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The Impact and Challenges of Coronavirus Pandemic on Engineering Education

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Abstract:
The Covid-19 pandemic has substantially impacted different facets of the world, with universities and other institutions of higher learning, especially engineering education, experiencing immense transformations. This paper investigated the multidimensional impact of the Coronavirus pandemic on engineering education,how the challenges and opportunities were adapted by the engineering education institutions, the efficiency of these adaptations, the potential enduring changes to the educational landscape, alterations in teaching and learning methodologies, the technology integration, the application of digital tools, the faced challenges, as well as the extensive implications for the future of engineering education training and practice.Through a review of current literature, the article also provided insights into how engineering education has been modified, and the potential long-term changes resulting from this unprecedented global crisis.
Keywords: *coronavirus, covid-19, pandemic, engineering, education, universities, teachers, students*

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I. Introduction

The coronavirus pandemic, declared a global health crisis by the World Health Organization in March 2020, had far-reaching consequences across the entire society. Originated in Wuhan, China, in December 2019, the novel coronavirus (SARS-CoV-2) is characterized by symptoms such as intense fever, shortness of breath, and cough. As global attention focused on the medical and economic impacts of the viral pandemic, which reshaped how people work, communicate and learn, the educational sector was also significantly affected.

The COVID-19 outbreak disrupted nearly all human activities, including education, research, sports, entertainment, transportation, worship, social interactions, economy, business, and politics. The entire world faced distress as a result of the pandemic's threats, and the education sector was among the worst hit. Schools and universities were forced to adapt rapidly to remote learning due to abrupt closures, impacting approximately 1.57 billion students across 191 countries. Educational institutions grappled with challenges such as low connectivity, lack of online content, and untrained teachers for distance learning.

The pandemic exacerbated existing educational inequalities, leaving less fortunate students excluded. Education, considered a fundamental human right and a key element in achieving the Sustainable Development Goals (SDGs), suffered disruptions that affected both teachers and students globally. Negative aspects included inadequate infrastructure, reduced socialization, and subjective examination methods. The necessity to adapt quickly to these new realities propelled educators and researchers to seek innovative methods in teaching and learning, allowing technology to bridge the gap created by social distancing measures.

Specifically, engineering education, which relies heavily on hands-on approaches, workshops, and laboratory experiments, underwent significant transformations. Institutions were unprepared to handle the immediate restructuring of their activities, leading to challenges in providing effective remote education. However, this period of upheaval also prompted a re-evaluation of engineering education methodologies, curricula, and the essential skills needed for prospective engineers. While the journey has been challenging, the pandemic has driven remarkable evolution in the educational sector. As engineering institutions navigate these unprecedented challenges, it is expected that they will emerge with more resilient and adaptable learning environments that will produce future engineers that are better equipped to handle similar or worse crises in the future.

II. Literature Review

The impact of the COVID-19 pandemic on engineering education has been extensively studied, with numerous researchers highlighting various aspects of this unprecedented global crisis. Edeh et al. (2020), discussed the broad effects of the pandemic on education, noting that the outbreak disrupted all human activities globally, including education, research, and social interactions. Gomez-Garcia et al. (2022), emphasized the unpreparedness of educational institutions to handle the pandemic's challenges, which affected 1.57 billion students worldwide. They highlighted issues such as low connectivity, lack of online content, and inadequate training for teachers.

Stankovska et al. (2022), pointed out the significant disruption in education, noting that the pandemic exacerbated educational inequalities and affected less-fortunate students disproportionately. They listed several negative impacts, including inadequate infrastructure, ineffective communication, and mental health challenges. According to Pintaric and Kravanja (2020), engineering education, which heavily relies on practical, hands-on approaches, faced particular challenges during the pandemic as distance learning was not previously preferred due to its dependence on laboratory work.

Gantait et al. (2022), observed that the technology and engineering sectors were significantly impacted, requiring radical measures to sustain university education. The rapid shift to remote learning posed challenges such as ensuring access to technology and rethinking the delivery of practical sessions. Marinoni, Land, and Jensen (2020) discussed the immediate effects of these measures, including job insecurity for staff and the need for universities to reinvent their operations.

Iqbal et al. (2022), highlighted the necessity for innovative approaches to meet the challenges posed by the pandemic, such as adapting active-learning and team-based activities and limiting hands-on laboratory experiences. Mall and Haupt (2022), discussed the additional financial burden on students from low-income households and the challenges posed by outdated devices and poor network connectivity.

Supernak et al. (2021), reported on the benefits of the COVID-19 induced transition, such as effective communication, interactive instruction modes, and early assistance for struggling students. Finally, the importance of hybrid models in engineering education was emphasized by AlMunifi and Alfawzan (2023), who noted that these models not only adhered to safety protocols but also improved learning experiences and prepared students for future demands.

1. Shifts in Teaching Methodologies

Virtual Classroom

The pandemic era has thus catalyzed a transformation in engineering education, highlighting the potential for blended learning, the importance of flexibility in teaching practices, and the need for resilient and adaptable educational frameworks. As physical classrooms and laboratories were abruptly replaced with virtual environments, engineering educators were compelled to innovate and adopt new teaching methodologies to ensure continuity and quality of learning. This shift not only involved the integration of digital tools and platforms, but also a re-evaluation of pedagogical strategies to accommodate remote learning. According to Yeddu (2022), as the universities closed in an attempt to mitigate the spread of the virus, the engineering faculties across the universities resorted to virtual teaching, thereby replacing the physical presence in the school with online presence. She explained that the entire structure of the education system like learning methodology,teaching techniques and assessment methodologies were affected, as it is now fully dependent on the internet and applications like Microsoft Teams,Google Classroom,Zoom,WhatsApp,etc.

As lectures, laboratory activities, seminars, and some workshop practicals were conducted virtually, and the communication among the parents, teachers and students became more pronounced, many people found the virtual learning quite convenient, as parents were able to sit in the comfort of their homes to monitor their wards' progress in school.Khan and Abid (2021), observed that as engineering laboratories are integral parts of instructions which require hands-on implementation of fundamental concepts learned in the classroom, that such laboratory environments are artificially created over internet to provide all basic tools to enable students to conduct laboratory experiments. They pointed out that numerous such models exist, for example, design and implementation of an interactive virtual control system laboratory for undergraduate students in electrical and computer engineering, and that such platforms are also realized for online DC motor test bench to demonstrate fundamental concepts in mechatronics engineering.

The benefits of virtual classroom which include live technical support, synchronous learning, session recording, screen sharing, multi-level fall back mechanism etc., are depicted in figure 1.

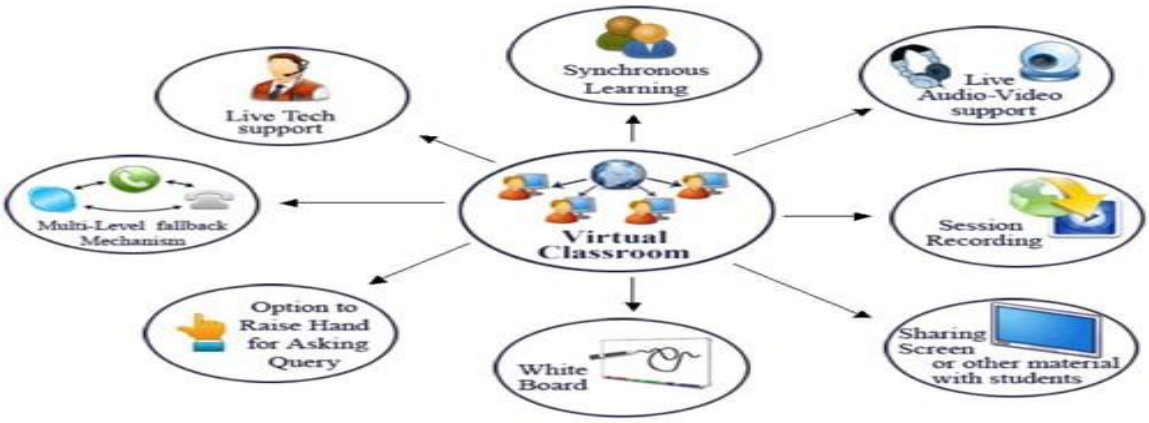

Figure 1: The benefits of a virtual classroom. Source: Yeddu (2022)

Hybrid Models

Amid the Covid-19 challenges, hybrid models of education which blends online and face-to-face teachings came on board as a majorpanacea for the sustenance of educational continuity. The methodology successfully incorporatedonline engineering teaching and learning with the engagement and immediacy of in-person interactions, thereby resolving the limitations of purely remote or entirely on-campus models. Singh, Steele and Singh (2021), defined hybrid learning as an instructional method that includes the efficiency and socialization opportunities of the traditional face-to-face classroom with the digitally enhanced learning possibilities of the online mode of delivery. They listed the characteristics of hybrid learning to include: (a) student centered teaching where each and every student has to be actively involved in the content, (b) increased opportunities for interaction between student-faculty, student-student, content-student, and student-additional learning material,and (c) opportunities to collect formative and summative assessment to improve course offerings.

Almunifi and Alfawzan (2023), explained that classes in Saudi universitiesin the pre-pandemic time were predominantly 100% face to face (traditional learning), but that during the Covid-19 pandemic, theeducation sector moved to 100% online and then went through hybrid mode (a mixture of both face to faceand remote) until the return to the old normal, i.e., 100% traditional learning. Traditional learning which entails direct interaction of the instructor with students and hybrid learning where students participate in classes virtually and the instructor also organizes face-to-face sessions with the student are depicted in figure 2.

Figure 2: Traditional learning versus hybrid learning. Source: 21kschool (2023)

The application of hybrid models in engineering education during the pandemicperiodwhich was targeted at adhering to safety protocols and maintaining the quality of educationdid not only encourage the continuation of academic programs in engineering faculties, but also propelledinventive pedagogical strategies, by improving learning experience and also preparing students for the ever changing demands of the engineering discipline in a post Covid-19 era.

Innovative Assessment Methods

With the suddenchange to remote learning, engineering lecturers were confronted with the challenge of retaining not just the quality but also the thoroughness of their programmes. Despite the challenges, theCovid-19 era of interference also propelled ingenuity as it led to advancements and introduction of different methods of

assessment for effective evaluation of student's learning and skills in a virtual setting. According to Zacharis (2010), innovative assessment can be explained as any form or method of assessment, which brings something new or try to do something different in an educational context. He noted that even if not all of the new assessment techniques are new inventions, all are geared towards enhancing the quality of student learning, engaging her actively in a feedback and adjustment cycle that encourages deep learning.

The application of innovative assessment methods in engineering education during the pandemic period entailed different types of strategies aimed at adjusting to the limitations of online teaching and learning, which consist of the integration of technology-improved assessments, the application of simulation tools, the execution of project-based and collaborative assessments, as well as the adoption of more flexible and inclusive evaluation criteria. These approaches were aimed at measuringnot just the technical skillsand knowledge of the students, but also to encourage critical thinking, innovation, creativity, ingenuity, and problem-solving abilities in a manner that is genuine to the engineering discipline.

By reconsidering traditional assessment methods like practical tests and written quizzes and examinations, engineering institutions adopted measures like open-book examinations, online quizzes, online workshop practices and laboratory works, as well as project-based assessments to determine students' understanding effectively. Thesemodifications revealed the potential for long-term improvements in engineering education, through the application of digital tools to create equitable, unique and effective learning experiences. As engineering universities andteachers continue to modify these methods, the lessons learnt during the Covid-19 pandemicwill definitely have a long-lasting impact byimproving further innovationson the process of delivering and assessing engineering education in the future.

2. Adoption of Digital Tools

By compelling faculties of engineering across the universities to quickly embrace and integrate digital learning tools, the Covid-19 pandemic led to an unprecedented shift in engineering educational curriculum around the world. Ohei (2023), observed that the Covid-19 pandemic has immensely impacted the adoption of digital learning tools in education across the globe, as studies have revealed that the pandemic forced educational institutions to quickly transition to e-learning platforms, thereby leading to a surge in the use of Information and Communication Technology (ICT) tools and technologies. He opined that this sudden shift highlighted the importance of digital technology in supporting online learning and necessitated the use of supplementary digital tools to ensure continuous education delivery.

Grodotzki, Upadhya and Tekkaya (2021), noted that the unforeseen turn of events pioneered by the outbreak of the covid-19 pandemic, compelled lecturers around the world, regardless of their stance on online education, their familiarity with it and their level of preparedness, to transition into a completely online system of education and with hardly any time available to embark on the transition, as teaching methods and assessment methods had to be developed or implemented immediately. The abrupt transition to remote learning environments led to appreciable advancement and deployment of creative digital solutions for the enhancement of continuous delivery of quality education to engineering students. By improving on virtual environments where theoretical knowledge and workshop and laboratory practical skills can be easily disseminated, collaborative tools and virtual simulations appeared as critical aspects of the novel paradigm. Some of the adopted resources and digital tools applied in the education of engineering students during the coronavirus pandemic period include the following:

a. **Learning Management Systems (LMS)**: LMS provided a central point for effective communication, course materials and quizzes for the engineering students through the application of different platforms like Blackboard, Flipped classroom, Moodle, Active learning, Canvas, etc. Other platforms are also available to engineering lecturers to assist in enhancing the quality of their teachings.

b. **Simulation Software**: By enabling engineering students to have remote practical experiences through experiments, software like ANSYS, MATLAB and SIMULINK were very useful for virtual laboratories as the students had no access to physical laboratories during the pandemic.

c. **Collaborative Tools**: as good engineering curricula involves teamwork and collaboration, tools like Collaborative coding, Slack, Project-based learning, and Trello assisted engineering students to have the experience of working together albeit remotely. Thereby enhancing a sense of teamwork, notwithstanding the physical separation occasioned by the pandemic.

Because of these, the Covid-19proved the flexibility and buoyancy of engineering universities,and also accentuated the benefits of digital tools for the expansion and enhancement of the engineering education capacity. Indeed, the robust blending of technology and traditional methods emerged to foster improved inclusivity, flexibility, and effectual engineering teaching experiences, as the Covid-19 pandemic era of digital application has greatly improved engineering education around the world.

3. Challenges of Covid-19 Pandemic on Engineering Education

Engineering education conventionally centers on collaborative projects, experiential learning, design oriented, in-person instructions, workshop practices, laboratory jobs, hands-onand contents teachings aimed at enhancing the analytical thinking skills of the students, for the definition and solution of real socio-economic and ecological problems. Pintaric and Kravanja (2020), explained that it is characteristic of university education in engineering that, in addition to theoretical lectures, practical knowledge is an essential complement, including computational problems, laboratory experiments, project assignments, the use of computer programs, etc. They posited that distance learning was not formerly preferred in engineering education, because of high rate of the experimental laboratory work done by students, which could be up to half of all contact periods.

Gentait et al. (2022), observed that the technology and engineering sectors have been hit extremely hard in the Covid-19 pandemic. They noted that the problems and challenges faced by the academia in the pandemic times are the opportunity to better brace up with the rapid humanity development also in terms of physical workspaces changing or complementing with immersive ones. Coronavirus pandemic necessitated the introduction of some radical measures for the sustenance of university education. According to Marinoni, Land, and Jensen (2020), the adopted measures had an instant effect as they have impacted, often dramatically, the conditions under which higher education all of a sudden had to perform research and what is referred to as 'emergency online education'; students need assistance; staff face unprecedented challenges, including job insecurity; university leaders had to reinvent how to run their campus operations. They noted that the consequences will still be felt way into the future.

The rapid shift to remote learning necessitated by lockdowns and social distancing measures posed remarkable challenges, from ensuring access to technology and stable internet connections to rethinking the delivery of practical, workshop and laboratory sessions. Iqbal et al. (2022), stated that diverse aspects of peoples' lives were disrupted due to COVID-19, including traditional in-person education systems applied in engineering education, as the education system had to implement innovative approaches to meet the challenges COVID-19 pandemic brought upon traditional learning. They pointed out that the change in instructional methodology compelled educators to adapt numerous active-learning and team-based activities and limit hands-on laboratory experiences and experiments, thereby affecting learning opportunities along with in-person interaction among instructors, students, and peers alike.

This is because maintaining the standard of education, especially for workshop practices and hands-on laboratory research, were quite difficult, as many skills and experiences inherent to engineering education are difficult to reproduce online. Also, engaging all the students in a virtual platform became quite challenging as the absence of corporeal attendance and informal interactions impacted negatively on motivation and results.These challenges enabled engineering educators to re-assess their teaching philosophy and methodology, by experimenting with new approaches, thereby leading to novel capacities and perspectives.

Mall and Haupt (2022), observed that as online learning platforms are primarily dependent on the use of gadgets and the internet, the requirement for technical devices such as laptops and data provision for instructors and students was a challenge for the South African engineering students, because students from low-income households were abruptly confronted with the added financial burden of having to procure data packages which are quite expensive when compared to elsewhere around the globe. Also, they noted that students that owned outdated devices observed most features were unavailable as the device was not compatible with the online platforms like MOODLE and MSTEAMS, thereby restricting teachers and students that resided in locations with poor network connectivity from fully benefitting from online trainings.

However, Supernak, Ramirez and Supernak (2021), reported that effective communication, proper pedagogical mode (e.g., student group projects), interactive mode of instruction, and availability of early assistance for students who struggle to overcome the problems with the online course transitions in response to covid-19, are few of the benefits of Covid-based transition for engineering students in Qatar. They noted that proper consultations with e-mail and the practice of mock quizzes are some of the methods to prepare students for an effective transition to a new learning model.

Engineering education which is an exigentfield that entailsproper integration of workshop practices and classroom teaching with corresponding laboratory instructions was immensely affected by covid-19, as the engineering faculties were unprepared to instantaneously grasp the swing to online platforms that were hurriedly introduced.During the lockdown, engineering students were compelled to endure several mainly unproven major obstacles, which impacted on the ways in which they would continue learning, and how and where that would take place. The most effectual tool in keeping the students' retention and also maintaining access to learning has been online courses. This is because online platforms have become quite crucial in offering continuity in learning, as trained educators, revised curricula and effective teaching aids will enable the engineering students to remain involved and active in the learning process.

Despite these challenges, Covid-19 also catalyzed innovation and adaptability within the engineering education community, as globally, engineering faculties were compelled to re-examine their teaching methodologies, embracing digital tools and virtual platforms to maintain the continuity of education. This period

of upheaval has underscored the need for resilience, flexibility, and creativity in engineering pedagogy.As educators and students navigated through this new terrain, several strategies emerged that not only addressed immediate concerns but also offered long-term benefits for the future of engineering education. By leveraging advancements in technology, fostering a supportive online learning environment, and developing new assessment methods, the field of engineering education has begun to surmount the challenges posed by the coronavirus pandemic.

4. Future Implications

The covid-19 pandemic brought a deep and multifaceted influence on engineering education, as it came with both challenges and opportunities that will shape the future of the discipline. While the world evolves from the unplanned remote learning to an improved and likely permanent transition, the future implications of covid-19 on engineering education requires close scrutiny as the pandemic has undoubtedly transformed various aspects of the community, with engineering education being one of the most affected facet of the society. Nahar and Baillie (2022), explained that there was a significant change in the way students learn as a result of Covid-19 pandemic, but that the application of advanced methodologies managed to align course competencies and skills with the requirements of individual students, maintain class dynamics, and motivate the engineering students to learn. They concluded that the online learning has significantly increased in terms of student engagement than it did before, and that peer-review of created problems and recorded solutions is also an alternative that can be explored in the future as a way of improving the acquisition of higher-level skills and competencies.

The hastytransference to online and hybrid learning paradigms has spurred novelty in teaching and research methodologies, technology incorporation, and accessibility, while also enhancing and, in some cases, worsening disparities that were in existence. This exceptional disruption brought a distinctive opportunity to reassess and re-imagine engineering education, to ensure more resilient, inclusive, and adaptable learning environments. Commenting on the future implications of covid-19 impact on engineering education, Iqbal et al. (2022), advised that teachers need to prioritize implementing activities that inspire collaboration and creativity, to ensure that students do not feel astounded by the monotonous nature of many online lectures. They explained that in the long run, the true success of online learning can be assessed from two major factors: the competency of graduated students in their respective fields and the social competency students exhibit in adulthood, and that this can be attained through proper training of the university faculty to properly teach online courses that provide the same, if not higher, quality of education as they provide in-person.

The potential future implications of the covid-19 pandemic-induced alterations in engineering education include the following:

a. **Blended Learning Models**: This is the combination of both the online and traditional (in-person) education. The accomplishments of hybrid educational model are expected to result in a permanent swing towards blended learning.

b. **Enhanced Digital Literacy**: Teachers and their students in engineering schools have over the post-covid-19 pandemic years developed improved mastery with digital tools, this will continue to be of immense benefit to the process of engineering education.

c. Redefined Assessment Methods: The assessment approach developed during the coronavirus pandemic which are quite innovative will be most likely sustained during the post Covid-19 era, thereby ensuring improved evaluations of the capabilities of the engineering students.

d. **Increased Flexibility**: The flexibility experienced in the teaching and learning of engineering during the Covid-19 pandemic will lead to enhanced compliant and resilient structures of education that has the capacity to respond to disruptions in the future.

The experience learnt during the Covid-19 era willaffect theadvancement of designing the engineering curriculum, students' methods of appraisal, as well as the general educational knowledge for thestudents of engineering, with implications that will definitelylastafter the pandemic period. Grodotzki, Upadhya and Tekkaya (2021), opined thatenhancing the learning environment for students should not be the only aspect that is in focus in the future, it must also be on improving the teaching environment from the side of the universities. They noted that the lack of support during the shift to digital teaching is something many educators observed, and that, universities must increase the effort to supply the hard and software needed but, moreover, educate the educators about how to use such tools.

It is quite pertinent to contemplate how the numerous changes that took place in the engineering education will impact on the skills and expertise of prospective engineers, the effect of technology in engineering education, as well as the approach in which institutions of higher learning can optimally equip their engineering students to confront the challenges of an overwhelmingly convoluted and interconnected world. According to Vergara et al. (2022), the present situation due to the pandemic caused by covid-19 has only increased a process of virtualization of education that had already begun previously. They maintained that despite this, university students emphasize on the need for them to be able to use physical laboratories in

practical teaching, as depending on the current situation and the opinion of students, it is necessary to affirm that both types of laboratories (virtual and real) will coexist in the new post-coronavirus hybrid educational models, which blend face-to-face and online teaching and learning.

III. Conclusion

The transformations that coronavirus pandemic brought to bear in engineering education necessitated the development and adoption of diverse digital tools, novel lecture methodologies, as well as innovative assessment methods. As the challenges like uneven internet accessibility and quality education still persist, the modifications recorded during the covid-19 era will in the nearest future continue to improve and optimize engineering education. This is because the lessons learnt during the pandemic have equipped engineering institutions and the stakeholders for possible future interferences, as efforts are being made for the application of flexible and resilient models of engineering education that can overcome related disruptions, thereby ensuring the continuity of education through blended or hybrid learning method.

The novel pandemic also had a lot of impact on the teachers' and students' mental health,as the stress and lockdown related with the protracted online study environment raised consciousness about the need for mental health support and the benefit of encouraging a helpful educative community, no matter the delivery mode. Also, the need for the adaptation of immediate online learning resulted to the re-evaluation of in-person teaching curricula. Engineering teachers were able to create novel pedagogical methods like asynchronous learning, flipped classrooms, as well as multiple application of multimedia resources, which have numerous advantages for the improvement of the students' learning outcomes. As the universities and other higher learning institutions reflect on the lessons learnt from the covid-19 pandemic, the future of engineering education is very bright and poised to becomemore inclusive, resilient, and flexible.

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