

Moving Forward in Engineering Education with the COVID-19 Challenges*

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The spread and threat of COVID-19 has brought the world under standstill. Educational institutions are not exempt. The pandemic has forced the universities to transform from traditional teaching-learning methods to web-based digital teaching-learning methods. Claims are being made that future teaching would be fully online rather than traditional or in-class mode. There are many challenges in implementation of online classes and at the same time there are possibilities to enhance the knowledge and resources required to build the global online education network. This paper reviews the challenges and possibilities in teaching and learning online, various technological tools and their outcome practiced by the academicians to conduct the lectures and assessment activities. A special attention has been paid to the impact COVID-19 on mental health and anxiety among the staff and student community.

Keywords: COVID-19; Online education; Ethics and Effectiveness; Student-centric approach; Technology enhanced learning

1. Introduction

Education is the key for any society or a nation to be successfully progressing forward in today's challenging times. Higher education and engineering education among others are essentially one of the important pillars in education systems which are benefitting the society. This could be easily realized by the increased number of students opting for these programs after 1960 and this trend is so strong that many developing countries' students are enrolling for higher education at faster rate than European countries did few decades ago [1]. Engineering education prepares engineers to make the environment a better place to live for everyone by using materials, energy, and information [2]. This is a continuous process and is based on life-

long learning due to rapidly changing of the technology day by day and becoming more complex too [3]. In the recent past, the teaching and learning processes/approaches in engineering have seen a huge change moving from traditional/conventional methods to technology-based sophisticated teaching methods which are majorly student-centered approaches focused on enhancing students' learning. The student-centered learning environment can be developed by applying web or internet-based technologies. These emerging teaching and learning pedagogies have potential to develop the critical and cognitive skills in students [4, 5]. Furthermore, today quality of engineering education of various universities around the globe is accredited by some standard boards like the most common organization the Accreditation Board for Engineering and

Technology (ABET). ABET has identified some skills that engineering graduates are expected to possess. The general philosophy of ABET is outcome-based education (OBE); which is a performance based approach, focusing on results unlike the traditional (or conventional) education system [6]. OBE has emerged as an important model in the context of engineering education and is gaining increasing recognition and acceptance globally. This is basically student focused philosophy rather subject oriented attention. This approach focuses on students' learning outcomes which can be attained by carefully designing the courses. Outcome Based Education is currently preferred globally to promote educational revitalization. It has been reported long before that *"It is a consequence of the scientific basis of engineering that it is international, not national"* [7]. Therefore, OBE model has improved engineering education ecosystem and has helped engineers to work and compete globally [8]. Today we are living in a world that is severely affected by the novel coronavirus COVID-19. And this has majorly affected different aspects of our lives. It has been predicted that the vaccine for curing the disease may not be available before 2021. With no sigh of relief with respect to the availability of approved drug or vaccine besides strict implementation of protocols like maintaining social and physical distancing, most activities especially in education have moved online. The COVID-19 has abruptly compelled all tasks that human beings were involved and to moving forward most of the tasks seem to undergo a major transformation in their approach. Today digital access has become a necessity and is no more a luxury [9]. This pandemic has heavily impacted the education space thereby calling for newer and smart approaches to teaching and learning to keep the education system up and running. This shift in teaching approaches is forced, but these experiences could be made interesting to both students and teachers. Due to the current situation, a lot of prejudices around online education now seem to break down for the better. And it is believed that there will be a huge shift to online classes now [10]. The current situation led the teaching and learning activities, and assessment and evaluation to be moved online either partially or completely since the end of last semester. Most universities with an aim to battle COVID-19 and simultaneously continuing to provide education, have planned to move online as the current situation does not seem to come under control anytime soon, not until a year at least. The COVID-19 pandemic has challenged the traditional teaching and learning methods which majorly involve face-to-face in-person approaches. Most teachers were well versed with

the in-person face-to-face setting of teaching and had accordingly designed their courses based on OBE. However, the pandemic has provided the education system an opportunity to look into the other modern methods of teaching and learning without losing the essence of OBE. In a recent article by Junaid et al., the authors have reviewed the principles and paradigm of OBE, and have described the seven evidence-based steps to be implemented by the teaching and learning community to achieve the principles of OBE in these pandemic times [11]. In this paper, the authors have made an attempt to review the latest literature focusing on different aspects of teaching and learning, such as challenges in digital transformation, its effects on mental health on staff and students, assessment evaluation and its effectiveness, besides ethics in teaching and learning.

2. Online Teaching Methods

Educational institutions in recent times are focusing on research in addition to teaching and learning, the inclusion of research helps provide better exposure and learning experiences to students. Following COVID-19 outbreak the universities are closed, and this has not only led to engage online classes but also to conduct exams online in an unprecedented scale at all levels of education. This section reviews the methods available for teaching and learning during pandemic. It is known that an early return to the face-to-face in-person teaching and learning is not possible anytime soon and hence we have to move to the online teaching and learning [12].

2.1 Virtual Classroom

To avoid the spread and threat of COVID-19 besides community transmission of the disease it is a must to maintain the physical and social distancing. Face-to-face in-person teaching and learning without social distancing has been a threat as this could spread the virus through community transmission. Virtual instructions to the students through voice or video conferencing was the first change that was introduced in Harvard to safeguard from the pandemic which otherwise would have spread from face-to-face teaching and learning [13]. The students can attend the lectures, interact with the instructors, access the courses materials, submit the reports and interact with the instructors through virtual learning environment [14]. The modern technological progress has made it possible to connect with people while working from home. It is an all-out effort from all administrative authorities to keep the continued running of education system during the pandemic despite disruptions. Many institutions have been conducting

their academic sessions/lectures through a virtual environment without major difficulties. Virtual learning has proved to be an effective and excellent way of teaching and learning while staying safe at home.

Learning through virtual classrooms has found to be effective and easy for certain types of courses that are mostly theoretical, however, more effort is required to make the virtual classroom experiences meaningful for courses that are laboratory focused which require hands-on activities. The web based virtual labs have added new dimension to the digital learning as the virtual labs offer remote access to laboratories which provides real time experiences of conducting experiments [15]. Students can learn from different learning tools besides web based animated demonstrations, and there is scope for self-evaluation which further helps students to monitor and improve their learning [16].

2.2 Mobile Learning

In recent years, use of mobile and tablets has become an important part in teaching and learning in education. The significance of mobile learning (m-learning) can be understood by the fact that it will be implemented in one or less stage of higher education [17]. In m-learning, mobile device is used to support the teaching and learning activities, this approach has become very popular as every student today has a smart phone and internet connectivity is also not a problem anymore [18, 19]. At the same time there are reports which warn about ill effects on health due to use of mobile devices [20, 21]. Therefore, it is stressed to employ good teaching practices (GTC) while using the technology for a better society where both technology and society exist in coordination [22]. The vision of education and educational landscape should move together with implementation of emerging technologies and of course these must be accompanied by GTC [23].

2.3 Flipped Classroom and Cooperative Learning

The traditional methods of teaching are more teacher-centric and do not necessarily focus on students' learning [24]. The principles of OBE are student-centric, which focuses on students' learning more than just teaching with an aim to complete to the syllabus. In this context, flipped classroom and cooperative learning could be potential strategies to make learning more personal and dynamic where students take charge of their own learning. In flipped class room approach, the teacher provides digital content related to the course in the form of video recordings and reading materials. The students can watch the videos and read the materials at their convenient time before attending the class (these days online or virtual class). This activity

provides students an opportunity to learn independently at their own pace which eventually helps them understand better and their learning becomes efficient [25]. Flipped class room pedagogy encourages independent learning by providing the background of the topic well before the start of lecture, provides a platform for interaction which improves students' communication skills, prompts group discussion which helps students to learn from peers [26–28]. Flipped class room pedagogy was implemented by Mason et al. in senior level course of mechanical engineering and they compared it with traditional method for effectiveness and found that students' performance was better with flipped class room [29].

Cooperative learning is yet another approach which requires students to study in a group to enhance their individual and group learning capabilities through interaction and discussion [30]. Cooperative learning helps the students to share their knowledge and learn from others in a systematic way [31] which helps students to enhance their deep learning and critical thinking skills. The cooperative learning needs careful management and monitoring to guide students for better learning experiences otherwise it may turn out to negatively influencing students learning. Though flipped classroom and cooperative learning strategies have been implemented separately, there is literature available which highlights combining these approaches and this is in developing stage. Munir et al. implemented the combined models of flipped class room and cooperative learning in an engineering course. They found that more than 90% of students were happy to learn from the combined strategy [32]. Using this model in today's challenging situation can help transform the in-class activities like group discussions into an online mode of delivery.

2.4 Blended Learning Tools

Blended learning is an approach which combines the positives of both traditional teaching and online teaching. Blended learning facilitates the usage of appropriate learning tools at different phases of teaching and learning to help students achieve the maximum possible learning. Though blended learning includes face-to-face teaching, which is not possible in the current scenario, there is an interesting approach by Liu et al. [33] who divided blending learning into three stages. The first stage requires students to watch the videos online which will provide them details about a concept/topic, and this stage demands students to complete the tasks by self-studying. The second stage deals with engaging the students in live online interactive session; and the third stage focuses on the after-class activities such as problem-solving, assignments and

reports submissions [33]. The same strategy was followed in King Khalid University, Abha, KSA in the previous semester. Teaching and learning, assessments and examinations were all conducted using the three stages of blended learning using Blackboard Collaborate, a hassle free online educational platform.

2.5 Google Class Room

Reaching out to students in a student centric approach is very crucial especially during disruptions which force the in-class face-to-face teaching and learning into an online teaching learning method. Today we are living in uncertain times due to spreading of the COVID-19 pandemic and are not sure about resumption of campus learning very soon. We must look into other alternate ways of conducting the classes which are in a way sustainable for higher educational institutes. During disruptions in Cape Peninsula University of Technology, Sweta Patnaik introduced online submission of assignments, the use of Google Docs for feedback. For in-class activities she used either podcast or screencast. She emphasized to make best use of technology by blending different approaches which should transform into lifelong learning skill [34]. Google Classroom (GC) has emerged as a potential tool for blended learning in higher educational institutes. GC saves time and enhances the teachers' work flow, flexible and cloud based, mobile friendly etc. [35, 36]. Most of the institutions in general which also include higher educational institutions in Malaysia have adopted this learning management system (LMS) technology as a pedagogical tool for supporting the campus learning. This pedagogy found to be useful and easy with some drawbacks as well [37]. Traditional method of teaching was the only way in higher educational institutes in Georgia. The spread of COVID-19 forced them to move towards other technology based teaching-learning tools. They implemented usage of G suite for education which has the capabilities to complete the academic tasks effectively. Basilaia et al. tested 8 google products successfully as learning tools in virtual online environment [38].

3. Challenges in Remote Engineering Education

It may be on-campus the (classroom and laboratories) or off campus, students require support and guidance to complete and excel in their studies. Online learning options are found to be suitable for adult learners and it has been proved that they are effective compared to traditional approaches used for teaching [39, 40]. Teaching online is not a

new mode of teaching in many universities but it is an add-on to the existing face to face in-person teaching [41]. The transformation from traditional to online teaching is not easy for both teachers and students as the digital transformation requires new skills set [42]. Although students may be able to demonstrate few of the competencies through online learning, but it is unlikely that all the principles of OBE are achieved [43]. COVID-19 pandemic has forced the universities to face these extreme challenges in all fields of education. It took a while for the academicians to move from their current approach of teaching to online. Furthermore, universities are realizing that just delivering the lecture online is not the best way to teach and this has called for innovative approaches to teaching online. However, it is anticipated that when in-person classes start, the teaching and learning experiences will be different as there will be with a lot more time for in-person interactions between student-student and students-teacher [44]. OBE is a student-centered approach, however, the online courses pose some challenges to the student-centered approach of teaching and learning like limited student guidance and limited teacher-student interaction which are important in enhancing student learning [45]. Almaiah et al. explored the critical challenges affecting the online education system. In a study where they interviewed 30 students and 31 experts in the field of E-learning from six universities of Saudi Arabia and Jordan. Furthermore, they reviewed the literature to explore the reasons for the failure of E-learning strategies. There are three main challenges which are impeding the implementation of E-learning strategies [46]. The challenges stated above have forced changes in university teaching and learning systems at a large scale that was not seen before [47]. In summary, even though the online education poses some challenges as stated above but there are possibilities and suggestions which may be used to overcome the challenges and provide good learning experiences. The following are five suggestions/recommendations for effective online teaching [48].

- Don't convert entire lecture to video.
- Don't completely rely on live videos.
- Invite student engagement and feedback.
- Check in with students often.
- Identify and support students who need help.

The shifting of traditional classroom teaching to online teaching coincides with the advent of artificial intelligence, machine learning and automation. The result will reshape the functioning of universities across the globe [47].

3.1 Mental Health and Anxiety

As the number of corona infections, and death mortality are rising, the mental health, uncertainty, and anxiety of infected as well as non-infected persons is a rising concern [49]. When the disruptions take place in daily routine activities, the chances of mental disorders are likely to increase even for a healthy person who is without any medical history [50–53]. Mental health status of teachers as well students are very important for quality education, as the effective teaching and learning of skills can affect success of students [54, 55]. International staff and students are not only concerned about their duties but also about well-being of their families as well [56]. COVID-19 will have serious impact on the career of students who have graduated this year, as the graduated students will have to bear the brunt of severe global recession caused by the pandemic crisis [57]. There is an urgent need to counsel the students through the support services from the universities before it is too late. An online survey has been conducted about how teachers reacted to deal with the depression, trauma and anxiety caused by the pandemic. The results published showed that the teachers practiced virtual learning and the purposeful activities to beat the depression [58]. Unnecessary fear, anxiety, stress does nothing but harm to the mind and body of oneself and everyone.

3.2 Ethical Challenges

Technology does not change an ineffective person to an effective person necessarily. In the context of education, technology acts as an enabler to enhance traditional teaching approaches. It demands commitment, desire, honesty, hard work, enthusiasm and passion towards the course from all stake holders. Teaching and learning are not just passing information from teachers to students or just uploading and downloading the lecture materials. Though there are many advantages of online teaching and learning but at the same time there some who may choose flexibility over handholding and the convenience of online tutoring over the multi-sensorial impact of face-to-face contact [59]. Cheaters never prosper, except maybe in a pandemic. Students who cheat make the job of their instructors more difficult [60]. It is important to draft the question/assessment strategy to measure the competency/performance indicators defined according to the OBE. The pandemic has shown us clearly that we must be more focused, attentive and responsive to the diverse and conflicting emotions and life experiences of our students and colleagues [61]. Higher education plays significant ethical role in societies

with respect to advancement of knowledge because the very purpose of higher education is production of knowledge and its application. The foremost ethical duty of everyone is to question truth claims, to seek explanations and to find good understandings [62]. Today we are forced to transform from traditional teaching to online teaching approach due to the uncertainty caused by the pandemic but at the same time we should not neglect the ethical implications which import asynchronous education. Online teaching and learning fundamentally alter the nature and ethical experience of human communication, education, and relation [63].

3.3 Assessment and Evaluation

All the educational assessment activities are being conducted online. Most exams had a time frame which required students to log in to a system and answer questions. This approach seemed to work however, it opened ways of cheating. Cheaters never prosper, except maybe in a pandemic. It was important to draft the question/assessment strategy to measure the competency/performance indicators (PI), modify the questions to suit the PIs, and design specific assignment questions to assess identified competency/Pis. All the questions of the exams and assignments should be based on analysis, and questions that depended on the student's ability to solve a problem or reach a conclusion. George conducted mock exams to promote students learning and made the students familiar to appear the exam through online platforms. In mock quizzes, the students were given structured essay-type questions to answer. To prevent the students from colluding and cheating the start and end time of the exam was same for all the students besides shuffling the questions. No opportunity for changing the answers was provided if already attempted/submitted, preparation of backup exam for unforeseen circumstances if any [64].

3.4 Effectiveness of Learning

'What gets measured, gets improved' is a famous quote of Peter Drucker [65]. Therefore, evaluation of effectiveness of online based teaching-learning tools besides core knowledge outcomes in terms of competency, performance indicators, learning outcomes is a challenging task for higher educational institutes which have not yet been addressed satisfactorily [66]. Cai et al. conducted effectiveness of self-regulated learning method during the COVID-19 pandemic. They found that self-learning method is effective for some courses. Therefore, they suggested that teachers may adopt suitable self-learning method based on the requirements of the course and academic conditions of the students [67]. Influ-

ence of COVID-19 confinement on students' performance in three different courses was studied by Gonzalez et al. [68]. They found positive effect of the COVID-19 confinement on students' performance when they compared their results with the last two batches of 2017–2018 and 2018–2019. However, they could not establish the reason for improvement is new learning tools or new assessment method [68]. There was a survey (Fig. 1) conducted to gain insight into the effectiveness of online based education at Southeast University in China [69].

The survey indicated that teachers need to accelerate themselves to the pace of online teaching and it should not be just transferring of traditional course materials into online content. Teachers should put effort to develop online courses, innovative lesson plans and teaching-learning tools. Swati and Jyoti found some chunks in the online education systems which were rolled out with fanfare in the beginning. They stressed the need of deliberation, introspection and planning to optimize the learning outcomes [70]. Manthalkar et al stressed the need of restructuring education post COVID-19 considering four key elements or pillars and a binder as follows [71].

- Flexibility.
- Cognitive, Social and Spiritual intelligence.
- Resilience.
- Creative thinking & design thinking.

The binder to these four pillars is the concept of “Lifelong Learning”. The real-life problems are not static, and they keep coming back to us at different times of our life. That is, the parameters of a problem may change over a period of time. We should be ready to deal with the changes without the need to learn from scratch after every change [72].

3.5 Student Projects

Projects are an important part in an engineering curriculum irrespective of the domain of engineering. Activities during the projects help the students to deal with authentic engineering problems [73]. Universities include student projects in curriculum to provide unique experiences which otherwise cannot be provided in class and/or in labs [74, 75]. Hence, students' projects need adequate consideration in an engineering curriculum and enough time must be spent by faculty members on framing details regarding projects. The project details framed by the faculty members, or the department will set expectations and guidelines for students to choose and work on projects accordingly. Inappropriate planning about projects by the faculty members can lead to low quality projects and reduced learning experiences. Considering the recent times of COVID-19, working on projects remotely is extremely challenging for both students and faculty members, and hence there needs a common ground/understanding for implementation (and execution) of project plans. Students can work individually or in teams depending on the class size. The student teams and the faculty member can meet virtually on a weekly basis to monitor the project progress and provide suggestions or feedback. Since students are not being able to access the resources on the university campus due to COVID-19, expecting them to work on projects that require hardware setup is unrealistic and impossible. Hence, it is the faculty members who need to propose ideas that help students work on projects from home and yet acquire the skills that their program aims at providing them if they were on campus. This seems difficult, but it is certainly not impossible. Different open source softwares are available (simulation and coding) that can be used to work on different projects [76]. More research is

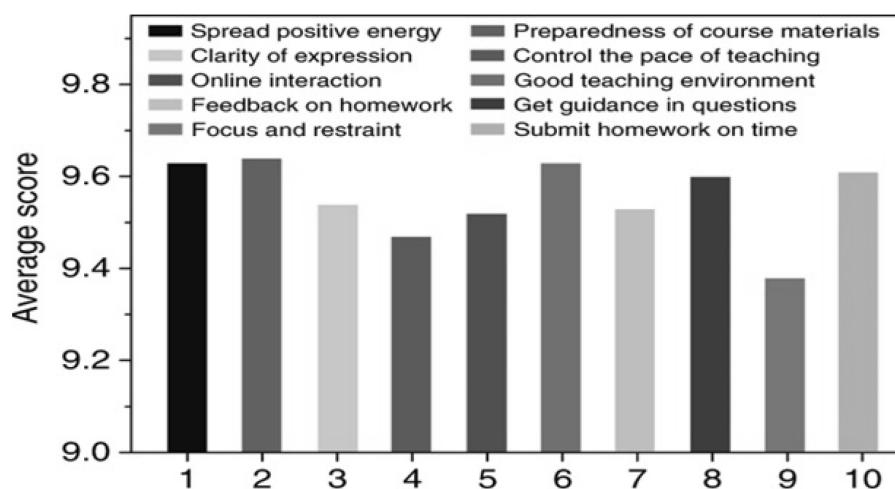


Fig. 1. Average scores of responses to questionnaires collected among 39,854 students [69].

Table 1. Key challenges and recommendations in online teaching-learning

Key Challenges	Suggestions/Recommendations
Mental health and anxiety	The institute should have trained academic counselors to counsel the students.
Ethical challenges	Staff should inculcate moral and ethical values among the students.
Assessment and Evaluation	Shuffling the questions, no backtracking if the answers are attempted/submitted.
Effectiveness of Learning	Don't rely completely on online lecture or live videos. Engage the students and get feedback through the polls during the lecture. Schedule regular online meetings with the students regarding their academic issues.
Student projects	Use open source softwares (simulation and coding) for projects.

needed in this direction to help the engineering education community to successfully implement projects in this crucial time.

The key challenges that may arise for online education are summarized along with relevant recommendations in Table 1.

4. Conclusions

The continuation of educational activities right from engaging the lectures to assessment in a sustainable way is challenging for higher educational institutions across the globe due to the spreading of COVID-19. The authors have reviewed the different online based academic practices implemented by the teaching community in the different parts of the world. In this context,

the authors wish to state that different approaches come with different issues and different solutions are emerging as we are moving forward. At this point of time it is very difficult to conclude about the suitability of specific approaches or blend of approaches which meet the fundamentals of OBE. There is lack of data in the literature on effectiveness and feasibility of online academic activities. In future, quantitative and qualitative research studies need to be conducted to dig deeper into this area of research and help the community with detailed steps moving forward in the pandemic.

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