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GRADUATE REVIEWS

Worldwide Consequences of COVID-19 on Research in STEM

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ABSTRACT

A global public health emergency like the Coronavirus Infectious Disease 2019 (COVID-19) pandemic requires accurate and timely data collection in the research community. High-impact research in science, technology, engineering, and mathematics (STEM) has been prioritized in the fight against COVID-19. The present study analyzed the consequences of COVID-19 on STEM research and the collaboration between research institutions and industries worldwide. It was noted that COVID-19 had caused significant delays in non-COVID-19-related research projects and the onset of several remote studies. Most importantly, researchers in the STEM fields directed their attention and expertise to help mitigate virus transmission, treat patients, and implement appropriate public health interventions. Innovations are being integrated in several fields of technological and engineering research to provide optimal patient care and enhance physical distancing measures. Global research platforms are also designed to encourage accelerated research, especially in potential medicinal treatment. Collaboration amongst different disciplines and countries has enabled remarkable progress in the dissemination of scientific knowledge and appropriate responses to address the multifaceted effects of this pandemic on global research in STEM.

Keywords: COVID-19, worldwide consequences, STEM research

1 Introduction

With more than 500 million confirmed cases across the world along with over 6 million deaths and counting, the Coronavirus Infectious Disease 2019 (COVID-19) pandemic has imposed a devastating global health challenge. Healthcare workers, public health professionals and researchers are working constantly in developing treatments and solutions to mitigate virus transmission. With the increasing fatalities in counties around the world, there is an urgent need for the global academic research community to respond to this public health emergency. Addressing a complex crisis like COVID-19 requires knowledge from all dimensions of academia. As a result, many researchers in science, technology, engineering, and mathematics (STEM) fields are joining forces to improve public understanding of the disease, track reported cases and develop containment and treatment solutions. Computational scientists, artificial intelligence (AI) experts, engineers and mathematicians are among the many individuals that can contribute to pandemic efforts. As many non-COVID-19 laboratories studies came to a halt, more opportunities in COVID-19-based research unfolded. This study will cover the impact of COVID-19 on research in STEM.

2 Impact of COVID-19 on Institutional and Industrial Research in STEM

Since the onset of the pandemic, research institutions have restricted several non-COVID-19 related laboratory studies. Onsite research has been reserved for essential projects and strict social distancing policies have been introduced. Essential onsite research has also limited the number of lab staff, permitting one laboratory personnel at a time [1]. Rutgers University in New Jersey, US is one of the many major research institutions that has called all non-critical research to be carried out remotely while encouraging clinical COVID-19 research [1]. The university's Cell and DNA repository organized high-throughput testing services for the virus, analyzing around 10,000 samples daily [1]. Similarly, immunology laboratories have halted non-COVID-19 research to study the immunopathology of SARS-CoV-2 [2]. As for several cancer research projects in hospitals, COVID-19 disrupted in-person appointments and study visits, drug accountability audits, outcome assessments and research staff training [3, 4]. Many of the research staff and resources have been relocated to COVID-19 cases instead. Remote research studies are still conducted through virtual modes, decreasing the time and cost of these projects while increasing the ease of participation. Online advertisements are used for recruitment, assessments have occurred through online platforms, and interventions are carried out through mobile reminders [4]. These remote methodologies have led to increase speeds in publications and reduced bias in assessments due to the removal of face-to-face communication [4]. With the pandemic being the new focus of scientific investigation, there is a substantial volume of COVID-19 literature published, 30% of which has originated from China and 14% from the United States [5]. Based on recent survey-data, it has been recommended universities and employers in the US carefully consider the uncertainties of foreign-born Early Career Researchers (ECRs) amid COVID-19, and reduce the adverse effects of national policies on their academic experience, while giving extra assistance during their career transitions [6]. Many different institutions, industries, and counties around the world have offered diverse competencies and resources to address the pandemic, encouraging global research collaboration.

3 Impact of COVID-19 on Science Research

The scientific community has made tremendous progress when responding to COVID-19. Robust research on SARS-CoV-2 and its impact on humanity is generated at an astonishing rate. Many of these research areas include characteristic of SARS-CoV-2, potential medical treatments, environmental impacts of the pandemic and the behavioral science behind physical distancing. Due to the multitude of research topics in the field of science, the impact of COVID-19 on biomedical, environmental, social, and behavioral science research shall be highlighted here.

Research on the structural characteristics and bioinformatics of SARS-CoV-2 has enabled scientific communities to understand the virus' transmission, trace the outbreak, and determine necessary epidemiologic controls. Within one month of the incident case, Chinese scientists isolated the virus and sequenced the viral genome [7]. On January 12, 2020, the full-length genome sequence of SARS-CoV-2 was shared with the World Health Organization. Researchers were able to determine the sequence homologies with other viruses, including a 79.6% shared sequence identify with SARS-CoV, 50% identity with MERS-CoV, and 96% identity with bat corona virus [8]. This enabled further understanding of possible hosts and the initial emergence of the virus. Since then, many independent investigative groups worldwide have been able to isolate the virus and share the sequences publicly on the Global Initiative on Sharing All Influenza Data (GSAID) database. The first clinical study was conducted from the Jun-yin-tan

Hospital in Wuhan on 41 confirmed COVID-19 patients, 66% of which had direct exposure to the Huanan seafood market [9]. Huang et al. determined the epidemiological, laboratory, clinical and radiological characteristics of the patients. They also reported the clinical outcomes of using a combination of lopinavir and ritonavir treatments [10]. Further studies observed radiological characteristics of COVID-19 chest CT scans and determined the common symptoms of the disease [9]. The first autopsy performed on a Chinese COVID-19 victim allowed researchers to understand the organs affected during the disease [9]. Angiotensin-Converting Enzyme 2 (ACE2)-positive cells and lung progenitor cells are generally decreased in older adults compared to children and mainly presented in the lower pulmonary tract; these risk-factors might affect the disease severity and recovery from SARS-CoV-2-caused pneumonia infection in older patients [11]. However, infants below one year of age infected with SARS-CoV-2 are more vulnerable to lung injuries; risk factors could encompass ACE2 expression in several types of lung cells including SOX9 positive progenitor cells, along with an immature immune system [12]. Numerous of such laboratory and clinical discoveries have aided COVID-19 diagnosis and demanded further research on antiviral therapies and vaccines.

Many companies have executed clinical trials to repurpose drugs and develop vaccine against SARS-CoV-2 [13]. The development of COVID-19 vaccines has been analyzed from multiple perspectives, highlighting the reactions and efficacy of the authorised vaccines, along with the storage, mechanisms, and dosage specification of vaccine candidates at the advanced stage of development, while also indicating potential challenges [14]. In a quantitative synthesis of phase III trials to identify altering factors that could affect the clinical efficacy of COVID-19 vaccines, network meta-analysis ranked the effectiveness in the following order: BNT162b2 ≃mRNA-1273 > Sputnik V >> AZD1222 [15]. More recently, the deadlier and highly mutated variant of SARS-CoV-2, named Omicron, has shown advanced transmission and partial resistance against COVID-19 vaccines [16]. Biotechnology organizations and medical research agencies such as the National Institutes of Health (NIH) in the US carried out randomized controlled treatments with major drugs that have the potential to treat hospitalized COVID-19 patients [13]. The drugs researched included Sarilumab, Remdesivir, Methylprednisolone, and Hydroxychloroquine. Capital Medical University and China-Japan Friendship Hospital conducted clinical trials on the efficacy of Remdesivir on adults with severe cases of COVID-19 [17]. Unfortunately, the intravenous Remdesivir showed no clinical improvement or clearance of the virus in patients. Researchers at Emory University, University of North Carolina, and Vanderbilt University Medical Center studied EIDD-2801, a new ribonucleoside analog drug that showed antiviral properties against Remdesivir-resistant viruses [18]. EIDD-2801 has been reported to effectively prevent and treat SARS-CoV-2 infection [19]. On the other hand, convalescent plasma showed effectiveness in several clinical studies, enabling the FDA to grant permission for its application on patients. In addition, research on traditional medicines and medicinal plants are being considered for COVID-19 treatment. The Ministry of AYUSH, Central Council for Research in Homeopathy, in India suggested the use of several medicinal plants and herbs to address the symptoms of COVID-19 patients [13]. Traditional Chinese medicines with antiviral properties were also studied in various clinical trials. Qingfei paidu decoction (QPD) become the general prescription in the treatment of COVID-19 in China due to its ability to reduce inflammation and lung injury and regulate immune system function [20]. The increasing rate of global COVID-19 cases has put significant emphasis on the discovery of potential therapies.

The changes to the environment after the onset of the pandemic is another area of interest in scientific research. With majority of cities and villages in affected countries in lockdown, travel has been significantly reduced. The decreased number of vehicles on the road resulted in a significant decrease in green-house gases [21]. The closure of industries has reduced waste emissions and lowered the use of fossil fuels, allowing recovery of ecosystems. A study analyzing air quality in India showed a 52% reduction in pollutants such as PM_{10}, $PM_{2.5}$, CO, NO_2, ozone, and SO_2 during lockdown [22]. In China, CO_2 emissions were reduced by 25%, which is equivalent to 1 million tons of carbon emissions [23]. Reports from NASA and

ESA satellites have also shown significant decreases in NO_2. Nevertheless, the demands to wear face-masks in public led to the increase in medical waste in the environment. Ocean Asia, an environmental non-profit organization, discovered large amounts of single-use masks along the beaches of Hong Kong [24]. Recent peer-reviewed literature on the environmental and human health impacts of COVID-19 personal protective equipment (PPE) litter have been critically analyzed in terms of novel findings and further steps [25]. Overall, the halt of several human activities during COVID-19 lockdown has created global short-term changes in the environment, an area that is being actively investigated by environmental scientists.

The associated psychological and neuroscientific effects of COVID-19 has led to increased priorities for mental health research [26]. A public survey conducted by the UK Academy of Medical Sciences and mental health research charity, MQ: Transforming Mental Health, highlighted concerns about increased social isolation, loneliness, anxiety, and depression during the pandemic [26]. In addition, those with previous mental health issues are faced with greater difficulty in seeking support and services. As a result, research agencies in the UK are collecting data on the mental health of the general populations and COVID-19 patients to devise appropriate psychological interventions. They are also stressing the need for global research on the effect of media usage and health messaging during COVID-19 [26]. In Pakistan, researchers are studying the role of electronic media in reducing mental health and boosting public morale. Many media campaigns are designed to address public mental health. These programs have recruited healthcare professionals, psychologists, and psychiatrists to console and guide citizens on how to cope with stress during uncertain times [27]. In China, mental health associations and academic societies have gone ahead and implemented mental health services through several internet platforms [28]. Online educational videos about self-help and coping mechanisms are available to the public and mental health professionals in Wuhan have organized expert services. In Australia, using the digital story completion method and thematic analysis, the mental health impacts of COVID-19 have recently been proposed [29].

4 Impact of COVID-19 on Technology Research

There are numerous technological advances arising in midst of the pandemic. Many countries around the world implemented mobile technology for contact tracing of individuals. In Taiwan, their health insurance database was integrated with the immigration and customs database to track high-risk individuals using mobile phones [30]. These technological measures were soon applied in China, Macau, and Hong Kong on January 30, 2020. Similarly, South Korea created a "trace, test and treat" method where the country's information technology system (IT) was used to track suspected cases and those in close proximity to infected individuals [31]. In March 2020, South Korea launched the COVID-19 Epidemiological Survey Prompt Support System for more advanced tracing [31]. Non-medical data from credit card companies, police, restaurants, and shops were shared with public health sectors to contain the spread of disease. In the UK and the US, the Coronavirus Pandemic Epidemiological consortium (COPE), combined the efforts of scientists in epidemiology and big data research to design the COVID-19 Symptom Tracker mobile app [32]. Officials were able to take the self-reported app data from infected populations and determine emerging hotspots. In Southern Wales, COVID-19 symptoms reported one week in advance would be followed by a surge of reported cases [31]. The opposite was true, with a decline of reported symptoms in the app leading to a decline in confirmed cases. The app's success has now led to its development in Canada, Australia, and Sweden. Larger technological companies such as Apple and Google have also collaborated in contract tracing applications using Bluetooth technologies [33]. Emerging technological research has proved to offer several benefits in understanding the global dynamics of COVID-19 incidences.

The Internet of Medical Things (IoMT) combines software applications and medical devices to help make healthcare services more efficient [34]. It has been used to monitor patients remotely, track medication orders and transmit health data through wearable devices to health care professionals Many of these tools are being advanced by medical organizations and government agencies to manage the pandemic. Experts in China employed IoMT in the COVID-19 Intelligence Diagnosis and Treatment Assistant Program (nCapp) [35]. Using a series of questionnaires, nCapp can identify patients as confirmed or suspected of COVID-19 as well as the severity of their cases. It can also link patients to physicians for online health consultation and follow ups to prevent disease transmittance. In Vancouver, hospital acquired infections have been limited by the creation of Wanda Quick Touch buttons, an IoMT device that monitors sanitation and alerts workers of any threats to public safety [34]. Shanghai Public Health Clinical Center sought to reduce the exposure of healthcare workers by employing body temperature sensors and remotely monitoring patients from nursing stations [36]. Meanwhile, Kinsa Health is sending millions of smart thermometers to households across the US [34]. The data from these thermometers is collected by a mobile application and organized into interactive maps for government authorities to determine potential hotpots in the nation.

The pandemic has prompted the rapid expansion of AI technologies. AI offers safe, automated solutions to medical imaging [28]. For instance, mobile CT platforms designed by visual AI technology enable contactless scanning. The technicians are able to evaluate the optimal scanning parameters remotely [36]. More independent AI systems are being integrated into the imaging workflow to avoid unnecessary interactions between healthcare staff and COVID-19 patients [37]. Furthermore, AI applications are being used to improve image scan qualities through similar automated determination of scan range and centering during CT imaging [37]. AI applications can also be used in efficient imaging-based diagnosis of COVID-19. For instance, researchers at Shanghai United Imaging Intelligence are currently attempting to use radiological methods to show changes in infected regions of COVID-19 patients. Healthcare workers are then able to determine necessary procedures using automated clinical reports generated from the AI technology. Research in AI has proved to help healthcare sectors tremendously over the past few years and it has now become crucial in the response to COVID-19.

Research into autonomous technologies has also made great global progress in reducing the burden of healthcare workers during the pandemic. Robots can provide food, clean patient-care environments, and reduce contact between frontline healthcare staff and infected individuals [38]. Asimov Robotics in Kerala, India, developed three-wheeled robots that serve patients food and medication [34]. Xenex Disinfection Services, founded by John Hopkins epidemiologists, created autonomic "UV LightStrike Germ-Zapping robots" to decontaminate hospital environments [34]. The UV light emitted from these robots can destroy virus DNA and disinfect several rooms in one charge. The robots are also equipped with several features such as self-navigation and computer vision to maximize cleaning [33]. Similarly, UVD robot company in Denmark developed several disinfection robots, delivering them to different parts of the United States, Europe, and Asia [34]. Spanish authorities have also employed robots for testing services. The testing features created by AI algorithms can alone increase the number of COVID-19 test from 20,000 to 80,000 daily. More recently, the heavy workload experienced by medical staff led to the creation of blood sampling robots by researchers at Robert wood Johnson University Hospital and Rutgers University [33]. The robots can take blood samples at a faster rate and with higher probability of success than manual sampling by nurses. Research within the field of autonomous technology is ongoing and many other applications such as service robots for body temperature testing are being designed for the pandemic. On the other hand, the impacts of COVID-19 in food preservation and cold chain have been reviewed recently as a potential step to implement green energy technologies [39].

Another challenge posed by the pandemic is the reduction and delivery of essential supplies. Research regarding Unmanned Aerial Vehicles (UAV) or "flying drones" have been conducted to distribute medical supplies, PPE, patient lab samples and testing materials in isolated areas. Marut Drones, a company created by alumni from the Indian Institute of Technology (IIT), recently launched the production of several drones for medication delivery, sanitization, and temperature analysis [34]. These drones have several navigation features and obstacle avoidance to ensure efficient deliveries. Besides the delivery of essential hospital supplies, drones in parts of China, Australia and the United States have begun to delivery groceries as well [34]. Drones with camera features are also being designed to ensure citizens are following government protocols, such as identifying those without a mask [40]. Furthermore, the most promising research on drones enabled early detection of potentially infected COVID-19 patients. Researchers at the University of South Australia has collaborated with DraganFly, a Canadian UAV manufacturer, to design the "pandemic drone", capable of identifying respiratory disease symptoms and measuring human temperatures and heart rates [34]. The pandemic has made great use of drone technology to enforce necessary protocols, determine future disease hotspots, and minimize human interaction in delivery services.

5 Impact of COVID-19 on Engineering Research

There have been many ways in which research areas in engineering and healthcare can be combined to help with COVID-19 containment. Like most respiratory virus infections, virion-laden respiratory droplets are said to be the main route of SARS-CoV-2 transmission [41]. Using knowledge in the physical sciences and engineering, researchers are attempting to combat the transmission of these droplets using self-sanitizing face-masks. Antiviral molecules would be released during exhalation and remain on the mask during inhalation [42]. Since face-masks provide a physical barrier to the droplets, these on-mask chemical modulation strategies are required to block and deactivate virus nanoparticles. Besides preventing spread of the virus, face-masks are also being studied for COVID-19 diagnosis. Researchers at MIT and Harvard are embedding RNA and DNA virus binding sensors into the mask, freeze drying the genetic material into the fabric and detecting the virus through florescent light [43].

Fomite infection is another form of COVID-19 transmission. To limit manual decontamination of highly touched surfaces, engineers are involved in the execution of self-sanitizing, antimicrobial surfaces and the application of copper, a metal with known antiviral properties, on stainless steel surfaces [42]. A small number of manufacturing research labs such as the Indian Institute of Technology Delhi and Cranfield University in the UK have begun to develop these manufacturing inventions [43]. Researchers from Northwestern's McCormick School of Engineering and biomedical researchers in China have begun to outline ways in which engineering can be used to invent multifunctional PPE. This includes PPE suits with wireless communication, temperature controls, physiological monitors, and anti-fogging properties [42]. Long term research in engineering innovations is pivotal to COVID-19 management.

The shortage in mechanical ventilators has also called on the efforts of engineers. In the US, ventilators are specialty products manufactured in low volume by a small number of medical suppliers [34]. The excessive number of patients in the Intensive Care Unit (ICU) and limited ventilators led to the creation of viable medical equipment prototypes [44]. Open-source manufacturing has enabled knowledge about these medical equipment designs to be researched and shared freely online for local manufacturers. "Project Open Air", created by a community of engineers and health professionals in both Portugal and the United States, is an example of one of the many rapidly evolving projects for open-source alternatives to traditional medical devices [44]. Research on oxygen conductors, PPE, tube connectors, and hands-free door handles has also been conducted and shared on online databases [44]. Although many of these alternative models are not approved by the United States' FDA, these online designs have been useful in countries with less restrictions and urgent demands for life saving equipment [45]. Students at research institutions have also begun to take part on open-source manufacturing. For instance, engineers from the University of Wisconsin began working with local industries to create open-source designs for face shields [45]. Knowledge in engineering plays a vital role in delivering solutions to the urgent need for ICU resources.

On the other hand, results of a recent case study based on a data-based pattern recognition approach in the Oslo area showed that the proposed method can identify abnormal patterns caused by COVID-19 and estimate its impacts on ship behaviors in that area; this could help decision-making and preplanning in a future health crisis [46].

6 Impact of COVID-19 on Mathematics Research

Recent research in mathematics is directed towards epidemiological models that predict the rate of COVID-19 transmission. Both simple and complex mathematical models consist of systems of equations that mimic conditions in reality [36]. Nine mathematical models have been reviewed in detail and characterized in order to comprehend the intrinsic characteristics of each model to enable prediction of COVID-19 disease transmission dynamics [47]. Mathematical modelling methods to optimize the strategies for allocating vaccines with differential efficacies have been reviewed, which could help policy development for disease control amid shortage of vaccine [48]. Several factors such as population interaction, economic conditions, and demographics must be considered to explore plausible scenarios of the spread of disease. There are several different types of models and they are often viewed complementary to one another.

Many models are inspired by AI machine learning, an approach using elements in statistics, mathematics, and computer science to forecast the number of infected individuals based on diverse data sources [49]. Researchers at John Hopkins University in Baltimore, US hosted projects to develop interactive, online dashboards to monitor and report COVID-19 cases [50]. The dashboard includes the number of reported cases, deaths and recoveries for all countries affected by COVID-19. One study conducted in China is using a susceptible-exposed-infected-removed (SEIR) model to predict epidemic peaks and trends in Zhejiang, Guangdong, and Hubei provinces [51]. This SEIR model represents the different phases of the infectious epidemic disease and is constructed based on data from the National Health Commission of China [51]. Various European countries have used The Nonlinear Autoregression Neural Network (NARNN) model, another machine learning technique that predicts the total number of COVID-19 cases over a certain time interval [52]. The machine learning algorithm has also been applied to identify COVID-19 cases using phone surveys. Information on people's travel history and symptoms is collected to identify high-risk cases and help them implement appropriate quarantine measures [53]. Ultimately, the many projects involving AI frameworks have become useful to both predict areas of high infection and employ necessary policies.

Epidemiological models are being used to understand the possible contours of the epidemic and predict the maintenance of ICU resources. An age-structured compartmental model on the spread of COVID-19 was developed in Ontario, Canada to determine different outcomes of the pandemic in several scenarios: one base case with limited physical distancing and testing, the second with increased testing and restrictive isolation and cases with a combination of increased testing and moderate physical distancing [54]. Results demonstrated that an absence of isolation and the combination of testing with moderate distancing will still overwhelm the health system capacity. Though these models, researchers determined that dynamic physical distancing offers the most sustainable solution to controlling transmission while reducing societal disruptions [54].

A similar mathematical model was constructed to determine the role of social distancing in decreasing the burden of COVID-19 in the United States. The model was inspired by the Kermack-Mckendrick theory which uses nonlinear differential equation systems to determine the distribution of infectious diseases in a closed population over time [55]. Based on mortality data, these models aim to provide a real-time analysis of COVID-19 in disease epicenters such as New York. Furthermore, an analysis of specific non-pharmaceutical intervention (NPI) strategies such as physical distancing, isolation, and using face-masks in public is conducted to predict appropriate protocols to minimize transmission. The models showed that strict physical distancing and lock-down could reduce hospitalization of reported cases in the United States by 92% and mortality by 80% [55]. The study also shows that if 75% of the population wears face-masks, there could be a 63% decrease in the hospitalizations of reported cases. Similar data results have been obtained from a stochastic mathematical model of the epidemic in India. The model shows that achieving 50% or greater quarantine compliance can lead to a 90% decline in the number of COVID-19 cases, deaths, hospitalizations, and ICU demands [56]. Moreover, the same model determined the long-term effects of

COVID-19, showing that 55-65% of the population in India will be infected when herd immunity is developed [56]. Performing these numerical stimulations proves to be extremely useful for global public health sectors to determine outbreak trajectories and the effectiveness of different NPI intervention methods.

Further research to enhance the accuracy of these mathematical models is ongoing. Resusceptibility plays a significant role in prolonging the pandemic [57]. As a result, recent SEIR models are redesigned to consider the possibility of a recovered patient being reinfected by COVID-19 and the associated time delays of resusceptibility. These characteristic time delays enable a better reflection on the timing of transmission across a nation. In addition, the models are incorporating demographic information about the aging population due to the higher fatality rate amongst these vulnerable groups [57]. Cases studies based on real-world data from South Korea and Northern Ireland have proven that these modified models enable more accurate predictions. As research regarding these models continue to expand, they will provide public health officials with valuable data on periods of possible overwhelming of healthcare capacity.

7 Discussion

COVID-19 has had a profound impact on global STEM research. The cancellation of in-person appointments inhibited several studies, causing delays in industry and hospital based- research. The same case is seen in academia, where research institutions have restricted non-COVID-19 related projects and limited the number of critical laboratory staff. COVID-19 research funding has also been prioritized, leading to potential discontinuation of non-COVID-19 research studies. Most importantly, researchers in STEM are now directing their efforts towards the pandemic. While virologists may seem to play the most important role in understanding the virus, it is the additional help of physical scientists, psychologists, engineers, mathematicians, and technology experts that has enabled a comprehensive look into COVID-19 management. The worldwide spread of the disease increased demands to understand the pathogenic and clinical characteristic of COVID-19 infection. In the field of science, medical communities have focused on the development of medication and therapies for COVID-19 patients. Several antiviral drugs have been tested in laboratories throughout the world and traditional medicines are being considered in parts of China and India. Global collaboration in this field has been essential, as demonstrated by the shared online genomic database used to understand the origins of SARS-CoV-2. By conducting clinical trials and creating global research platforms, scientists have been able to make faster advancements in vaccine development.

Emerging technologies has relieved the demands of healthcare workers while enforcing physical distancing measures. Countries around the world are using technology in hospital services, medical equipment delivery and diagnostic tests. As technology in one country succeeds, this knowledge is passed on to the creation of similar applications in another country. This is particularly true in contact-tracing technologies where public health officials can predict COVID-19 hotspots. Research in mathematics has played a similar role, with epidemiological models providing accurate information on COVID-19 transmission rates. Meanwhile, research in engineering has proposed several solutions to the shortage of medical equipment and advancement of current PPE. Although the science, technology, engineering, and mathematic fields contribute in different ways to address COVID-19, all the research has been essential in mitigating virus transmission and treating infected individuals. Many of these studies will also prepare experts in unforeseen outbreaks. Overall, the collaboration amongst different disciplines and countries has enabled rapid and substantial global output in COVID-19 research.

COVID-19 adversely affected practically all sectors of education worldwide including STEM and healthcare, in addition to research in those disciplines [58-66]. Improving research in STEM largely depends on greater efficiency at meeting specific requirements of STEM education in schools and colleges. College STEM education stakeholders, viz. students, faculty, and academic institutional administrators have already been facing multifarious challenges [67, 68]. On top of that, COVID-19 imposed the need to complement or supplement in-person STEM classes with virtual instruction along with other pedagogical and assessment strategies for sustaining the quality and rigor of education [69, 70]. Educators and administrative personnel may address this requirement by considering pertinent reports of increasing student engagement and learning in science through free/low-cost mobile apps in middle/high school or college [71-74], developing and implementing virtual classrooms [75], organizing and contributing to digital leadership forums [76], harnessing novel ways of assessment such as peer-video-blogs [77], and may need to adopt innovative methods of assessing science research-based courses like those recently designed for a Biochemistry course-based undergraduate research experience (CURE) [78-83]. In this context, it is STEM research which could be leveraged to mitigate the viral contagion by empowering communities with health literacy [84] and awareness about food safety as well as about the role scientific research can play in meeting the heightened demands of food production and nutrition owing to the pandemic, indicated through numerous reports [85-88].

8 Conclusions

This current study evaluates the worldwide impacts of COVID-19 on research in STEM subjects. It was inferred that research in all disciplines is essential to the global fight against COVID-19. In the field of science, institutions and industries are focused on developing vaccines and anti-viral treatments for patients. Nevertheless, other lenses of the pandemic beyond therapies are considered as well, with psychologists understanding the psychosocial impacts of isolation and environmentalists determining the impacts of lockdown on the climate crisis. The pandemic has also pushed the development of health and AI technologies, reliving burden from healthcare sectors, and encouraging physical distancing. A coalition of research institutions and engineers have contributed to health services through innovative ideas to PPE and medical technologies alternatives. Finally, different countries have implemented all types of mathematical models to understand transmission rates and inform decision-makers about necessary interventions to ensure public safety. Through all these research projects, corporation and coordination amongst different countries has enabled faster solutions to the array of social, economic, environmental, and clinical problems that arise from the pandemic. It is also noted that the rapid expansion of COVID-19 research suspended several non-COVID-19 studies. As a result, remote research is being conducted through online platforms. Ultimately, this literature review shows that global health emergencies like the COVID-19 pandemic requires attention and expertise from diverse disciplines as well as international collaboration. Each research project examined in this work has devised actionable solutions to COVID-19 in its own way and can be applied in future outbreaks. It should be noted that a limited number of research projects were mentioned in the study due to the wide scope of investigations occurring during the pandemic. It is also recommended that future studies should focus on further, in-depth analysis of the impact of COVID-19 on research associated with each specific discipline in STEM.

9 Declarations

9.1 Study Limitations and Future Recommendations

Insights into the major research projects within STEM fields were encapsulated in the present study. There are several projects from other disciplines that were not covered, being beyond the context of this analysis. Additionally, research in Africa and parts of Europe were not as prevalent as studies conducted in the United States, China, and the United Kingdom. Future studies should investigate the effects of COVID-19 on subject-specific research activities in STEM.

9.2 Competing Interests

The authors declare no competing interests involved.

9.3 Publisher's Note

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