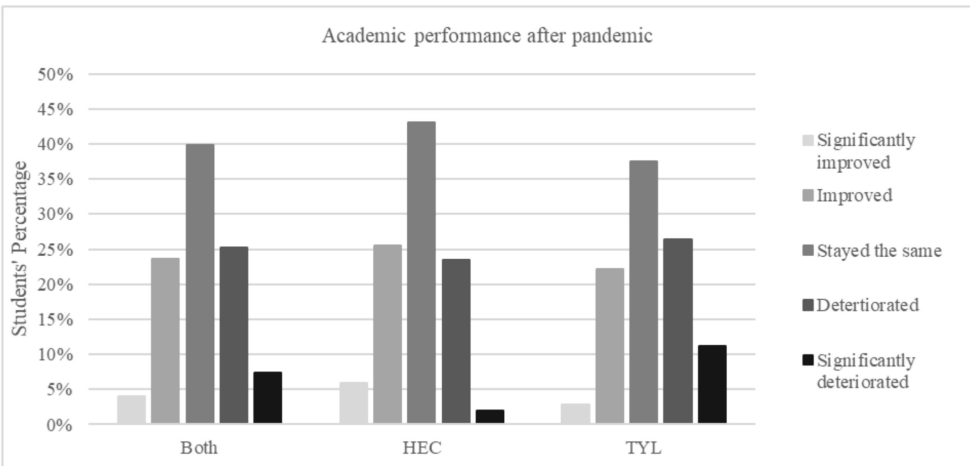

Fig. 7. Students' assessment of their academic performance status during the pandemic.

Table 7 Interdependence between performance, adaptation, and access-and-compatibility as seen in students' answers to the open ended question of challenges in accommodating changes due to the pandemic

Items	Challenges and Opportunities		
	Performance examples	**Adaptation examples**	**Access & compatibility examples**
Online lectures	The in-person dynamic is impossible to simulate via the web. Being distracted so often and not being able to concentrate appropriately.	Trying to stay focused when listening to the lectures on zoom, or during a pre-recorded lecture.	Teachers online lessons being impossibly monotone and lacking any sort of interaction.
Schoolwork and study the material	The most difficult thing was being stuck in the same desk 12+ hours a day for work, studying, and lectures.	Main problem I face is my ability to focus on schoolwork and study the material as thoroughly as before.	Finding a quiet space at home to study and have meetings.
Interact and communicate with instructors and TAs	Professors needed some training on how to use remote learning tools. Furthermore, they needed better funding for tablets to allow for better note taking during lectures.	I am a hands-on learner so having to force myself to somewhat become a visual/ auditory learner was probably the hardest part for me.	Not having as much interaction as normal with professors and TAs.
Connection to the internet	Quizzes and in class examples used as busy work.	It is harder to pay attention to lectures because of the technical problems and connection issues.	My internet connection was often weak, making online learning harder than it needed to be.
Interacting with other students during group activities	It is difficult for me to meet other students in the first place because I am introverted and one of only a few females. The pandemic has made it even harder to meet new students, making it difficult when I need to choose a group for a project.	The inability to meet with students one on one makes studying more difficult.	Staying engaged while surrounded by distractions. Lack of communication with other students.
Flexibility	Remote classes improved my grades.	I work full time so being able to zoom and watch recorded lectures has been beneficial for me.	It removed the loss of time since there was no commute which provided the needed flexibility to be successful in class and at work.

learning styles and personal preferences have a significant effect on the entire educational experience they had during this pandemic. On the positive side, remote learning seems to have served a few students as it allowed them the flexibility needed to organize their schedule and accommodate education tasks leading to better achievement.

5. Discussion

This study was set out to investigate the effect of changes imposed by the COVID-19 pandemic on students' learning and the entire engineering education process. The study aimed at identifying the most critical or dominating challenges and the underlying reasons behind these challenges. Therefore, various corresponding students' responses and opinions regarding these challenges and related responses were surveyed. All challenges, solutions, and responses were found to belong to three categories: performance, adaptation, and access-and-compatibility. The final goal was to present the outcomes of the study as a roadmap to propose themes for consideration towards building a sustainable and resilient engineering education system that is robust and flexible enough to handle sudden interruptions similar to the COVID-19 pandemic.

The theoretical framework resulted in a hypothesis stating that challenges resulting from changes in engineering education, in response to the pandemic, partially overlap with challenges related to implementing remote learning rapidly. These challenges stem from four factors which are: accessibility and compatibility, remote assessment, experiential learning, and interpersonal interactions and support societies. This hypothesis was proven by this study in the majority of its parts, except the challenge related to remote assessment. The majority of students did not seem to see it as a challenge because intuitively this is seen as a burden from the instructor side. The relation between students' performance and accessibility as well as compatibility (accessibility-and-compatibility) was investigated as part of this study. Also, as part of the research goal the relation between performance and students' ability to adapt to change in instruction modes and related life changes during the pandemic was investigated. Ultimately, this required investigating the correlation between the three research categories of performance, adaptation, and accessibility-and-compatibility.

The study included collecting students' answers to an open question describing the most challenging issues in accommodating to changes resulting from the pandemic in their engineering education. As was mentioned, these results were collected and coded in the same research categories as challenges and opportunities as shown in Table 7.

The methodology to conduct the study implemented mixed quantitative and qualitative methods utilizing an anonymous questionnaire. A group of 124 engineering students chose to fill and return this questionnaire. These students were from different engineering disciplines and in two geographically separate campuses. Results from the two campuses were different but no difference was detected based on the students' different disciplines. The questionnaire targeted the three research categories of performance, adaptation, and accessibility-and-compatibility.

Results of this study revealed that the socio-economic status of students, life experiences and maturity levels, and availability of resources by location or other means, play a significant role in improving students' adaptation to rapid changes in the education process. Moreover, diversity among the students provides a positive effect when it comes to adapting to changes. This adaptation reflects positively on the performance of students and their level of satisfaction with their educational experience. Since the collective of results from this study showed that performance and motivation, adaptation to change, and accessibility-and-compatibility are highly interdependent with a reciprocal type of relation, it is expected that each of those categories influences the others proportionally with results of this correlation showing in the performance levels of students.

Among the outcomes of this study was the confirmation that rapid changes to the education process such as those imposed by the COVID-19 pandemic cause a significant amount of anxiety and fear of the unknown in all parties involved, especially the students. The level of this anxiety can be significantly moderated if effort has been invested in the ICT infrastructure and in training personnel while providing student access to advanced technology and the internet. Unfortunately, institutions operating very lean when it comes to infrastructure investment where they rely on reactive modes would be negatively, and significantly, impacted by such interruption. The reality is that institutions can play a big role in alleviating the majority of issues related to a sudden change in the education process by making their infrastructure and training ready. The COVID-19 pandemic can be considered as an extended extreme weather condition which will justify accounting for it when investing in infrastructure.

Institutions can also resolve many challenges related to accessibility and compatibility by reaching out to their students during challenging times, particularly those with challenging socio-economic status, and providing what is needed in terms of internet, equipment, and access to needed resources to continue the education process and facilitate learning. This is where equity moves to the front of institutional actions and where leadership takes effect.

The challenge related to peer interaction and personal interaction with instructors was more apparent in lower class students, which is expected. The solution to this challenge is not as easy and requires some creative facilitation of remote grouping to build comradery and cohort relations similar to those which existed during normal times. Instructors can play a leading role in initiating these groups based on light and fun activities until the group or team connects using any communication platform, then the instructor can pull away slowly. However, this is definitely a future topic for exploring.

One main limitation to this study was the relatively small number of participants. To overcome this limitation and to increase the findings' trustworthiness, qualitative tools were used alongside quantitative ones. The study contributed to the theoretical side through the quantitative and qualitative characterization of the interrelations between performance, adaptation, and access-and-compatibility. This contribution is valid in view of the many efforts put into promoting the online instruction during COVID-19 pandemic.

6. Conclusions

This study was initiated to investigate the effect of the COVID-19 pandemic on engineering education. Three categories were found to encapsulate most challenges, solutions, and responses, which are: performance, adaptation, and access-and-compatibility. In addition, rapid changes to engineering education while facing the pandemic faced challenges which partially overlap with challenges coming classic remote learning. These challenges belong to four areas: (1) accessibility and compatibility, (2) remote assessment, (3) experiential learning, and (4) interpersonal interactions and support societies.

One result of this study was to confirm that the socio-economic status of students, life experiences and maturity levels, and availability of resources, were the main factors influencing students' adaptation to rapid changes in the education process. Diversity among students was found to provide a positive effect when trying to adapt to changes.

Meanwhile, performance and motivation, adaptation to change, and accessibility-and-compatibility were found to be highly interdependent causing a proportional influence on the performance levels of students.

At the institutional level, this study indicated that institutional investment in infrastructure readiness and essential training of personnel to prepare for unforeseen events is critical to alleviating the majority of issues such as those experienced during the pandemic. Additionally, institutions can be leaders by extending help to their students during challenging times, particularly those with challenging socio-economic status, to ensure a level playfield in terms of access to resources.

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Appendix A – self-reporting questionnaire

The questions included in the questionnaire are given below.

What was your college classification for the academic year 2020–2021?

○ Freshman
○ Sophomore
○ Junior
○ Senior
○ Graduate Student
○ Other

What is your gender?

○ Male
○ Female
○ Non-binary / third gender
○ Prefer not to say

Please select the ethnicity with which you identify the most:
- ○ White
- ○ African American
- ○ Hispanic
- ○ American Indian or Alaska Native
- ○ Asian
- ○ Native Hawaiian or Pacific Islander
- ○ Other

What was your average class size during the academic year 2020–2021?
- ○ Less than 15 students
- ○ 15 to 30 students
- ○ 31 to 45 students
- ○ 46 to 60 students
- ○ More than 60 students

What mode of instruction did you experience **before and after** the COVID-19 pandemic? **Select all that applies.**

	Before	After
Remote Lectures	☐	☐
Remote Labs	☐	☐
Remote Discussion / Tutorial sessions / Group meetings	☐	☐

Rate the effectiveness of the different modes of instructions you have experienced **after** COVID 19 in helping you learn:

	Least effective	Less effective	Same as before	More effective	Most effective
Remote Lectures	○	○	○	○	○
Remote Labs	○	○	○	○	○
Remote Discussion / Tutorial / Group meetings	○	○	○	○	○
Remote Quizzes and Exams	○	○	○	○	○

Your Department at your University took measures to ensure continuity of the educational process (Teaching, Learning, Assessment) during the COVID-19 Pandemic. How sufficient and effective were these measures?
- ○ To a very large extent
- ○ To a large extent
- ○ To some extent
- ○ To a very small extent
- ○ Totally ineffective and inefficient
- ○ No opinion

Rate your level of satisfaction with the following different aspects of instruction in your engineering courses after COVID-19.

	Least satisfied	Less satisfied	Same as before	More satisfied	Most satisfied
Quality of instruction	○	○	○	○	○
Quality of your engagement	○	○	○	○	○
Level of distraction from course work	○	○	○	○	○
Staying motivated to do well in the courses	○	○	○	○	○
Fitting education with your other changing responsibilities	○	○	○	○	○
Knowing where to get help with the course	○	○	○	○	○

How did any of the following affect your learning **during** the COVID-19 pandemic?

	Very Badly	Negatively	Neutral	Positively	Very Favorably
Availability of connection to the internet	○	○	○	○	○
Availability of digital equipment (phone/tablet/ laptop/computer)	○	○	○	○	○
Availability of a quiet place to study	○	○	○	○	○
Ability to interact and communicate with instructors and TAs	○	○	○	○	○
Ability to interact with other students	○	○	○	○	○
Your performance on Quizzes and Exams	○	○	○	○	○
Quality of online products (Audio, Video, Zoom, etc.)	○	○	○	○	○
Your motivation to learn	○	○	○	○	○
Ability to do labs in person	○	○	○	○	○

Comparing your workload related to studying and courses, before and after COVID-19, would you say that your study workload after COVID-19 has:
- ○ Significantly increased
- ○ Moderately increased
- ○ Stayed almost the same
- ○ Moderately decreased
- ○ Significantly decreased

Comparing your academic performance before and after the COVID-19 pandemic, would you say that after the COVID-19 your academic performance has:
- ○ Significantly improved
- ○ Improved
- ○ Stayed the same
- ○ Deteriorated
- ○ Significantly deteriorated

[Optional] What were the most problematic or challenging issues when you had to accommodate changes in your education process due to the COVID-19 pandemic?

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