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REVIEW ARTICLE

The Impact of COVID-19 Pandemic on Academic Laboratories

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ABSTRACT

Background/purpose – The COVID-19 pandemic plagued economies and education at all levels and on a global scale. However, there has been limited research on the impact of the pandemic on academic laboratories. This brief review expounds the impact of the COVID-19 pandemic on academic laboratories by discussing their roles and responses on different continents during the peak of the crisis and since. The study also relates the pandemic's impact on academic laboratories to existing theories of science education and suggests recommendations for future practices.

Materials/methods – This review employed the PRISMA item checklist and Arksey and O'Malley's framework, with minor adjustments applied to best suit the aims of this review. Information was obtained from the PubMed® and JSTOR bibliographic databases, plus via the Google Scholar academic search engine.

Results – The study demonstrated how most academic laboratories in developed countries responded rapidly to the pandemic; whereas, most African academic laboratories were unproductive due to emergent challenges faced such as inadequate funding for virtual laboratories and e-learning infrastructure, Internet instability, and other issues related to technology and its wider accessibility. The study highlighted how some existing theories of science education were affected by the pandemic, followed by what academic laboratories should have done differently.

Conclusion – This review clarified some of the expedient responses needed for academic laboratories to be productive during crises such as a pandemic. The study revealed that embracing certain suggested recommendations could help build more resilient academic laboratories globally, and help to sustain laboratory practices and operations whilst championing quality education.

Keywords – Academic laboratories, COVID-19 impact, scientific research, development

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1. INTRODUCTION

For 2 years, the Corona virus (COVID-19) pandemic plagued the entire globe (Joris et al., 2022), gravely affecting world economies and education at all levels. The pandemic seriously impacted the lives of many and caused numerous deaths in almost every country worldwide (Kumar, 2021; Mahesh et al., 2021). These difficulties also highlighted significant gaps in school-based education and the sector's willingness to plan for alternative management of the effects of such a crisis (Espino-Díaz et al., 2020).

Study sectors in the engineering, natural, medical, and allied health sciences profession accentuate the importance of developing theoretical and practical learning by students (Abdurazakov & ugli Odinaboboev, 2022; Hofstein & Mamlok-Naaman, 2007). During the development of practical aspects for individual learners, utmost emphasis is placed upon activities that teach students experimental procedures and methods, how to synthesize observations, as well as good communicative skills and hands-on laboratory practices. Suspension of practical teaching sessions and experiments due to the worldwide pandemic adversely affected academic activities (Jacob et al., 2020; Sahu, 2020). Well-designed experiments form a vital part of science and are a vital means of imparting knowledge to students, helping them gain valuable experience through several techniques and also to develop the skills needed for future employment in industry or academia (Lewis & Gospel, 2015). Academic laboratories include both research and teaching and are considered a "vehicle" that unravels the nexus between theoretical content, practical processes, and novel discovery. They also serve as a breeding hub for scientific research, innovation, and development. However, research, teaching, and demonstrational practices in academic laboratories came to an abrupt halt in most countries at the peak of the COVID-19 pandemic (Cheng et al., 2020; Czerniewicz et al., 2020). This restrictive action was taken in order to help minimize the rate of infection and spread of the disease by adhering to protocols set in place by the World Health Organization (Mahesh et al., 2021). Consequently, this affected both researchers' and students' work output in many academic laboratories (Klont & Hopfgartner, 2020).

Most European and western countries have well-equipped academic laboratory facilities, and these were not immune from the detrimental effects of the pandemic (Burman, 2021; Coughlan et al., 2021; European Society of Radiology, 2021; Gobbi et al., 2021). However, with systems already in place and through immediate proactive measures taken, most developed countries were able to salvage the situation to some extent. Although certain developing African nations were able to continue to offer academic activities via other available options, addressing hands-on practical activities was insufficient for the purposes of practicum knowledge transfer. This situation was largely due to inadequate Internet connectivity and insufficient availability of advanced technological tools such as virtual laboratories (Aristovnik et al., 2020).

In retrospect, higher academic institutions in African countries were particularly susceptible to the consequences of the COVID-19 pandemic (Jacob et al., 2020). A survey from the International Association of Universities (IAU) in 2020 revealed that at the time the pandemic hit, most developing African universities were still attempting to transform and improve their higher education system. However, the COVID-19 pandemic destabilized the higher education sector with severe consequences (Marinoni et al., 2020). As part of the preventive measures taken during the peak of the pandemic, most African universities and college institutions were required to cease most of their academic activities, significantly disrupting the academic

calendar. Thus, some initiatives were later launched in a few developing African nations that aimed to deal with the pandemic's impact. Despite this, some African countries simply initiated a cancellation of all academic activities (Muftahu, 2020; Nkengasong & Mankoula, 2020; Osseni, 2020).

Notwithstanding the numerous studies that have reported on the impact of COVID-19 across several sectors of the global economy, as well as health and education at all levels (Debata et al., 2020; Phillipson et al., 2020), a gap in the literature still exists when it comes to the pandemic's worldwide impact on academic laboratories, and especially those situated in Africa. The current study seeks to highlight how the COVID-19 pandemic impacted academic laboratories. It also aims to address why this situation is still current through discussing the role of academic laboratories (as research and teaching laboratories) and the response of African and other (western and European) academic laboratories to the COVID-19 pandemic. Finally, the study aims to relate the pandemic's impact on academic laboratories to existing theories of science education and to suggest recommendations for future practices.

2. METHODOLOGY

2.1. Selection Process

A limited assessment of the published literature was conducted with a focus on the impact of COVID-19 on academic laboratories, their function (teaching and research) within higher education, the response of academic laboratories in Africa and other locations (western and European countries) to the pandemic, the difficulties faced at various academic laboratories at the peak of the pandemic, and potential recommendations for improvement. In-depth content comprehension and information extraction were based on patterns identified from the evaluated literature. The current study took the form of a review based on the PRISMA item checklist and Arksey and O'Malley's framework, with minor adjustments applied in order to best suit the aim of the review (Arksey & O'Malley, 2005; Phillips et al., 2021; Westphaln et al., 2021).

2.2. Procedure

2.2.1. Identification of Research Articles

In order to identify appropriate scholarly publications, searches were performed from the PubMed® (National Institute of Health [NIH] and National Center for Biotechnology Information [NCBI]) and Journal Storage (JSTOR) bibliographic databases, plus the Google Scholar academic search engine, based on material published between July 2020 and July 2022. When compared to PubMed® and JSTOR, it was the Google Scholar academic search engine that provided the majority of the material. As of July 2022, only a small amount of research had been published that discussed the effects of the COVID-19 pandemic on academic laboratories.

Google Scholar had the most easily accessible articles from journals with a high international impact, followed by PubMed® and JSTOR. The aforementioned bibliographic databases and academic search engine were selected in order to identify research papers and other informational items relevant to the current study, since they are known to contain trustworthy information. However, due to the limited availability of translation resources, non-English language publications were exempted to a certain extent. PubMed®, JSTOR, and Google Scholar were all used as primary sources of information since they are considered comprehensive and widely recognized in academic research. From this criteria, it may be said that the exemption of non-English language publications constitutes a limitation of the study.

2.2.2. Extraction of Information and Data

Scholarly publications from the PubMed® and JSTOR bibliographic databases and from the Google Scholar academic search engine were selected where deemed pertinent to the review's objective. Basic research papers, reviews, editorials, newsletters, technical reports, notes, and books were among the scholarly publications extracted. The following search terms were employed as the authors believed they best described the phenomena under study; "impact of COVID-19 on academic laboratories," "impact of COVID-19 on research laboratories," "impact of COVID-19 on teaching laboratories," "impact of COVID-19 on research and teaching laboratories," "impact of COVID-19 on educational and research laboratories, impact of COVID-19 on higher level education laboratories," "impact of COVID-19 on education," "impact of COVID-19 on scientific research," and "impact of COVID-19 on scientific research and education."

3. RESULTS

The initial search, conducted in July 2022, returned a total of 321,336 publications or informational resources that may be considered useful. Table 1 presents a summary of the material retrieved from the academic search engine and bibliographic databases used in this review.

Table 1. General Characteristics of Publications and Informational Resources, plus Distribution, Qualification, and Rankings from Three Selected Sources

Sources Bibliographic database/ search engine/ academic search/ other web-based sources	Total publications/ informational materials retrieved	Eligible publications/ informational materials retrieved based on refined search	Rank
PubMed®	231	27	2
Journal Storage (JSTOR)	105	3	3
Google Scholar	321,000	48	1
Total	321,336	78	

NOTE: Rank is based on eligible selected publications/informational materials following extensive search filtering and screening.

3.1. Data Analysis

The aforementioned search queries returned a total of 321,336 publications or educational materials. The vast majority were found via Google Scholar, followed by PubMed® and JSTOR, with volumes 321,000, 231, and 105, respectively. In contrast, from the 321,336 eligible publications/informational materials, only 78 were selected for further analysis after being subjected to additional relevance filtering and deduplication aimed at tailoring the search results to the objectives of the current study.

The most eligible publications/informational materials were again found via Google Scholar, followed by PubMed® and JSTOR with 48, 27, and three items returned respectively. The authors decided to analyze all 78 of these eligible publications/informational items, which were in the form of technical reports, notes, research articles, review articles, or books. The analysis was conducted against the backdrop of certain relatable existing theories of science education, and how the impact of the pandemic had inevitably constrained science education to some extent. Following a thorough inspection and examination, the eligible publications/informational items are discussed as shown in the following section.

4. DISCUSSION

This section presents a discussion on this brief review's findings and expounds them based on the roles of academic laboratories at the higher education level. Additionally, it also highlights how academic laboratories in developed and developing countries (i.e., some African countries) responded differently to the COVID-19 pandemic. It also elaborates on the situation of academic laboratories in developing African nations that thrived during the pandemic's peak. Moreover, it shows how most of the findings can be mapped to existing theories of science education. Finally, recommendations are suggested that could help make academic laboratories more sustainable and resilient to future pandemics or other crises.

4.1. Roles of Academic Laboratories in Higher Education

The academic laboratory at the higher education level serves as a fundamental unit of scientific production, innovation, development, and education (Chaoming & Weixi, 2022). This is evidenced through the top-notch research and discoveries emanating from such institutions in fields as diverse as health, the natural sciences, and engineering (Feng, 2019; Teng & Yang, 2018).

Science education at all levels revolves predominantly around laboratory demonstration, practical sessions, and research (Gericke et al., 2022; Reid & Shah, 2007). The continuous nature of activities being undertaken in laboratories, especially in universities, requires laboratories to have robust contingency plans in order to set achievable research goals, procure the necessary equipment and logistics, and to construct a portfolio of suitable research projects (Higgins et al., 2022). This requires an enabling environment for laboratories to deliver effective scientific research and investigation. Among the resources required, laboratory staff are the most dynamic and vital element. Academic laboratories are responsible not only for teaching and research, but also their administration, with laboratory technologists and technicians providing both the management of the lab as well as tuition services (Lewis & Gospel, 2015).

In summary, university teaching and research laboratories play an important role that cannot be overlooked (Muscio et al., 2022). The primary role of academic laboratory management is to ensure the unit is a fulcrum of knowledge, invention, and discovery. Additionally, the best academic laboratories deliver notable developmental trends in novel research. These laboratories cannot function successfully without dedicated, high-standard laboratory staff (Zhang et al., 2022).

4.2. Response of Academic Laboratories in Developed Countries to COVID-19

During the early part of 2020, the COVID-19 pandemic caused most higher education institutions worldwide to shut their doors to face-to-face tuition, significantly impacting both teaching and research (Farnell et al., 2021). Consequently, academic laboratories, which comprise of both teaching and research laboratories, were either closed or required to operate on a "shift system" in order to limit the rate of transmission and infection (Ahwireng, 2022; Gramigna, 2022). Most real-time laboratory analysis and investigation was, to a certain extent, compromised due to the severity of the pandemic's impact on their day-to-day operations.

Despite, the cutting-edge technologies and the enabling environment present in the laboratories of most western and European countries, there was still cause for alarm since most of their research activities where either postponed or halted (Karakose, 2020, 2021b). The pandemic significantly impacted the entire basis of the educational ecosystem. Consequently, an increase was seen in physiological stress as well as emotional discomfort

and anxiety among both the student population as well as their instructors (Tull et al., 2020). This was, in part, due to many suffering from headaches, blurred vision, and even depression from the excessive use of electronic devices during prolonged e-learning (de Oliveira Araújo et al., 2020; Drane et al., 2020). Most western and European countries were able to reduce the impact of the pandemic due to the availability of instructional design, online support learning tools, and financial support received from local and national governments (Alqahtani & Rajkhan, 2020). The virtual laboratory and e-learning model was substituted as the primary mode of delivery for laboratory practicals and demonstrations in place of traditional laboratory activities (Mseleku, 2020).

4.2.1. Intensifying Virtual Laboratory Sessions and Emergency E-learning

Globally, conventional laboratory sessions, as well as research and practical lessons, were significantly interrupted during the peak of the pandemic. Although virtual laboratories cannot completely replace the physical experimentation and research undertaken in traditional academic laboratories, the online medium was employed worldwide to augment laboratory sessions and research during the pandemic (Vergara et al., 2022). Options available already existed for academic work such as e-learning, video conferencing, as well as virtual laboratories (Fauzi, 2022). Therefore, the acquisition and transfer of knowledge did not halt abruptly in all cases, although different media were employed to achieve some level of continuity. Most universities used virtual laboratories to replicate their practical teaching. Some institutions already had "virtual laboratories" set in motion prior to the pandemic and just had to intensify the process; whereas, many were forced to suddenly adopt and adapt to the online method. Those institutions with an enabling environment were already prepared, as well-equipped academic laboratories with cutting-edge technologies soon embarked on research related to vaccine development and studies aimed at unravelling the intricate biology of the virus responsible for the pandemic (Guerrini et al., 2022). This approach was proven effective (Rashedi et al., 2022).

4.3. Response of African Academic Laboratories to the Pandemic

Unlike academic laboratories in European and western countries, many of those in Africa were already under-resourced prior to the COVID-19 pandemic. It is apparent that the inadequacy of laboratory equipment, instructional materials, and appropriate technologies impeded the smooth running of laboratory experiments and research (Dankers et al., 2022; Mukama et al., 2022; Puplampu et al., 2022). Similarly, limited or inadequately trained laboratory personnel and staff were unable to meet the current trends in science, technology, and development, presenting a significant disadvantage for some developing African nations during the pandemic (Koomson et al., 2021). Lack of developmental budgets and investment from institutions into some African academic laboratories made it difficult for them to operate during the pandemic, leaving very few options open to many developing African university laboratories. This significantly impacted their research and scientific activities. Rotational or shift systems of running laboratories were employed in most academic institutional laboratories in order to help reduce overcrowding and rate of infection and transmission of the virus (Petersen & Harfitt, 2022). Some e-learning platforms were also developed; however, Internet instability, inadequate funding, technology limitations, and accessibility challenges were faced by students and laboratory staff. This led to chaotic learning environments at home and along with other external exigencies, with the situation quite difficult for many researchers and students to continue their academic activities (Karakose, 2021a; Zar et al., 2020). Technology and accessibility challenges on the side of

students, researchers, and also laboratory staff made it difficult to deliver practical sessions online in virtual laboratories (Eli-Chukwu et al., 2022). During the pandemic, it became very difficult for laboratory staff together with faculty members in most developing African nations to redesign practical science courses for online delivery, since planning for such a change of medium requires significant work and thorough practice (Zar et al., 2020). Egypt was one of the few African countries that developed effective systems to overcome these issues during the pandemic. For example, they implemented an e-learning system, and a hybrid system of tuition was then introduced across the different education levels (Mortagy et al., 2022).

4.4. Situation at the Pandemic's Peak, and Since

During times of crisis, it is the laboratory staff who keep the daily operations and activities running, and are considered dynamic links in most academic laboratories (Koomson et al., 2021). The commencement of most research, experimental, and analytical techniques require a great deal of implicit knowledge and practicum experience (Cetina, 2022). As such, it can be of significant difficulty for researchers, students, laboratory personnel, and principal investigators to effectively execute state-of the-art techniques and protocols when they themselves lack good health or are trying to operate in the absence of an enabling environment (Karakose, 2020). Thus, COVID-19 became a threat to all, although over time effective vaccines were developed and things improved as populations became largely vaccinated (Li et al., 2022).

The pandemic distorted the harmony between research planning and its organization and execution. With the health and safety priority considerations for academic laboratory staff and students during the outbreak, most were unable to effectively coordinate laboratory activities and operations, particularly at the pandemic's peak since COVID-19 safety protocols were strictly adhered to in order to limit infection and transmission. As such, most laboratory operations came to a standstill (Martin et al., 2022), although some resilient academic laboratories were able to reorganize and effectively reorient their various laboratory activities (Mustafa et al., 2022). It is worthy to note that, following interventions such as the introduction of vaccines, some academic laboratories in Africa were able to resume their laboratory operations, activities, and also research practices. These institutions were able to put in place the necessary systems for academic activities to continue (Aboagye et al., 2022).

4.5. Relating Theoretical Frameworks COVID-19's Impact on Academic Laboratories

Academic laboratories primarily thrive on science education, since they offer a secure setting in which teaching, learning, and research can be undertaken, and they have the capacity to offer an environment where theory and practice comes together (Araneo et al., 2019). This has added to the ongoing discussion of the role and objectives of laboratories for scientific research (Byers et al., 2022; Hofstein & Mamlok-Naaman, 2007). The debate over the function of academic laboratories has given rise to a landscape of ongoing laboratory learning objectives (Russell & Weaver, 2008).

In the current study, we aimed to provide a succinct discussion of how most of the study's findings from this limited review relate to certain science education theoretical frameworks and existing theories. As will be shown, lockdown restrictions during the pandemic subtly affected these existing theories and frameworks of science education. Firstly, it relates to the roles of academic laboratories in higher education, and highlights how knowledge is acquired from subject-specific science concepts, theories, explanatory models, and to learn how to conduct scientific investigation within the academic laboratory. Secondly, it is noticeable that this brief review also revolved around the challenges and responses of academic laboratories

to different activities or science practices employed during laboratory analyses or investigation at the peak of the COVID-19 pandemic (Hodson, 2014). Additionally, it shows that the interactional, factual, and conceptual learning, experience, and research within the academic laboratories were not fully realized during the pandemic due to the need to strictly adhere to lockdown restrictions and other pandemic-related safety protocols (Ney et al., 2009).

Furthermore, this review relates to how the pandemic impacted scientific practices, a set of fundamental abilities and know-how employed in scientific research across various continents, including those in developing African nations as well as those in the west and Europe (Gericke et al., 2022). This review confirms the connection between the four distinct learning objectives of science education, identifying laboratory work as both curricular content and aim, and outlining what students are expected to learn (Hodson, 2014). The pandemic's impact on academic laboratories fragmented and constrained the ways and means for those on different continents to acquire science, learn how to do science, and to connect conceptual understanding with procedural knowledge and investigative expertise (Osborne & Dillon, 2008).

Nonetheless, successful laboratory education can be described as emulating the conditions and thought processes of practicing researchers through the application of critical thinking to translate arguments beyond the simple knowledge of how to complete content-specific tasks. This was particularly significant and difficult to achieve in some developing African countries due to such operations being quite costly even prior to the pandemic (Ding et al., 2016). The pandemic's impact on laboratory education help justify the need to restructure curricula design framework to enable a more successful online laboratory education, experience, and delivery (Richmond et al., 2020).

5. RECOMMENDATIONS

5.1. What Academic Laboratories Need to do Differently?

Academic work and activities have resumed globally, albeit with certain high-level strict COVID-19 safety protocols in adherence during an interim period (Anas et al., 2022). This helped to create the conducive environment for academic and research activities to prosper and get back on track. Nevertheless, it was imperative that the same pandemic safety measures and protocols were extended to various universities' teaching and research laboratories and to ensure their adherence. The following points highlight a few salient facets that African academic laboratories should consider in order to thrive following the pandemic.

5.1.1. Sustainability of Laboratory Operations and Practices

Sustainability of laboratory operations is an issue of vital importance which should be addressed with some urgency in order to effectively mitigate the issues faced during any future pandemic or other similar crisis (Zaman et al., 2021). Although the world recently had to face an unimaginable degree of turmoil, that does not justify the constraint of innovative research, or the transfer of knowledge and development (Karakose et al., 2021). Laboratory operations and practices need to continue, and solid laboratory practices as well as the introduction of modern hybrid academic laboratory sessions (face-to-face, virtual/e-learning) should be employed in order to facilitate the continuance of academic and research work within higher education institutions (Chauhan et al., 2022; Zhao et al., 2022).

So as to help ensure that laboratory operations remain sustainable in such times, there is a need to look beyond the normal practices of laboratory activities, with teaching and research which involves the physical presence of students and tutors. Higher education institutions

should refurbish their academic laboratories and invest the necessary time and resources in cutting-edge laboratory equipment and technology, frequent capacity building of laboratory staff through e-learning platforms, and to enforce strict adherence to accepted health-related protocols during a pandemic or other crises. An integrated education system (including laboratory operations) is essential in progressing towards a sustainable agenda within the recognized Sustainable Development Goals (SDG), as has been highlighted during the peak of the COVID-19 pandemic where the challenges faced affected timelines for SDG agendum four (4) (Ameli et al., 2022; Komarulzaman et al., 2022).

5.1.2. Proactive Changes Needed Within Academic Laboratories Following the Pandemic

The COVID-19 pandemic exposed certain deficiencies in higher education systems, and this was especially evident in Africa. Hence, it is incumbent on us to train educators in the use of appropriate digital technologies and to help introduce them within the evolving education climate. Introducing continual professional development and intensive periodic capacity building and training for laboratory staff to meet the technological and evolving demands of the day can also serve as emergency response tools to be enacted during future crises (Phillips et al., 2021). In the post-pandemic era, the use of digital technologies, virtual education, and e-learning may become a more essential part of the higher education system. Universities and higher education institutions therefore need to plan their post-pandemic education strategies to ensure that student learning outcomes and standards are of a appropriate educational quality (Wangenge-Ouma & Kupe, 2022; Zelmer et al., 2022).

5.2. Empowering Academic Laboratories to Become More Resilient Following the Pandemic

The activities of laboratory academics in Africa were largely brought to a halt during the COVID-19 era since their laboratories could not conform to the social distancing directives issued by various governments, since the labs were too small to accommodate students and also were not sufficiently well ventilated (Stenson et al., 2022). Hence, laboratory teaching and learning should be delivered to smaller groups in order to make its operations safe and effective. Health regulatory bodies, scientific agencies, academics, and world governments should strengthen public health systems through the conducting of innovative research to mitigate the impact of future pandemics on academic laboratories and other sectors. Economic support from both government and non-governmental agencies is also considered essential to the development of academic laboratories. Owing to this, it is expedient that academic laboratories are fully equipped with robust e-learning material and also undertake capacity-building workshops in order to ensure sustainability of laboratory operations during future pandemics (Martin et al., 2022; Nassiri-Ansari et al., 2022; Pertegal-Felices et al., 2022).

6. CONCLUSIONS

Globally, academic laboratories were not spared from the “tentacle hooks” of COVID-19 during its peak. The current study revealed that it is vital that the adverse impact of a pandemic on academic laboratories is not ignored. Despite the limited number of scholarly publications found associated with this limited scope review in various academic bibliographic databases, after thorough screening, little evidence was revealed as to the most pressing issues faced by academic laboratories during the peak of the COVID-19 pandemic. It was seen that the roles played by various academic laboratories in higher education were compromised. The study also highlighted the proactive response that developed countries including those of western and European academic laboratories undertook during the peak of the pandemic to intensify their use of virtual laboratory sessions and emergency e-learning. How the pandemic impacted on academic laboratories was revealed to have affected certain

existing theories of laboratory education and frameworks of science education. It was suggested that embracing various salient recommendations could help build more resilient academic laboratories, and to champion sustainable laboratory practices and operations through delivering improved quality education in Africa and worldwide (König, 2013; König & Evans, 2013).

DECLARATIONS

Authors' Contributions JN, PD, EK, DTA, RSA and DD helped with the structure of the study, design, critical literature review, drafting and manuscript editing. AK conceived of the whole idea, participated in critical literature review, coordinated the study and helped in writing the manuscript. All authors read and gave final approval of manuscript for publication.

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