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REVIEW ARTICLE

Global Education in STEM and Healthcare: Implications of COVID-19

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ABSTRACT

The Coronavirus Infectious Disease 2019 (COVID-19) was declared a pandemic in March of 2020. Since then, most schools, colleges, and universities across the globe stopped delivering classes face-to-face and transitioned into virtual modalities of instruction. This reformation of academics has had an impact on every field of study, especially those students in the areas of Science, Technology, Engineering, and Mathematics (STEM), and in the realm of healthcare education. Ranging from middle/high school to undergraduate and graduate programs, STEM degrees require intensive curricula integrating extensive lectures on theoretical topics and laboratory exercises to apply those concepts in a practical setting. Likewise, healthcare education involves hands-on, clinical lab components working on patients, guided by supervisors. The guidelines developed by the Centers for Disease Control and Prevention (CDC) in the United States recommended refraining from these physical learning environments since social distancing has been an important preventative measure against the contagion. As in-person classes, labs, and residencies across the world were disrupted, students, faculty, staff, and administrators of STEM and healthcare fields had to face and navigate multifarious challenges to continue the education effectively, while maintaining safety. This review encapsulates such effects of the pandemic on STEM and healthcare education in various countries. The analysis aims to provide an insight into the strategies of distance education and alternative pedagogies for these disciplines adopted by institutions globally in the light of COVID-19, which could potentially serve as a reference model during any future pandemics.

Keywords: COVID-19 pandemic, Global healthcare education, Global STEM education.

1 Introduction

The Coronavirus Infectious Disease 2019 (COVID-19), caused by the novel coronavirus, Severe Acute Respiratory Syndrome Coronavirus 2 (SARS-CoV-2), emerged within China in December 2019 (Patel et al., 2020). This disease was declared as a pandemic on March 11, 2020 by the World Health Organization. Following this announcement, the United States declared a national emergency on March 13, 2020. COVID-19 is characterized by symptoms of cough, chills, fever, fatigue, muscle aches, and difficulty in breathing, among several other possible symptoms (McKechnie et al., 2020). In the United States of America, the Centers for Disease Control and Prevention has outlined specific guidelines for each type of organization to follow. These directions pertain to self-owned or commercial businesses, corporate sectors, or healthcare workers, students, and faculty in academic institutions, to name a few. Guidelines for the entire population include proper hygiene and handwashing often, maintaining a physical distance of at least six feet apart from one another, regular disinfection, and wearing a mask in a public place or in proximity to others. One study determined the characteristics of the virus through an examination of over 70,000 patient records in China (Zhi, 2020). This study revealed that, majority of cases (approximately 77.8%) were patients in the age range of 30 to 69 and (51.4%) male. Of 44,672 confirmed cases, 1,023 deaths have occurred, rendering a 2.3% fatality rate; the results determined that comorbidities such as cardiovascular

disease, diabetes, chronic respiratory disease, hypertension, and cancer lead to a fatality rate higher than patients without comorbidities (Zhi, 2020).

The novel coronavirus 2019 is a strain of the coronavirus family. There have been two previous coronavirus epidemics, SARS-CoV and MERS-CoV (Katirji et al., 2020). SARS-CoV originated in China and spread to over two dozen countries. In its wake, there were a total of 8000 cases with 800 deaths. MERS-CoV began in Saudi Arabia causing 2500 cases and 800 deaths (Cascella et al., 2020). In the 2003 SARS-CoV-2 epidemic, Canada and Hong Kong were two major locations affected. In Hong Kong, 17 medical students became infected with the SARS-CoV virus at the Chinese University of Hong Kong (Patil et al., 2003). This triggered a suspension of clinical training and academic meetings at every level from primary school to university and graduate schools. The solution chosen by medical instructors to continue education was to use PowerPoint files with the lecturer's voice embedded. Once there were no new reported cases, students were able to return to clinical trainings with adequate PPE as necessary (Patil et al., 2003). In Canada, some clinical activities and trainings were cancelled for students in any healthcare field including pharmacy, medicine, nursing, dentistry, and physical therapy (Clark, 2003). Any student or faculty member who may have had contact with someone infected or in a location in which someone could have been infected, such as the hospital, was required to self-isolate. Students not in a professional program, such as those in undergraduate training sessions, were unable to attend trainings in teaching hospitals. Once students have not been inside any clinical location for ten days, they were able to return to lectures again. There were no academic penalties on any student, given the circumstances (Clark, 2003). The 2003 SARS-CoV pandemic had developed a baseline understanding of how to deal with a widespread disease and so, some of the solutions used in this epidemic have been harnessed in the handling of the COVID-19 pandemic, such as the removal of students from the classroom.

Healthcare and STEM education involve the major areas overarching several subjects which require extensive lecture sessions complemented by active learning in a lab or clinical environment. In healthcare, courses center around pharmacy, medicine, nursing, dentistry, and so on. The curricula require a training program that can accommodate classroom lectures and time for lab with three dimensional simulations, models, live or preserved specimens, microscopy, physical/chemical/biological experimentation, and dissections, and/or clinical activities with patients. The education of these topics forms the basis for future pharmacists, doctors, nurses, and dentists that will be working on patients in their own field. Therefore, lectures and the hands-on practice are of the utmost importance to develop this base of knowledge and these foundational skills. Every subject in STEM requires an in-depth understanding using lecture sessions to introduce new concepts and build upon them. COVID-19 disrupted the live interactions of students with each other or with faculty in person and therefore, had to rely on virtual learning modalities.

2 Global Impacts of COVID-19 on Education in STEM and Healthcare

2.1 Effects on Secondary Education in STEM

In Hanoi, Vietnam, research questionnaires were distributed to over 1500 schools from Pre-Kindergarten to grade 12 to estimate the effects of COVID-19 on education (Tran et al., 2020). These questionnaires were directed at students interested in STEM-related or social science-related careers to compare effects of the pandemic on study habits. The students' learning habits, socioeconomic status, and desired occupations were taken into account. The surveys returned 420 valid responses which demonstrated studying over seven hours to be highest in percentage for students studying STEM-related fields of math and physics; studying from four to seven hours was highest for students also studying STEM-related fields of chemistry, math, and biology; and finally, studying under four hours was highest for students studying social science-related fields of literature, history, and geography. These results were consistent with increased studying time required by students in a STEM-related field to make-up for live lesson time lost as a result of COVID-19 (Tran et al., 2020).

In Zambia, the consequence of COVID-19 in terms of student performance was analyzed to determine the effects of virtual education on learning and retention (Sintema, 2020). In mid-March 2020, the Zambian government decided to close all academic locations indefinitely as a result of COVID-19. Interview data were collected from three teachers at a secondary school in the Chipata District of Eastern Province in Zambia. These teachers were a Head of the Mathematics Department, a Head of the Natural Sciences Department, and a science teacher. They apprehended that the lack of live contact between students and teachers would cause a drop in General Certification Examination (GCE) performance. Without a teacher, there is a decline in the commitment level of a child, a lot of work is assigned to account for lost lesson time, and some students are at a disadvantage with the lack of technology. There is also a disadvantage to STEM students deprived of access to materials and tools that would help them succeed in the GCE, such as labs or hands-on instruction (Sintema, 2020).

In Georgia, schools follow traditional and modern classroom education layouts with books, blackboards, and projectors as supplemental aids for teaching (Basilaia & Kvavadze, 2020). When the pandemic influenced schools across the world to convert to distance learning, Georgia introduced a study on 47 virtual classrooms using Google Hangouts at a private school of 920 students. An assessment was conducted every day to gauge success with online learning. After one week, a total 78 hours of screen sharing produced 513 hours of video and 605 hours of audio stream. Adjustments were made to class times across every grade. Before the pandemic, first grade students had 35 minutes of average class time while grades two through twelve had an average of 45 minutes. After the pandemic, all grades from one through twelve were limited to only 30 minutes of class time to minimize screen time of students. First and second grade students were adjusted to only two to three lessons a day, grades three to seven were adjusted to three to four lessons a day, and grades eight to twelve were adjusted to four to five lessons a day. The study concluded that students in lower grades were scoring better compared to those at higher levels (Basilaia & Kvavadze, 2020).

Science education is enhanced by problem-based questions to facilitate critical thinking among students (Ray & Srivastava, 2020). Massive Open Online Courses (MOOCs) in science, technology, and engineering were already developed and used prior to this pandemic. Supporting resources for lecture component of these courses are online videos, case studies, etc. A list of virtual labs has been compiled that simulate actual labs for students to learn the procedures and materials without the need for physical attendance. These labs also enable students to perform in research studies as they will need to represent their own background data. Due to COVID-19, these labs and lectures are being converted to online accessibility so that students can still have all of the resources necessary to succeed on exams and for future use (Ray & Srivastava, 2020).

2.2 Effects on Higher Education in STEM

Higher education in mathematics requires attentive students and a focused lesson using sample problems to reinforce the learning material. Mathematics classes are generally in-person, where the teacher provides notes on a whiteboard or chalkboard. In Zambia, all academic institutions were shut down with the emergence of COVID-19 (Mulenga & Marbán, 2020). The University of Zambia (UNZA) and Rusangu University (RU) declared that their schools will proceed with online learning, using various platforms, viz. Moodle, Astria, Google Apps, Edmodo, and various social media sites. In the Mathematics Department at Copperbelt University (CBU), 102 questionnaires were distributed to students pursing a Bachelor of Science in Mathematics Education to comprehend the extent of technology access. These surveys show that majority of students (52.9%) owned smartphones and approximately 46.1% had access to some form of tablet or computer (Mulenga & Marbán, 2020). The teaching styles that were explored involved four categories: video, live casting, social networking, and communication. Each of these teaching styles included tutorial videos, online lectures or discussion, sharing information, and book information (Mulenga & Marbán, 2020).

Physics, as a science discipline in STEM, is similar to mathematics in the development of the subject through visual and hands-on learning methods. Several universities across the world have derived alternative methods to allow students to have these same experiences from the safety of their home instead of in classrooms (Yadav & Darbinyan). At the University of Colorado, Boulder, a project, titled PhET, was developed with 150 interactive simulations in which students are immersed into an environment comparable with that of a video game. The PhET project integrates fundamental principles of physics into these simulations to provide key conceptual knowledge to students. In Singapore, a program, known as Open Source Physics Singapore, uses simulations to demonstrate how to use different lab tools. The general app of Open Source Physics has a centralized focus on computational physics and programming. Finally, Google apps are being utilized universally to share documents and connect students and teachers. The limitations noted by these endeavors include the inability to replicate a full experiment. Although it allows students to visualize the experiment, it does not replace the hands-on work in a lab. Yet, as of the current climate, these virtual experiments are the best option and even after the effects of the pandemic waiver, these virtual labs may still be useful to accompany the in-person labs (Yadav & Darbinyan).

Anatomy, another branch of life science within STEM, involves extensive information provided in lecture format supplemented by lab experiences to assist in visual and tactile identification of structures. As a result of the complete shutdown of educational institutions across the world, students must learn topics, such as anatomy, from within their homes without the access to the materials provided in school (Singal et al., 2020). Anatomy is a core component of the foundation of any healthcare knowledge and allows students to develop concepts of the body leading to further investigation of pathology, immunology, and so on. In order to supplement the lecture materials of anatomy, lab activities of cadaver dissection are provided to students. As a result of COVID-19, students can no longer access this procedure, nor can they access models, specimens, or microscope slides. Besides the effects of social distancing as a loss access to materials, academic programs ceased to acquire cadavers due to the potential COVID-19 risks. Without cadavers, institutions in the US and India investigated options of anatomy without the use of cadavers. The challenges faced in these investigations include the limitations of the student mind. Without the ability to hold and assess organs, students lose the ability to understand size ratios of organs and the body. However, cadaver dissection has been a practice that has been controversial in practice even without the challenges of COVID-19. Cadaver dissection allows students to practice surgical skills, but at the same time, causes students to lose the emotional aspect of working with patients. Yet, it is still an imperative procedure for students to be able to perform procedures from the molecular and microscopic levels to the surgical levels. Because of the pandemic, anatomy students have become without cadaver dissection as a supplemental learning tool; the timeline of this setback is unknown (Singal et al., 2020).

In Australia and New Zealand, regulations for isolation and distancing went into effect in March 2020 (Pather et al., 2020). Anatomists have been recruited to assist in the development of online programs and resources for students in universities to use to accommodate the new wave of virtual learning. One study focused on the disruption of anatomy in regions of Australia and New Zealand to determine the efficacy of online delivery of materials and the loss of study materials. The study revealed that the lectures were delivered through pre-recorded and live streaming methods for students to follow synchronous and asynchronous lectures. One school utilized only online resources, such as discussions and other activities to maintain engagement. Of the nine schools investigated, only one still has an open human body donor program whereas the other eight are suspended. The study found that students were more successful in anatomy courses prior to the pandemic with the access to resources and greater student engagement in lecture and lab. Videos and website resources were the new supplements to anatomy course material. Assessments have yet to be determined as of publication. Instructors have set guidelines to ensure constant and clear communication to all students with an understanding of coursework. Altogether, anatomy lectures and labs have faced a shift in quality of delivery without in-person and hands-on coursework (Pather et al., 2020).

In Ghana, students from universities, colleges, and some senior high schools responded to an online survey to determine how the conversion to online education has affected learning (Owusu-Fordjour et al., 2020). The survey produced results of over half of the students finding it difficult to study from home and nearly half find that learning alone and learning online is not as efficient as in the classroom. Thus, COVID-19 was noted to negatively influence academic performance of students and added to their struggle (Owusu-Fordjour et al., 2020). Besides, mental health of students has been adversely affected owing to the pandemic. Wuhan, China was locked down as of January 23, 2020, leading to closures of public facilities and transportation locations (Sahu, 2020). Of those public facilities closed were educational institutions leading to online delivery of courses instead of face-to-face meetings. As a result, technology became in high demand while there was a lack in access to such technology and internet. Exams were suspended given the inability to prevent cheating. Mental health across the student body has struggled due to the difficulty to ensure that every student has access to food, accommodation, and safety. The university developed a task force related to COVID-19. Since all sports events and large gatherings had to be cancelled, the task force developed a plan to allow students to remain in contact with one another for positive mental health strategies (Sahu, 2020).

Pathology as a science course is the study of disease. Generally, education in this subject relies on the use of microscopes and specimens to demonstrate various samples collected from patients. Yet, with the parameters of six-foot social distancing and the inaccessibility of students to microscopes or specimens, education in this subject has now had to re-focus using online platforms (Kwon et al., 2020). One solution, like the one used by other education topics, is to use as much of the virtual programs offered as possible. Schools are setting up meetings in which participants can join and talk through live video and chat. Some challenges with this include the decrease in student engagement and potential for technical issues with working with technology. These challenges are being prevented by having students leave their webcams on, having a member of IT support available, and using phones for dial-in connections. In order to continue the study of pathology using a microscope and specimen slides, remote scopes are being used. Video broadcasts allow the specimen under the microscope to be viewed by all participants in the chat enabling students to visualize morphological differences between specimens and the necessary information for exams. The combination of activities, slide-based learning, and microscope visualization allows pathology students to continue their education with the assistance of these supplemental tools (Kwon et al., 2020).

The third overarching theme of STEM is engineering. Engineering students depend on hands-on curriculum to demonstrate their knowledge of concepts within their field of engineering. Students from the Information Technology University in Pakistan, Hamad bin Khalifa University in Qatar, and Western Michigan University in the USA provided a comprehensive guide for engineering students to navigate education during the times of COVID-19 (Qadir & Al-Fuqaha, 2020). The guidelines provided by these students outlined seven steps of familiarizing oneself with the objectives, focusing on fine tuning learning methodology, aiming for a new thinking methodology, developing the ability to self-assess, conducting active learning, grasping concepts of greater themes, and committing to a continuous practice of these methods. These methods are designed to enable engineering students to learn independently when faced with a remote style of learning. The National Engineering Academy (NEA) depicts the necessity for students to engage in critical thinking to solve engineering-based questions. The National Academy of Engineering reports engineers should have a broad scope of knowledge to tackle inquiries in any field. This series of methods continues to discuss effective learning strategies students can use to mediate their own learning. The purpose of this study was to assist engineering students and outline the necessary tools to successfully self-study in a time of COVID-19 and quarantine (Qadir & Al-Fuqaha, 2020).

2.3 Effects on Healthcare Education

Healthcare education is built by a foundation of hands-on lessons and clinical experiences to develop the skills necessary to become successful healthcare professionals. The hands-on lessons and clinical experiences work simultaneously with in-person lectures to cultivate a meaningful background in medical

education. Due to the limitations of being in the lab, clinical settings, or classroom by COVID-19 restrictions, students face a lack of the necessary tools for success in their examinations and future careers. This demand for adequate medical education resources has inspired a renovation of the medical school curriculum. Even before the pandemic, attendance in classrooms has declined after it was no longer required and the lectured were published online as recordings. These minor changes already occurring has produced a baseline for the changes caused by the pandemic. Online recorded lectures have produced results of saving time for students by enabling them to pay more attention to difficult subject matter (Emanuel, 2020). There are also online resources available to students, such as Pathoma to study pathology online and YouTube for extra lecture materials. The challenges associated with online instruction include the lack of necessary materials. Medical school employs several aids to lectures, including cadaver dissection, group discussion, and more. The alternative solutions provided to these challenges involved virtual and augmented reality for visualization of dissections and labs and the use of online platforms for group discussions (Emanuel, 2020).

Medical student education is now relying on technology in the time of COVID-19 (Rose, 2020). Anatomy and labs can be held virtually accompanied with the opportunity to have group discussions and individualized learning. In the Pre-clerkship environment, lecture halls are limited due to the social distancing guidelines. Therefore, lessons and group discussions, exams and clinical sessions have transitioned to a remote virtual format. In the Clerkship environment, medical students work in clinical settings in a group environment under supervision. In past disasters, such as in natural disasters or events like 9/11, students were still able to continue their education and help out in the effort [36]. Yet, in the pandemic, this option is not possible due to the limited PPE, lack of COVID-19 testing, and potential to contract or transmit the virus. The Association of American Medical Colleges (AAMC) determined on March 17 novel guidelines for all medical schools to review; however, they were to be followed by the discretion of the school (Rose, 2020).

An estimated two hundred medical schools in the US have suspended or cancelled activities in clinical settings for medical students (Newman & Lattouf, 2020). First and second year students are at a slight advantage given that their programs are lecture-based curriculums. However, third- and fourth-year medical students spend most, if not all, of their time in clinical settings. Some schools have chosen to allow students to fulfill graduation requires that can be online virtually and once there is a safe way to continue clinical rotations, they can finalize those requirements. Therefore, third year students are finishing fourth year requirements before completing third year requirements. One school has given students in their third year a new curriculum in which they do not attend clinicals. In this case, students attend lectures via web apps, like Zoom, and supplement their instruction with medical-based apps and programs. For now, these new approaches to the third- and fourth-year education as well as to hands-on education in general are being used until a vaccine for COVID-19 is developed or a plan for classes to be held safely is developed (Newman & Lattouf, 2020).

In the United Kingdom, all medical students and shadowing students were suspended from attending any clinical activities as of March 2020 (Ahmed et al., 2020). This decrease in the ability to view clinical education experiences caused a reduction in exposure to different specialties, ultimately leading to a decline in exam performance. These medical school exams are developed with the intention that medical students are attending clinical settings and clinical workshops for background knowledge (Ahmed et al., 2020). In another setting in the UK, healthcare education was continued using technology (Wyres & Taylor, 2020). Cameras that had 360º field-of-view were installed in medical situations to allow students to view a virtual scene and guide their learning. Footage, stimulation, and case studies are supplemental materials for students to watch certain tasks, repeat difficult lessons or task procedures, and use critical thinking to understand the situation of the case study. SIM Share is a website developed to provide medical students with additional materials to supplement classroom lessons. SIM Share incorporates videos, extra courses, documents, and more as external resources (Wyres & Taylor, 2020).

In China, investigators examined the faults of the medical school and public health education system (Yang et al., 2020). This study highlighted the impact of the developed medical education system on COVID-19. It outlined the unpreparedness of the public health emergency system, the inability to handle interdisciplinary cooperation, and the lack of focus in medical ethics. Chinese investigators have agreed that there has been a delayed and insufficient response of medical professionals in the handling of this pandemic. There has also been a lack of communication between medical professionals in different fields to enhance the understanding of the virus. Finally, there has been discrimination against certain patients as a result of the virus. Therefore, the COVID-19 pandemic has inspired a wave of reformation of the Chinese medical education system (Yang et al., 2020). In Brazil, moreover, the population has feared the pandemic effects given the already overwhelming large volume of patients to low population of health professionals given that Brazil is a developing country (Carvalho et al., 2020). Students and instructors call for a reformation of the medical education at Brazil in accordance with the pandemic. There is a call for virtual education to be mandatory so that students may continue learning in safety while still being able to remain in contact with instructors and the hospitals. This, in turn, would overall improve the exchange of knowledge. One challenge that has been discussed is the lack of access to the necessary technology. Officials determined that the best course of action to manage the pandemic and, also to reform the medical education in Brazil, would be to guarantee equal access for all students to education. Due to COVID-19, much needed reforms are now being brought into light and enforced across the world for better medical education (Carvalho et al., 2020).

COVID-19 has had a similar impact on students pursuing education and careers in dental medicine. In the United States, COVID-19 has developed concerns regarding the safety of the students, faculty, and patients as well as concerns for the continuation of education and studies. The Commission of Dental Accreditation (CODA) has developed an obligation for all 67 American dental schools to provide a testimony to support distance learning, an alternative to assessment administration, and a modification to student curriculum (Iyer et al., 2020). The challenges stressed by these dental schools include the suspension of all clinical activities with the exception of emergency cases and the inability to properly social distance in pre-clinical simulation labs. Without proper social distancing available, the labs would have to be transitioned online; however, the mannequins used in these simulations are not a viable option virtually and the virtual reality systems cannot be distributed to students. Most of the dental schools have opted to transition to remote settings, but still face the challenge of determining student competency without the administration of exams (Iyer et al., 2020). In European Dental Institutions, alternatives to clinical settings are being explored. These alternatives include instructional software, live videos, external resources online, virtual meetings, and group discussions using social media sites (Quinn et al., 2020). All assessments have been postponed or transitioned to an online format and program dates were extended. Students were provided with a support contact number for academic-related inquiries and emergencies. Online meetings were developed to aid in the support of students during these uncertain times. The long-term challenges envisioned as a result of the COVID-19 pandemic include the uncertainty of the timeline of this virus, the increased risks of COVID-19 transmission due to the environment of dental education, and the deployment of dentists away from their routine schedule to the frontlines to assist with the COVID-19 battle (Quinn et al., 2020).

Pharmacy students from the Cedarville University School of Pharmacy have improvised in the time of the pandemic by accumulating educational background in alternative forms (Weinstein, 2020). These pharmacy students have managed to discover a way to assist on the frontlines in several ways. Some students have been providing medications for employees and patients at Cleveland Clinic. Other students have been assisting pharmacies with curbside pickup (Weinstein, 2020).

Nursing education was adjusted in the addition of protocols related to safety in the time of COVID-19 (Nashwan et al., 2020). Nursing students have now had to undergo fit-testing for N95 masks and have received PPE necessary to continue education in the clinic. Education was also reformed for nursing students in the addition of courses on triage awareness and procedures, such as nasopharyngeal

and oropharyngeal usage safety. Unlike other healthcare fields and STEM education, nursing education is an in-person field-of-study. Therefore, a new addition to each program was a training program for nursing educators to follow to assist them in the transition to an online curriculum (Nashwan et al., 2020). Students in undergraduate nursing education in Scotland face similar challenges with a lack of proficiency in virtual classes by nursing instructors (Carolan et al., 2020). This challenge is accompanied by other challenges of restructuring clinical requirements, students' acceptance of a virtual nursing program, and access to technology and technology support. In the United Kingdom, student nurses have been recruited to volunteer for paid clinical placements. These clinical placements are offered for students to continue their clinical education while assisting on the frontlines of this pandemic. Similar programs have been offered in Australia as this pandemic has caused universal clinical cancellations. For other students, the National Council for State Boards has determined to enable clinical hours to be earned through virtual simulation courses. Medicine in the UK, much like in the USA, has transformed into remote virtual appointments. The academic institutions in the UK followed this change with integrating face-to-face classes into synchronous classroom meetings online. Officials have investigated underlying factors that would affect the efficacy of online learning. These factors include the student environment of isolation or potential distractions, modified curriculum, time, and cost. The modeling of the modified curriculum involves a transformation from serial teaching to parallel teaching in which mediate concerns for social isolation and environmental problems as well as cater to time issues. The overall curriculum and method of delivery of this curriculum has been reformed and continues to evolve with new information regarding student situations and available resources (Carolan et al., 2020).

Overall, nursing education has been greatly impacted, similar to other healthcare programs. Colleges and universities struggle to counter the challenge of student engagement while maintaining ethicality in grading and still answering questions regarding the inaccessibility to technology and internet of some students. The American Association of Colleges of Nursing proposed an addition of coursework to the students already rigorous load, this coursework focused on infectious diseases (Morin, 2020). More specifically, this coursework is covering important topics related to safety during the COVID-19 pandemic including proper handwashing techniques, quarantine, hygiene, and more. Institutions are also considering a restructuring of programs to fit more coursework into less time. Some programs have examined the possibility of having new methods of testing and evaluation of students. Given the circumstances of this pandemic as being unknown, the routes to which nursing schools will evolve to are still changing; however, many options are being considered as to how to effectively train the next generation of nursing students to handle their regular duties as well as in the environment of a pandemic (Morin, 2020). In Canada, one academic nursing program determined the best option was to cease all clinical practicums as of March 15, 2020 (Dewart et al., 2020). One of the requirements of the Bachelor of Nursing degree is to attend in-person clinical placements. However, due to the guideline requirements set by the CDC and enforced by officials, this is not a feasible option for students to complete. Athabasca University in Alberta transitioned into a fully online program quickly. Due to the risk of COVID-19 exposure in clinics and the necessity of clinical instructors to assist on the frontlines, the decision to hold all learning online has created a safe environment for students to still learn the material necessary to succeed on exams. As of now, officials in Canada are still attempting to create a reasonable solution in which students can attend clinical without the risk of COVID-19 exposure (Dewart et al., 2020).

One of the external resources available to medical students are narrative medicine workshops (Iwai & Lusk, 2020). Narrative medicine workshops are reflective environments developed through the Columbia University Narrative Medicine master's program. These reflective settings are workshops in which connect medical professionals and students to channel thoughts and inquiries through writing or discussion. A case study focused on six 90-minute workshops aimed to assist pre-medical students in their pursuance of medical school. As a result of COVID-19, attendance expectedly declined after the program was held virtually. In order to maintain interest, attention, and participation, program directors declared that these meetings would be reduced to only an hour long and the attendance requirement would be waived. For

students that did attend, webcams needed to be activated and any questions were asked via audio delivery rather than chat methods to increase engagement. These methods proved to be effective in increasing engagement while still maintaining a safe space for students (Iwai & Lusk, 2020).

Comparable to STEM education students, one of the concerns of a possible impact due to the COVID-19 pandemic was pressure on mental health and well-being of healthcare students. One study interviewed students at Sichuan University in China (Li et al., 2020). The study concluded that, after two weeks of nationwide quarantine, health professional students showed approximately 26% reporting clinically significant psychological distress and 11% meeting criteria for acute stress reaction. Approximately 9% showed signed of both psychological distress and acute stress reaction. This data demonstrates stress related to the COVID-19 outbreak and the potential impact on healthcare education and knowledge retention that these students face (Li et al., 2020).

2.4 Effects on Healthcare Residencies

After medical school, newly graduated doctors continue the path to medicine in residency programs. These residency programs focus on work in the hospital, shadowing attending doctors for experience. Without adequate PPE or sufficient opportunities of elective surgeries, there is a strain on residency programs across the world as students are not achieving program requirements involving clinical hours.

In Washington State, the first confirmed case of COVID-19 was January 20th of 2020. On March 13th, the American College of Surgeons internationally declared a recommendation to stop all elective surgeries. Rotations for students in residency training were cancelled to reduce potential exposure to COVID-19 and prevent the depletion of personal protective equipment (PPE). At teaching hospitals, there was a reduction in surgical volume, lack of PPE, and cancellation of didactics in person. This shift in hospital routine caused a shift in education for neurosurgery residents in Washington State (Bambakidis & Tomei, 2020). The Association of American Medical Colleges (AAMC), Accreditation Council for Graduate Medical Education (ACGME), American Board of Medical Specialties, and American Board of Neurological Surgery made several recommendations to mediate this shift caused by COVID-19. These recommendations included the suspension of medical student-patient contact, adequate supervision provided for students with patients with potential COVID-19 cases, the prevention of punishing students for measures that they have no control over, and the postponement of examinations (Bambakidis & Tomei, 2020). The reduction of neurological surgeries to only emergencies; including neurotrauma, shunts, stroke, malignant tumors, cord compression, and aneurysmal subarachnoid hemorrhage; and the transition to telemedicine has put a strain of the ability of the neurosurgery residents to learn. The firsthand experience in the hospital and operating room is paramount to the success of residents in their exams as well as in their future careers as neurosurgeons. The Congress of Neurological Surgeons (CNS) and American Association of Neurological Surgeons have ensured that online education has become an available option as well as a Virtual Visiting Professor Program. In these virtual portals, residents have the opportunity to connect with professors and neurological healthcare professionals to continue their studies (Bambakidis & Tomei, 2020). The academic neurosurgery department at Johns Hopkins shares similar feedback regarding education during the COVID-19 pandemic (Khalafallah et al., 2020). Hopkins academic department analyzed the statistical data of student performance before and after the pandemic began. The data generated results of a deduction in surgery numbers from 120 cases to 17 cases. This great decline in surgeries has created a reduction in the ability of students to benefit from valuable clinical exposure, therefore enhancing their medical knowledge (Khalafallah et al., 2020).

Urology residency training has felt the waves of impact from the COVID-19 pandemic. Urology residents have faced a modification to their training to prevent the spread of COVID-19 while also continuing their education through residency (Kwon et al., 2020). There is a stressed necessity of PPE and available COVID-19 tests to ensure a safe environment while working in the hospital or clinic. The demand for PPE has increased, perpetuating a demand for PPE training for all healthcare workers. Tests are needed to determine exposure risk of COVID-19 and asymptomatic carriers. The hazards for urology residents

involve common procedures of bag-mask ventilation, endotracheal intubation, and laparoscopic surgery. Each of these procedures introduces airborne transmission risks as they are aerosol-generating measures. Given these circumstances, urology residents are required to leave the room during intubation procedures and adhere to proper PPE standards. There has also been a reformation of the hospital protocols and residency program. Any patient going to the operating room is to be tested for COVID-19 and all precautions all followed to prevent transmission COVID-19. Rotating teams cover urology services with assigning individual residents to make rounds and handoffs as virtual instead of in-person. All non-urgent cases are transitioned to telemedicine. Urology residents were also deployed to areas of increased demand, such as the emergency room and intensive care unit (ICU) per novel protocols of the ACGME. Finally, clinical training was expanded to involve training in the ER and ICU instead of only urology sites and the use of simulation for surgeries was implemented in which fundamental surgical skills were demonstrated through home laparoscopy training and virtual reality (Kwon et al., 2020). On a similar note, urology residents in Italy have experienced a comparable transformation of training (Amparore et al., 2020). Across the world, urologists have been recruited to allocate some or all of their time to COVID-19 management. Thus, Italy and other countries have seen a decline in the clinical and surgical case load of urology patients. Prior to COVID-19, 87.2% of urology residents routinely worked on-call duty, whereas during COVID-19 there was a sharp decline to only 12.3% of urology residents working on-call duty. This intense regression was produced across the board for urology residents with a drop in rates in out-patient visits, diagnostic procedures, endoscopic surgery, open major surgery, and miscellaneous procedures; these deviations are the result of COVID-19 impact on safe practicing of urological medicine and urological procedures (Amparore et al., 2020).

In the case of students pursuing residency in general surgery, the Division of General Surgery at the University of Washington has provided a complete program restructuring plan to accommodate student education and student safety in the times of this pandemic (Nassar et al., 2020). This plan is a four-series establishment in which physical distancing, team structure, macrostructure, and conceptual points are accounted for. Within physical distancing, there is a plan to have virtual rounding, handoffs, and communication, and work with assigned teams, workstations, and bedside rounds. The team structure involves larger teams with independent terms within. Residents at every level are assigned to these teams. Members affected by illness are supplemented with research according to the macrostructure division. Finally, a committee has been developed for the review of triage and implementation of these new revisions. These modifications ensure that general surgery residents are still able to participate in clinical activities while still adhering to COVID-19 protocols (Nassar et al., 2020).

Radiology residency programs developing new program guidelines for faculty and students to follow to ensure proper education, clinical experience, and safety (Chong et al., 2020). The first part of the plan developed a redistribution of work following the stages of the Accreditation Council for Graduate Medical Education (ACGME). Stage one is a normal business day; stage two is an increase for demand of clinical work and transitioning to remote and virtual education; and stage three is pandemic emergency status in which there is suspension of programs and strict protocols in place. The next part of the plan ensures physical distancing with specific resident-attending assignments and the cancellation of procedural rotations. Then, staff and patient protection were emphasized with the re-training of all staff and students on infection protection, PPE, proper handwashing, and distribution of thermometers and health kits. Education was transformed into virtual conferences, interactive teaching, and external online tools. Novel websites have been created to assist radiology residents with radiology-specific education. These websites include the Radiological Society of North America Diagnosis Live, Society of Thoracic Radiology online course, Skeletal Radiology online course, and more (Chong et al., 2020). Students were also provided with a research project development to keep them actively studying and critically thinking. Disaster preparedness training was provided to all residents and healthcare workers prior to their deployment to the emergency room to assist with the pandemic. Finally, requirements for radiology residents were expanded to include

telemedicine opportunities and certain procedures were made available for residents to accomplish clinical hours, such as mammography (Chong et al., 2020).

Emergency medical student residents are affected in the decline of clinical exposure, too (Katirji et al., 2020). One of the requirements of medical students and residents is to have Standardized Letters of Evaluation (SLOE) to determine program acceptance of residents. These SLOE are letters produced by clinics in which the student is working at to demonstrate the abilities of that student. Due to the travel restrictions and rotation closures caused by the pandemic, students have been unable to attain these letters. Therefore, the Council of Residency Directors in Emergency Medicine (CORD) and Advising Students in Committee in Emergency Medicine (ASC-EM) have produced flexible program requirements. There are new weight alternatives to these letters and the ability of students to express their loss of opportunities to the council for further determination. These councils declare that students should not go on away rotations and if possible, they should rotate at the emergency room nearest their home (Katirji et al., 2020).

Students pursuing education in plastic surgery have been provided with free access to an online education program (EdNet) by the American Society of Plastic Surgeons in which they can explore modules related to lectures, discussions, and case studies related to their field of study (Abi-Rafeh & Azzi, 2020). The Online Education Network gives students access to everything within the field of plastic surgery and it is free to use. Other programs being explored include Yale University Virtual Grand Rounds, UC San Diego Virtual Grand Rounds in which students can attend weekly virtual rounds for lessons in plastic surgery (Abi-Rafeh & Azzi, 2020). Furthermore, continuing medical education (CME) provides education in plastic surgery as do Ortho Bullets, Plastic and Reconstructive Surgery Journal Clubs, Aesthetic Surgery Journal Club, and so on. This list provided by one study contains 18 study materials for students focused on the field of plastic surgery. Each of these programs provides pre-recorded and live videos for students to visualize procedures or activities in which they can follow along and participate. While students cannot be physically in the hospital or clinic due to COVID-19, the American Society of Plastic Surgeons has ensured students have access to free services online in which they can continue learning necessary procedures and information in their field (Abi-Rafeh & Azzi, 2020).

Similar to the conversion of STEM labs to online mode, administration at medical schools have researched new methods of delivery of instructional materials to students in surgical residencies (McKechnie et al., 2020). One method has been the use of computer-based programs. The Surgical Council on Resident Education has provided a virtual training program with modules for students to study from to succeed on board exams. Other programs offer virtual surgery simulations to watch surgeries or interact with the programs. There are also atlases available for students to cover head-to-toe the necessary curriculum related to surgery, from anatomy to different procedures. In addition to the computer-based programs, phone-based programs have been made available in which students can use apps to learn step-by-step surgical procedures and cover the necessary information required for exams (McKechnie et al., 2020).

3 Discussion

Global education in STEM and healthcare have been immensely affected by the COVID-19 pandemic. Significant findings when researching the effects of this pandemic on secondary and higher education in STEM reveal removal of opportunities for hands-on, active learning of experiential courses in a live classroom. Students, faculty, and institutions across the world rely on in-person classes owing to several reasons. For some, interpersonal interactions within the campus environment fosters the candidate's mental health and wellness. For most, it is the real access to teachers and professors that engage students to learn, understand, and apply the concepts as students must pay attention, participate, develop class manners or etiquette, and gain working knowledge of lab safety. In secondary and undergraduate education, new programs have been designed for students to perform simulations to observe and learn about the practical applications without the requirement of physical attendance. Most important, exposure to actual lab equipment or practical activities/experimentation are not available at home. COVID-19 has added to a

plethora of challenges already faced by college STEM education in recent years, necessitating novel strategies of effective teaching and assessment online (Arguello et al., 2020; De & Arguello, 2020; Santanu De & Georgina Arguello, 2021; Santanu De & Georgina Arguello, 2021). Results of a recent STEM education project involving a biochemistry course-based undergraduate research experience (CURE) demonstrated differences in efficacy of anticipated learning outcomes (ALOs) and participant perception indicator (PPI) surveys as novel assessment tools for research-based science lab courses run in person versus online (Kapil, De, et al., 2021; Kapil, Gonzalez, et al., 2021; Kapil, Pathak, et al., 2021; Kim, Haughton, et al., 2020a, 2020b; Kim, Muchintala, et al., 2020; Pathak et al., 2021).

In healthcare education, face-to-face lab resources such as models and microscopic tissue specimens as well as organ dissections, are even more essential. This is because in healthcare education, these experiences pave the foundation of students' future careers in medicine or research. Cadaver dissections at several higher educational institutions have been indefinitely limited due to the potential risk for COVID-19 transmission. Additionally, healthcare students need to participate in clinical settings to put the conceptual knowledge to test; they have to engage with patients by shadowing medical practitioners, assisting nurses, etc. to demonstrate thorough understanding of the profession and the required skills. However, due to the risk of COVID-19 exposure and transmission, most clinical rotations have been suspended. These cancellations affect students from graduate and professional schools to residency programs. Most officials overseeing each of these programs have developed a plan of action for students and faculty to safely continue the education. In healthcare, some criteria are being waived for programs; for instance, exams are being made virtual, postponed, or converted to project-based assessments. Students are rotating in hospitals in smaller groups to decrease the risk of exposure.

COVID-19 has impacted practically all global academic sectors, some of the most affected of which are education and research in healthcare and STEM (Autore & De, 2021; Autore & De, 2022; Autore et al., 2020; Autore et al., 2021; Hallett et al., 2021; Hallett & De, 2020; Hoang & De, 2021; Hoang et al., 2021). However, it has especially increased the demand on STEM and healthcare educators, students, and officials, individually and in collaboration, to strive for the pursuit of effective education despite the disruptions. In this context, it might be useful to promote innovative, online technologies to attract and engage the youth to STEM education by possibly leveraging free/low-cost mobile applications with real-world relevance (De & Nethi, 2019; De & Nethi, 2020; Nethi & De, 2019; Nethi & De, 2020), or to healthcare education through virtual classrooms (De & Cavanaugh, 2020). Discipline-specific leadership forums, such as a recent one organized to discuss emerging ways of increasing active learning among students and exchange ideas on effective technology usage to reach out to students via supportive digital course material (De, 2020a), could be all the more meaningful during pandemics like COVID-19. On the other hand, due to the worldwide socioeconomic crisis arising out of the pandemic, it could be useful to spread awareness among people, particularly in developing and underdeveloped countries, about food safety and scientific research strategies to meet the increasing requirements of food-supply and nutrition (De, 2010; De, 2019, 2020b; De & Bandyopadhyay, 2008).

4 Conclusions

COVID-19 has been one of the most devastating global disasters in recent times. This pandemic has caused worldwide lockdowns with mass quarantines following recommendations of social distancing in order to prevent transmission of the disease. The global shutdown included suspension of academic institutions and programs, among the most important of which are in the fields of STEM and healthcare. STEM programs entail intensive lessons in the classroom complemented by hands-on lab activities. Healthcare students develop a foundation of medical knowledge in the classroom lectures and build on that with the use of laboratory and clinical hours. With the closure of academic institutions and students sent home, access to these in-person experiences suffered and online instructional modes had to take over. Schools, colleges, and universities strived to continue attaining the expected learning outcomes in order to maintain the rigor and quality of the courses and curricula. Challenges of e-pedagogy also included ensuring student

participation to promote active learning, especially in experiential courses within STEM and healthcare disciplines, while implementing anti-plagiarism strategies during exams. The programs adopted synchronous online lecture meetings and virtual labs, digital simulations, e-learning platforms, cost-effective mobile applications or other open education resources, and more. Alternately, some institutions undertook the more flexible, asynchronous delivery of course content to allow students at different time zones access the recorded classes whenever convenient per their new schedules, inspiring greater academic potential that students can review difficult topics in STEM and healthcare. Faculty held virtual office hours to help one-on-one interaction with students. Grading criteria for courses as well as requirements for graduation or certification such as in-person assessments were adjusted or postponed. This paper presents a comprehensive review of the impacts of COVID-19 on healthcare and STEM education, globally. The analysis could help restructure educational approaches in these disciplines during any further pandemic. A limitation of this study is its inexhaustive nature owing to fresh reports on this topic that continue to be published, since the pandemic is not over yet. However, the work forms a foundation for recommended future projects focusing on novel approaches to counter the challenges associated with virtual learning, as well as address mental health concerns among students struggling to excel or cope in absence of physical exposure to the tactile subjects of STEM and healthcare education.

5 Declarations

5.1 Study Limitations

Due to the ongoing status of the pandemic, new publications on the topic are continuing to be generated in different nations. Therefore, this literature review does not provide an exhaustive list of all the effects of COVID-19 on healthcare and STEM education reported globally yet.

5.2 Competing Interests

The authors declare no conflicts of interest.

5.3 Publisher's Note

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