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Leveraging technology to enhance stem education Amidst the Covid-19 pandemic: An overview of pertinent concerns

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Abstract. Although technology in its various forms had already permeated peoples' lives, the closure of educational institutions worldwide due to the outbreak of the Covid-19 pandemic thrust education sectors in many countries into fraught experimentation with online learning. Many educators had to adopt pedagogical practices that were in tandem with online instruction. The pandemic had a silver lining as it opened doors to new ideas and technologies that could be leveraged to enhance STEM education. This paper adopts the desk top research approach to establish the technologies that were leverageable for STEM education during the ongoing pandemic, and to determine pertinent concerns about moving STEM education online. The study found that most institutions leveraged basic synchronous and asynchronous technologies for STEM education during the pandemic. The study also established that a few institutions were embracing sophisticated technology like Virtual Reality and Augmented Reality in enhancing STEM education. There were also institutions already training VR and VR experts to meet anticipated STEM education manpower needs. It was established that while the use of technology enhanced STEM education during the Covid-19 pandemic, it raised concerns about access, equity, quality and student engagement. To address these concerns, the study recommends that governments should invest in the provision of power in rural settings and subsidize the cost of hardware for students. For equity considerations, the disadvantaged should be prioritized in the provision of technology enablers for online STEM education and measures that safeguard them should be inbuilt in the online transition plans. Finally, where possible remote labs should be established but this is not possible, students should be allowed to take series of scheduled physical lab sessions in turns and rules of social distancing enforced. Countries should look to superior technologies for online STEM education so that any similar future occurrences do not stall practical STEM education sessions.

Keywords. Leveraging, technology, STEM, Covid-19 pandemic and pertinent

1. Introduction

Worldwide, it is recognized that high quality STEM education is an important ingredient in economic growth. This sentiment is echoed by Brooks and Grajek (2020), in their assertion that STEM is critical for personal and national prosperity. Curiosity, creativity and innovation are born of STEM making technology as an indispensable element in any STEM or project-based learning (Dogan & Robin, 2015). Technology allows for exploration of STEM based disciplines and can enable students to connect different ideas especially when they use simulations (Yang & Baldwin, 2020). According to Lucena et al. (2020), the methodology on teaching STEM has evolved from using the traditional media to more advanced media. Thus, today technology is widely integrated in STEM education because it has been found to have positive effects on axiological dimensions of education and especially where the choice is participatory. The use of technology in STEM education has also been championed for engaging students (USA National Research Council, 2011) and the outbreak of covid-19 just presented the ideal opportunity for STEM educators to combine technology with pedagogical practices for improvement in student learning outcomes.

Although technology in its various forms had already permeated peoples' lives, the closure of educational institutions worldwide due to the outbreak of Covid 19 thrust education sectors in many countries into fraught experimentation with online learning (LeBlanch, 2020). This is because technology had hitherto not been seriously integrated in teaching and learning by students and most educators. Specifically, STEM online education in African contexts had been unexplored until Covid -19 as Aseey (2020) states that, less than 25 per cent of low-income countries were providing any type of remote learning. The pandemic woke up educational institutions to the realization that they had clang to traditional instructional approaches for too long, and that it was a high time they harnessed and utilized a wide range of technological tools to create content for remote learning for their students in all courses. Many institutions were forced to adopt online learning and remote work in order to curb the spread of the disease. At the individual level, adapting to online teaching was stressful for many educators (Kong, 2020), and students alike because of the demands of the new teaching and learning approaches. There were considerations of pedagogy and engagement which posed unique challenges. Many educators had to overhaul their pedagogy and overall instruction since online instruction required specialized knowledge (Smith, Basham, Rice & Carter, 2016) of integration of pedagogy, technology and content (DiPietro, Ferdig & Preston, 2008). During the transition to online teaching, most educators found themselves confronted with the problem of instant double innovation whereby, they first had to learn the technology before deciding on the integration process. Thereafter, they had to design online instruction materials, provide interactive learning experiences for students, and assess students' levels of understanding. Then there were generational divides in how educators felt about the use of technology in teaching (Vegas, 2020). While all these resulted in unfeigned anxiety and frustration, it presented opportunities for learning.

The pandemic had a silver lining as it opened doors to new ideas and technologies that are expected to outlive it (Lempinen, 2020). It underscored the discovery of how technology could deliver great content and engage students as well as educators (Allen, 2020), and in the process boost the role of teachers so that they become co-creators of knowledge, coaches, mentors and evaluators (Janssen, 2020). The pandemic also led to the discovery that STEM online classes could raise the profiles of instructors and spark the development of better teaching techniques, and position educators to actually improve their teaching of STEM disciplines by experimenting with competing pedagogical strategies (Study Staff International, 2020). More importantly, the pandemic reasserted the fact that STEM education was invaluable as students could use their skills to alleviate the effects of the pandemic.

Objectives

i. To the establish the technology that was leverageable for STEM education during the Covid-19 pandemic

ii. To highlight pertinent concerns in the use of technology in STEM online education during the Covid-19 pandemic.

2. Methodology

This study adopted the desk top research approach to investigate the technology that was leverageable for STEM education as well as pertinent issues associated with STEM online education during the Covid-19 pandemic. The purpose of this approach was to gain a general insight into how educational institutions had dealt with STEM education. Comprehensive reports from diverse sources as well as snippets of information on the subject of the study were all reviewed and generated the information presented herein.

3. Findings

i.Leverageable Technology for STEM Education

Necessity is the mother of invention and the pandemic brought about a surge of online educational activities. Partida (2020) states that STEM learning is diverse and full or real-world activities. The pandemic ignited the use of synchronous online activities, (web-conference, live chat and live streamed lectures) as well as asynchronous activities which allowed students to access at their own time recorded web conferences, emails, and recorded lectures on video or audio (IDRA, 2020). Such web-based applications were handy during the pandemic because they promoted learning and were easily accessible from anywhere (Kefalis & Drigas, 2019) to those who had the hardware. Educators and students were able to share their screens in presentations. It was also possible to draw, write or illustrate a concept graphically using the online whiteboard (Greene, 2020).

Educators with a knowhow on the use of break-out rooms on the Zoom platform assigned group tasks that allowed students to work collaboratively in smaller teams, use each other's skills and expertise to accomplish the assigned tasks, and then present to the class via the same media. Pedagogically, this approach turned the teacher into a mentor who helped the students achieve the learning goal. Such tools enabled students and teachers to work synchronously the way they might interact during class sessions. In addition, as per the individual preferences, there were those who used Microsoft Teams, Google meet and the Google classroom (Parker, Sprague, Brown & Casablanca, 2020). Google classroom had the advantage of being free, cloud based and mobile friendly (Duffy, 2013; Iftakhar, 2016; Magiera, 2020). Chat functions on the conference platforms allowed voiceless interaction that favoured extroverted students who were "invisible" in face to face learning. Such students could comfortably post questions and comments in the chat box, enabling educators to gauge if their teaching was having the desired impact.

In other instances, educators' pedagogical practices during the pandemic were shaped by their own prior knowledge and abilities in the use of technological tools at their disposal. These STEM educators were able to record, edit and publish their lectures online. According to Fiorentino (2020), high videos provided students with effective learning experience and supplemented live demonstrations effectively because in the video format, specific parts could be highlighted and zoomed in on just at the right moment to reinforce a concept. For instance, some faculty members at the Singapore Institute of Technology had competencies in live streaming, pre-recorded teaching sessions, facilitating discussions in digital platforms and providing assessment and feedback (Lim, 2020). Licenses and access to technology like Zoom, Respondus and Microsoft Teams were made available to staff and students. This resulted in a positive online experience for both faculty and students.

Before the outbreak of the pandemic, there were already countries experimenting with superior technology. Higher education institutions in such countries were already using simulations and remote laboratories (De Jong, Linn & Zacharia, 2013). These positively impacted STEM education during the pandemic. Chui and Linn (2011) established that within web-based science inquiry environment, students easily developed STEM skills like identifying problems and finding possible solutions. Furthermore, this environment allowed for collaboration among the students as they worked on diverse projects. In cases where the technology was fairly advanced, the use of both Immersive and Interactive technologies helped students perform experiments or investigate phenomena beyond physical constraints (De Jong, Sotiriou & Gilliet, 2014) like those imposed by the covid-19 pandemic. Yang and Baldwin (2020) report that, Immersive and interactive technology like augmented reality (AR) and virtual reality (VR) enhanced students' understanding in STEM subjects. AR was very relevant in STEM fields because it provided students with opportunities for authentic learning (Hsu, Lin & Yang, 2017). Therefore, Covid-19 more than ever amplified the need for AR in STEM education. An advantage of immersive and interactive technologies like computer simulations was that they overcame the boundaries of single disciplines. Additionally, using simulation laboratories provided students with an equivalent learning experience of using a physical laboratory (Yang and Baldwin, 2020) and helped them develop practical skills (Odeh, Shanab & Anabtawi, 2015) without having to worry about purchase of expensive equipment, storage of materials as well as the risks associated with some experiments. Students were able to see what was complex and learn from hands-on experience (Naidu, 2006). The advent of virtual and remote labs would never have been more timely than during the Covid-19 pandemic as Sun and Looi (2013) state that they reduce equipment needs, were available any time anywhere, provided more information and allowed students to work at their own pace.

According to University World News (Sawahel, 2020), efforts in setting up virtual laboratories were lauded for allowing students gain practical knowledge in STEM without taking risks. Indeed, virtual and augmented reality are poised to impact STEM education in an unprecedented way. Craig and Georgieva (2017) disclose that, the Stanford Human Computer Interaction Lab released a free virtual reality simulation dubbed, the Stanford Ocean Acidification Experience which transports students a simulated ocean. Students use the HTC Vive headset to observe the effect of carbon dioxide on marine life and collect samples from the ocean floor. In medicine, VR was already increasing the aptitude of diagnosing and treating disease as exemplified by Cambridge case where VR's were being used to detect navigational problems in patients prone to Alzheimer's. Already many doctors and surgeons world-wide were using VR to plan complex surgeries and even rehabilitate stroke victims as well as those with head injuries (Smith, 2019). In Ireland, Microsoft launched its DreamSpace HomeSpace initiative. This is a STEM content hub where people accessing it could get a themed STEM lesson every day of the week (Partida, 2020). The content could also be watched anywhere within 24 hours of the original publication via the company's YouTube channel. This made it possible for students who missed the live presentation for one reason or another to still catch up on what they had missed.

Harvard researchers also showed that, online STEM demonstrations did not only teach students more, but were just as enjoyable (Fiorentino, 2020). Therefore, where the respective STEM educators have requisite competencies, adopting online teaching would actually engage their students better. In Spain, the university of Almeria created the NeoTrie VR programme which allowed students to create 3D geometric shapes and models that they could alter within the virtual world. Seemingly, VR and AR are taking the STEM by storm. To keep pace with emerging manpower requirements for these technologies, universities like Staffordshire, University of London and Solent University have added virtual reality systems design courses to their curricula (Smith, 2019).

In Africa, there have been attempts to embrace new technological trends and this has been to the benefit of STEM education. Countries are exploring both virtual labs and remote labs for their varied advantages. At Fort Hare University, a virtual laboratory (Remote and Virtual Education Laboratory-ReVEL) set up at the Physics department in 2019 enables students to interact with peers from 20 universities and around the world on experiments in STEM (Sawahel, 2020). In addition, Universities in Moroco, Tunisia and Algeria were implementing remote labs in collaboration with other Universities in Jordan, France, Spain and Belgium as well as with LabsLand (Ibid). In South Africa, Africa Teen Geeks (ATG) launched the STEM digital Lockdown school in partnership with the Department of Basic Education which reached 500,000 learners across the country. It offered free live classes to all South African students with computers and internet connectivity (Matlali, 2020). Because the classes were recorded and shared on social media sites like YouTube, the information was preserved for future reference.

In Kenya, UNESCO launched a STEM digital a mentorship programme designed to use technology to disseminate information on STEM to students wherever they were in the country. It utilizes available online and media platforms (radio stations and television channels) to keep students connected to STEM (UNESCO,2020). The mentors record their voices to be aired through Kenya Broadcasting Cooperation and radio stations. Besides this, there was also a pilot programme of STEM online lessons through Zoom platform which helped educators to effectively manage online environments as their skill improved in the use of virtual whiteboards and video sharing (Ombuor, 2020). The collaborative nature of this approach enriched the learner's experience because while a traditional class utilized a single teacher, a Zoom online class tapped the teamwork of at least two to three teachers and used the five E (Engage, explain, explore, elaborate and evaluate) instructional approach. Further attempts to boost online STEM education were made through the Virtual STEM Hub which was meant to provide science teachers with content and skills to engage students during the pandemic. This is a programe hosted on WhatsApp and is economical on data (IHUB ADM, 2020).

There are other success stories in the use of technology in STEM not just in teaching but also in assessment. Tapper, Batty & Savage (2020) report that, the Imperial College London Medical students took unsupervised exams from the comfort of their homes. They were presented with a patient, the necessary information and data, and tested on diagnosing the patient's condition. The success stories reveal that after Covid-19, school systems that are prepared to use educational technology will be better placed to continue offering education in the face of subsequent school closures (Vegas & Winthrop, 2020) occasioned by waves of the pandemic or any such pandemics that will warrant remote learning.

ii. Pertinent Concerns

a). Access

The first step in effectively integrating technology in STEM is access to hardware and appropriate software. It is therefore imperative for educators and institutional managers to establish whether their students have reliable access to technology before commencing any online classes. Furthermore, teaching and learning online requires access to internet connectivity. Johnson, Jacovina, Russel and Soto (2016) observed that, inconsistent computer access made it difficult for instructors to integrate technology in instruction. According to Janssen, (2020) close to 800 million students did not have access to a household computer and 43% had no internet access at home. Online education was unworkable when students and /or educators could not access the enabling technological tools (IDRA, 2020). This marked the greatest challenge because while transition to online learning was urgent, it was observed that in many countries, the students who could access digital tools and had internet connectivity were unfortunately just a minority (Greene, 2020). Secondly, even for those who had access to internet, there were problems of internet stability and speed, as well as power connectivity and stability. In some cases, students had to share bandwidth with parents and siblings working or taking classes from home (Vegas, 2020), limiting access especially for STEM disciplines which have high data requirement.

African students in rural settings were the most affected during the transition to online learning because they faced challenges of internet unavailability and the high cost of data. Matlali (2020) reveals that, South Africa is ranked as one of the countries with the most expensive data in the world. This is a factor that hindered digital learning in rural areas within the country. Although some students in other pockets of the country had access to smart phones and had internet connectivity on their phones, completing assignments still remained a big challenge. Using Smart phones for online learning was not always comfortable for many students because it restricted the effective use of a number of functions. In Senegal, it was found that learners were unlikely to continue with education using technology because of lack of access. Of the survey respondents, less than 11 per cent said students accessed educational materials using radio, television or web-based resources (Vegas & Winthrop, 2020). To assure access, in Singapore, arrangements were made to have university students who did not have laptops borrow so that no student was left behind in the transition from face to face to online learning (Lim, 2020). While this may have worked for general courses, for STEM education, access required more than access to the computer. Access called for provision of the requisite software to facilitate STEM learning, completion of projects and assignments.

STEM education courses utilize special software like the computer aided engineering and simulation software. These are accurate and professionally used. Software like MATLAB, AUTOCAD, ARCHCAD AND MULTISIM are very key in engineering courses. However, they are expensive. In institutional environments, students easily access them because their laboratories already had computers that support the applications. Apart from the cost implication, some of the software is too large and too heavy to run on certain machines. For students who were over-reliant on university machines, online learning restricted their access to this important software. Consequently, this was bound to affect their assignments and projects.

While there were a number of platforms to support interactive online classes like Zoom, Google Hangouts and online video streaming, for students using their phones, these consumed a lot of their data bundles in a single lesson. Again, it was easy to use these platforms to effectively convey theoretical STEM and non-STEM content. However, practical STEM content delivery required longer time which translated into more data bundles. Insufficient data bundles or frequent power outages led to frequent interruptions during the lesson or termination of the class altogether. In Kenya, some companies like Telkom actualized their good will by providing discounted internet access to students and educators. However, the sim card provided by Telkom for online teaching and learning purposes posed new problems. Accessibility of internet remained a nightmare during the day for both educators and learners. This rendered the sim cards useless for the users because while there was night-time internet access, this failed work for most of the would have been beneficiaries! Another innovative team in Kenya also came up with the Virtual STEM Hub which was meant to provide science teachers with content and skills to engage students during the pandemic. This programe was hosted on WhatsApp and economical on data (IHUB ADM, 2020). While enhanced online education for the participants, the coverage was low with only 30 teachers being impacted for the initial cohort.

b) Equity

Equity is about fairness and impartiality. A study by (Cassen, McNally and Vignoles, 2015) found that the use of technology education could reduce social gaps. However, the reverse actually happened during the Covid-19 pandemic outbreak because in low socio-economic status homes, lack of technological tools was a sure ingredient of the digital divide (Alexiou-Ray, Wilson, Wright &Peirano, 2003). Literature reveals how the pandemic exposed issues of privilege and equity. The general digital divide occasioned by uneven distribution of and access to technology and other online learning enablers threatened to exacerbate inequalities already in place. Reetz (2020) affirms that, the shift to virtual learning merely amplified disparities in access to education by marginalizing the already marginalized. For instance, in India, a few private schools moved learning and assessment online, while some government schools experimented with recorded lessons and shared via WhatsApp. Unfortunately, these were not available to all children (Kaushik, 2020). Moving classes online disadvantaged those struggling with poverty because they could not afford computers or smartphones increasing the possibility of the current crisis leading to greater gaps in student learning (Vegas, 2020).

In some countries, equity concerns governed transition to online learning in other countries, this was totally disregarded in others. For example, in Singapore, during the transition to online learning, attention was paid to learners with special needs and the academically weak to ascertain that they too were transitioning smoothly from the face -to face mode of learning (Lim, 2020). On the contrary in South Africa, although the STEM digital programmed reached 500,000, this was a very small percentage of the 12 million learners raising equity concerns (Matlali, 2020). In a country where nobody bothered to establish whether they were teaching all their students and if they were only teaching the minority, whether it was fair to continue and ignore the rest, this only heightens inequities. Disparity in access to online STEM education among students can create performance gaps because STEM education courses required extensive applied experiential content (Xu & Jaggers, 2014). Students who were able to undertake STEM education using one mode or another definitely stay ahead of the others. They are better resourced, access general STEM content but also have an opportunity to access STEM sessions that others cannot. Hinting at the likely lack of equity, Moore and Valenzuela (2020) are emphatic that, it is not enough to identify STEM content and skills, rather, there must be mechanisms put in place to ensure that all students and especially the underprivileged access experiences that will develop STEM competencies. This could cushion students who suffered exclusion from STEM online learning because of cultural practices and disability issues. For example, students from nomadic communities and those with varied certain disabilities (visual and hearing impairment) were most disadvantaged in the online STEM education. Effective STEM education should thus be about ensuring that all students feel they have equal chances regardless of their abilities, identities and backgrounds.

STEM education called for hands-on investigations using materials and equipment which were unavailable to the majority of the students in their home settings (Jolly, 2020). Generally, when students had differential access to technological tools, different resources and skill levels but were expected to complete similar STEM assignments and projects, were subjected to the same examination and grading, this negated the equity principle.

c) Quality

While Sawahel (2020) acclaims Covid 19 for driving the development of online laboratories among African Countries, he acknowledges that it is complicated to set up remote laboratories because the process requires equipment that is not easily found in Africa. This aspect makes the quality of STEM education provided in many countries during the Covid-19 pandemic questionable. Although Darrah, Humbert, Finstein, Simon & Hopkins (2014) found that virtual labs were just as effective as physical labs, the lack of remote laboratories in many countries created reservations over the quality of online STEM education. Real STEM learning has a practical orientation that is crucial to information retention. Secondly, hands on learning through participation in experiments or demonstrations grants students an opportunity to experience STEM with all their senses (Billings, 2020). This explains Tamm's (2019) observation that E-learning is more suitable for social sciences and humanities rather than for scientific fields like medicine and engineering. This view is echoed by Viegas et al. (2018) whose study on the impact of a remote lab in engineering higher education found that virtual labs were useful in basic courses than advanced ones.

Experimentation allows collaboration with peers (Moore & Valenzuela, 2020) and the grounding of best practice. Even in remote laboratories, students could work from a library of instrument panels, receive a lot of information from the help function or even have embedded assessment for feedback (Cooper & Ferreira, 2009). However, most online environments in developing countries could not allow for collaboration among students, and between students and educators because appropriate technological tools were unavailable.

Tamm (2019) maintains that, STEM fields are practical intensive and no amounts of online lectures can replace for example, the autopsy that is carried out by medical students or real-life industrial training for trainee engineers. This brings into question once more the quality of online education imparted in fields like medicine and engineering during the pandemic. To what degree were practical sessions part of the learning that may have taken place? Hemandez-Alenda (2020) affirms that, the immediate shift to online learning due to the pandemic was specifically difficult for students in STEM courses, and particularly for those who work in laboratories where the work was hands-on. The need for wholesome training must have informed the decisions taken in Singapore where classes with enrolments of above 50 students moved online but those that needed to remain face-to face such as laboratory sessions were broken into smaller groups, and individual departments allowed to decide how to implement social distancing during lab sessions (Lim, 2020). It was thus ensured that these classes had their laboratory sessions by remaining on campus and observing the social distancing requirements. For classes that went online, attempts to address quality concerns like effectiveness of online lectures, assessment changes and self-discipline were made. Online meetings were conducted with directors and teaching staff to share experiences and rectify common mistakes that were made thus assuring quality.

The element of quality is intertwined with access. Lack of requisite hardware (laptops or tablets), software (reading/writing software, internet browsers) and internet connectivity hampered effective delivery of STEM content. Laboratory time was as paramount during the online STEM learning as it is in face to face engagement. However, in many institutions, online STEM education remained purely theoretical. In the isolated cases where attempts at online lab engagement was deemed workable, it required large and costly bandwidth which was beyond the reach of most learners and some educators.

Another quality dimension is that, online STEM education required proper investment by institutions as well as adequate pedagogical training. Supporting students during remote learning is not just about technology. Pedagogy is at the centre of the integration of technology and content. It was therefore imperative to have educators understand how to use the technology at their disposal and involve them in planning how it would fit in their instructional needs. In Singapore, various types of trainings were organized for lecturers. In addition, students were orientated on how to operate in online learning environments (Lim, 2020). In other countries, educators were merely floundering in their online STEM instruction because they lacked sufficient training on how to effectively use virtual platforms at their disposal.

Then there was the issue of poor quality assurance and lack of credited online providers (Tamm, 2019). Mckenzie (2020) reiterates that, many universities and colleges offered minimal online teaching because of concerns about quality and limited mechanisms for oversight and regulation. This was especially important in regard to the question of contact hours. While some quality assurance officers were categorical that universities' standards should be maintained and students must meet learning outcomes (Tapper et al., 2020), the same cannot be generalized to all institutions that transited to online STEM learning. Depending on the platforms used, some had time restrictions unless they had been duly paid for. Educators who opted for free platforms for online STEM education had a lot of interruptions and even lesson termination which affected the quality of the delivery. In other higher education institutions, existing policies were re-drafted to include online pedagogy (Assey, 2020). However, the new approaches were received with mixed reactions from stakeholders. Change in policies notwithstanding, there was hardly sufficient time to in-build quality assurance processes in the online STEM models due to the hurried transition. Perhaps, his explains the past skepticism about the quality and value of online education which many employers have always viewed as inferior to face-to-face education (Fain, 2019).

In many institutions of higher education, STEM education is assessed through theory as well as practical examinations. The practical examinations in many instances are part of continuous assessment taking place throughout the semester as the students undertake laboratory sessions. This is how acquisition of requisite competencies and knowledge is gauged. The switch to online learning therefore jeopardized this aspect of learning and evaluation in many developing economies whose institutions are still hooked onto physical laboratories that were rendered unfunctional during the pandemic. By merely watching a live demonstration or a pre-recorded one on YouTube, STEM students would not really claim to have acquired a competency or mastered a skill. Lempinen (2020) admits that, even where adaptive tutors have been embraced, they tend to be limited in STEM domains.

d) Student Engagement

The fear that most students lacked disciplined orientation to online learning (Lempinen, 2020) was real as most of them were averse to online education. Students' attitudes, beliefs and perceptions of the effectiveness of educational technology became a barrier to their own education in STEM based fields. While the current student generation are regarded as "Digital Natives," their digital orientation has always been skewed towards social interaction; not academic. Therefore, while some students had access to the required technological enablers for online learning, they lacked the motivation and self-direction. Secondly, some of them were not proficient at the software they were expected to use. Another explanation for students' lack of motivation to engage in STEM learning online was occasioned by their being off campus and therefore being more in a holiday than an academic mood. This was compounded by the fact that, during the pandemic online STEM education technology used was imposed on the students in total disregard of what they would have preferred. The choice was made by either the institution or the course instructor. The suggestion that, the students ought to play a role in choosing the technology they use (Wynn, 2013) could have mitigated this problem.

Online learning also required not just high levels of self-direction but also self- efficacy. Unfortunately. these were not universally shared among STEM students. For many students, face-to-face interactions in science laboratories was more engaging because there was interpersonal interaction. While De la Torre et al. (2013) established that students showed an increased level of engagement working collaboratively in virtual and remote labs, a later study by Odeh et al. (2015) found that on the contrary, teamwork was better built in traditional labs than in virtual and AR labs. The fact that there is lack of physical contact with the experiment potentially reduces the lack of realism (Andujar, Mejias & Marquez, 2011) and might explain students' lack of enthusiasm observed by Wynn (2013). Odeh et al. (2012) acknowledge that, solutions such as virtual and remote labs cannot completely replace physical labs because they lack reality and try to visualize instruments and experiments graphically. It is the very element of reality that keeps STEM students engaged.

Although it was possible for students in certain developed economies to successfully undertake their STEM classes virtually and remotely, and still collaborate (De la Torre et al., 2013), in many African contexts this was impossible. Institutional environments provided atmospheres for information sharing through working collaboratively which was lacking in online environments. This is best illustrated by Study Staff International (2020) study which established that, although STEM students' learning outcomes in online environments were similar to those attained in brick and mortar ones, online students reported feeling less dissatisfaction with their course experience compared to students in in-person and blended classes. Face-to-face learning environments had the advantage of supporting teamwork which most practical STEM sessions ride on.

Another observation is that, while technology was expected to positively engage students, it was also likely to have the opposite effect as French (2016) indicates that students could actually be wrongly engaged. This is whereby students would seemingly be working on class content yet still be disconnected from what was happening in the very class. Students thus faced the danger of being derailed by technology such that, their focus would be more on the technology than the course content. This was the case in the use of AR and VR where the nature of the technology would easily drive pedagogy and shifts the focus away from the STEM content to the technology instead.

4. Conclusion

This study found that a wide range of technologies were adopted for STEM education during the Covid-19 pandemic. The study found that both synchronous and asynchronous technologies were leveraged for STEM online education. The study also established that some institutions were embracing more sophisticated technologies live Virtual Reality and Augmented Reality to enhance STEM education especially in medicine and engineering fields. The adoption and use of technology for STEM education was informed by the skills of the educators and the cost of the implication of the kind of technology leveraged. The successful integration of technology in STEM education during Covid-19 demonstrates that it is possible to move STEM education to the next level.

It was established that, while online STEM was inevitable during the pandemic, there were problems of access by many students especially in developing countries. This was because they did not have the required hardware and software. In addition, there was lack of internet connectivity in the rural homes of many students. Secondly, the migration to online STEM education presented equity issues. It discriminated inadvertently against those who could not afford the hardware and software required as well as those with special needs. Thirdly, it brought into disrepute the quality of education offered. STEM fields are practical oriented and in cases where this practical component was disregarded because of the nature of technology used or the affordability, wholesome STEM education was not provided. Thus, online STEM education during the Covid-19 pandemic faced the challenge of limiting hands-on, interactive and problem-based learning that would have enriched students' academic experiences hence compromising the quality. Finally, students failed to exhibit self-direction and self-efficacy which are the mainstay of online STEM education. This was partially due to lack of participation in the technology used, and also because there was lack of physical lab sessions which would offer inter-personal interactions and provide realism.

5. Recommendations

Following the above findings, it is recommended that:

i.Governments should invest in the provision of power particularly in rural settings and then enhance internet provision. The Covid-19 pandemic just showed that rural educators and students were the most affected during transition to online teaching in general and STEM education in particular. It is recommended that, governments should subsidize the cost of laptops and computers for students so that most of them are encouraged to buy. When these machines cost what can feed a family for a year, most it disadvantages students from low socio-economic status families. When educational institutions should enter into partnerships with internet service providers for subsidized data, they should ascertain that this will work for their educators and students.

ii. To ensure that all students access STEM education during the current and any future pandemics, governments and institutions should invest in diverse technologies. People living with disabilities should be prioritized in the provision of any technology enablers for online education during such pandemics to ensure inclusion. Before moving classes online, institutions should ensure that all their students are on board. To teach a handful of students who can afford online education tools and disregard those who cannot is to perpetuate inequalities. Measures to safeguard the disadvantaged should be inbuilt in the online learning transition plans.

iii. Because STEM education is about on experience for acquisition of skills and competencies, the quality of online STEM education should not be compromised. Educators should adopt technologies that favour practical sessions. Governments should fully embrace the idea of remote labs. As much as possible, the collaborative effort in setting up remote labs should be stepped up so that, in each developing country, each region has an institution with a remote lab accessible to other institutions in the region. Where it is not possible to set up remote labs, educators should schedule a series of practical sessions to be done in physical laboratories by students in shifts. Governments should begin to invest in superior technologies that can be easily tapped during such pandemics to enhance STEM education practical sessions.

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