Pertanika J. Sci. & Technol. 31 (1): 237 - 256 (2023)

SCIENCE & TECHNOLOGY

Journal homepage: http://www.pertanika.upm.edu.my/

Technology Adoption for STEM Education in Higher Education: Students' Experience from Selected Sub-Saharan African Countries

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ABSTRACT

Challenges of a lack of formal technology-embeded teacher training, collaborative learning models, adequate technology know-how, and internet access are barriers to adopting technological-enabled teaching and learning STEM subjects in the African context. This study examined technology adoption for STEM in higher education while evaluating students' experiences with evidence and implications for less developed countries. The survey research design was adopted for the study. The study population was students in higher learning institutions in selected countries in the sub-Saharan African region using a multi-stage sampling procedure consisting of convenience and purposive sampling techniques. A self-developed questionnaire titled Technology Adoption for Teaching and Learning Questionnaire "TATLQ" premised on the unified theory of acceptance and use of technology (UTAUT) model was used for data collection. The instrument had an overall reliability coefficient of 0.96. The collated data were analysed using descriptive of the median and a network chart to answer the research questions. In contrast, the inferential statistics of t-test and Analysis of Variance statistics were used to test the hypothesis generated for the study and implemented in the psych package of R programming language version 4.0.2 software. Findings revealed that students had a positive experience with online teaching and learning and concluded that technology adoption for STEM education online teaching and learning is feasible in sub-Sahara Africa, with the need for improvements in internet access and technical support on the basis for which recommendations were made.

Keywords: Higher education, online teaching and learning, STEM education, students' experiences, technology adoption

ARTICLE INFO

Article history:
Received: 23 February 2022
Accepted: 07 June 2022
Published: 20 October 2022

DOI: https://doi.org/10.47836/pjst.31.1.15

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ISSN: 0128-7680
e-ISSN: 2231-8526

INTRODUCTION

The world is changing exponentially with technological innovations. These changes require training to acquire a new skill set for problem-solving while grasping the available print and digital information. While these changes have become inevitable, Kärkkäinen and Vincent-Lancrin (2013) highlighted the lack of formal teacher training, peer learning and adequate professional development as barriers to adopting technological-centred teaching models and resources. Furthermore, technological difficulties, time management issues, and a lack of readiness for online learning are weaknesses of technology-integrated teaching aggravated by digital inequalities among different groups and a lack of personal support (Oladele et al., 2021; Lee et al., 2021). These challenges are not without implications for Science, Technology, Engineering, and Mathematics (STEM) education (Vahidy, 2019). STEM education is a teaching approach that integrates all four disciplines into a single, multidisciplinary, cross-disciplinary, and transdisciplinary program that offers real-world instruction using appropriate teaching methods (Dalton, 2019; Hasanah, 2020). Understanding these four disciplines is considered a precondition or enabling factor for 21st-century economic development, international competitiveness and job creation which necessitates an improvement in the quality of education delivered as STEM (Ismail, 2018; Schwab, 2016). LaForce et al. (2016) employed a “bottom-up” approach for deriving a theoretical framework of eight elements that represent the common goals and strategies employed for inclusive STEM in schools which were personalisation of Learning; Problem-Based Learning; Rigorous Learning; Career, Technology, and Life Skills; School Community and Belonging; External Community; Staff Foundations; and External Factors. Technology is fast becoming relevant for teacher training in developing countries. Also employing the bottom-top approach, Ayanwale and Oladele (2021) examined online learning indicators and learners’ satisfaction during the COVID-19 pandemic revealing a passive to interactive shift in instructional activities through student-teacher collaboration. This utility-centred approach creates an enabling learning environment for students and instructors to co-create and consolidate knowledge while leveraging technologies for STEM education. This is the gap this study aims to fill (Ismail, 2018).

CONCEPTUALISING STEM EDUCATION

STEM education means a variety of perspectives considering its widespread among stakeholders such as politically and societally, personally, and interactively. Politically and societally, constituting a primary motivation for educational policy, leading to heavy investments in the field in curriculum developments and research policy inherently concerned with axiological objectives (Chesky & Wolfmeyer, 2015). Personal conception deals with the individual opinion of people on STEM, with no wrong or the right type of individual opinions. This perspective of STEM education as a unit is driven by integrating

Science, Technology, Engineering and Mathematics disciplines to solve emerging challenges. Kubat and Guray (2018) further stressed the need for STEM education as a discipline rather than teaching these four disciplines independently. STEM education as the integration of disciplines can be seen in reform initiatives needed for producing a skilled workforce (Chesky & Wolfmeyer, 2015; Siekmann, 2016). For this study, STEM is conceptualised as a discipline. This stance is premised on a review by Hasanah (2020), revealing that most authors conceptualise STEM as an integrated discipline and a fundamental definition of STEM education.

Thus, acceptance of the STEM element in the process is crucial. The unified theory of acceptance and use of technology (UTAUT) was adopted in this study (Venkatesh et al., 2003). This theory is a full-grown and intensive model to examine users' ability to accept technology and their experience in adopting new technologies. The UTAUT theory has underlying constructs such as performance and effort expectancy, social impact, ease of deployment and behavioural objectives. Venkatesh et al. (2003) described performance expectancy as the benefits of technology in terms of performance enhancement in line with user expectations, while effort expectancy relates to ease of use. Social impact speaks to how users engage technology and its continuity, depending on the available organisational and technical infrastructure, and behavioural objectives are seen as users' intent and decisions on the use of technology. In this study, among these constructs outlined by Venkatesh et al. (2003), performance expectancy described the significance of this study by establishing the students' experience with online teaching and learning. Consequently, items developed for this study were tailored toward this direction.

LITERATURE REVIEW

STEM education equips learners with problem-solving skills and helps them become knowledge creators, composed, analytical thinkers, and technologically literate (Stohlmann et al., 2011). STEM education drives skills such as tenacity, collaboration, and knowledge application to careers requiring versatility as determinants of success and economic competitiveness in the global market (Boe et al., 2011; Bailey et al., 2015; Tanenbaum, 2016). In addition, STEM education helps to adequately equip students with attributes for the future, such as problem solvers, innovators, inventors, self-confident, logical thinkers, and technology literacy (Hasanah, 2020). According to Dogan and Robin (2015), advances in computer and network technologies aid cooperative learning among students while providing constructivist feedback, enhancing constructivist learning models in education.

Furthermore, the integration and effective use of technology is vital to enhancing learning STEM subjects which have completely changed the way teachers and students communicate and collaborate using various online interaction platforms, enabling students to experience phenomena they normally would not be able to experience first-hand through simulations, teachers can involve students in the process as well as give them a wider understanding of a particular topic using augmented and virtual reality. Also, gaming for learning puts the students in control, offers incremental difficulty levels, provides instant and ongoing feedback, and creates community by allowing for multiplayer participation (Kärkkäinen & Vincent-Lancrin, 2013; Vahidy, 2019). This process necessitates a strong STEM education from the grassroots, recognised as a key driver of opportunities. The literature on gender disparities within STEM education reveals that in sub-Saharan Africa, females have less access to STEM education at the higher education level, with statistics revealing less than average female participation in STEM-related studies at the tertiary level of education (Ismail, 2018). Gender has continued to be one of the factors in the adoption and use of e-learning systems with various applications (Abahussain, 2017). Eliminating gender imbalance in technical education and training is one of the Sustainable Development Goal 4 targets, which further points to the importance of gender in research and largely contributes toward strategic development at the country level (UNESCO et al., 2015; Oladele et al., 2021). The response to issues relating to gender gaps and mainstreaming in STEM education are geared towards addressing inequalities (IOS, 2017).

Amid these efforts comes the COVID-19 pandemic with the potential of further straining the meagre opportunities for STEM education. In addition, digital literacy has become more prominent concerning 4IR since 2016. The rationale for investment in STEM education relates mainly to acquiring new skill sets required for the 21st Century job market with increasing emphasis on technology skills and gender equity in Africa (Ismail, 2018). Therefore, STEM education is a priority for medium to low-income countries. Stemming from this rationale, some benefits of STEM education are improved teacher professional development, enhanced meeting of 21st Century workplace demands, and sustainable work. Similarly, the mastery of STEM is correlated to secondary school enrolment and retention, innovation leading to economic prosperity, national peace and international competitiveness (Breiner et al., 2012; Chesky & Wolfmeyer, 2015; Hasanah, 2020).

The COVID-19 pandemic has necessitated electronic instruction (e-learning) to adhere to the COVID-19 safety protocols while leading to the rapid growth in online education (Widodo et al., 2020; Ramírez-Hurtado et al., 2021). This learning model allows students to learn virtually while leveraging online teaching and learning. Electronic instruction leverages the internet. E-learning is the umbrella term for learning across distances, not in a traditional classroom (Kessler, 2018). Forson and Vuopala (2019) described four generations of online teaching and learning, starting from the era of correspondence courses to that of the internet-driven solutions adopted by many universities in developed countries. For Barr and Miller (2013), online teaching and learning focus on a wide range of technological-based platforms for delivering the curriculum. Learning management systems (LMS) such as Blackboard, Moodle, MS Teams, Zoom, Google Meet, Google

Classroom, and Sakai, among others, encourages knowledge diversification and self-driven learning engagements allowing for a flexible implementation framework (Sabharwal et al., 2018; Kessler, 2018; Škobo, 2020; Alturki & Aldraiweesh, 2021). While these are some of the benefits of technology in teaching STEM subjects, the success of instruction driven by digital resources is premised on effectively adapting these resources to attain learning goals (Drijvers et al., 2019). Also, instructors must either create their "virtual classrooms" from scratch or leverage existing LMS software with low-cost alternatives and open sources.

While the COVID-19 pandemic has had its downside for higher education, the digital revolution has enabled instructional delivery modes for inclusiveness while technological affordances beg for answers (Ndlovu & Mostert, 2018; Forson & Vuopala, 2019). Also, how these technologies can aid teaching is germane in mathematics education (Drijvers et al., 2019). Teaching in a web environment comes with tons of requirements, like students' and teachers' readiness (preparedness) (Qazaq, 2012; Fakinlede et al., 2014; Rasouli et al., 2016; Ndlovu & Meyer, 2019). Instructors must also have a positive attitude, while the institution must provide supporting resources. As a sequel to the present, education instructors may need difficulties handling online teaching and learning; they will experience discomfort when handling technology-embedded classrooms and related issues (Palloff & Pratt, 2013). Technology users should also be interested in using technology as a learning tool and teaching platform for strengthening the education system globally (Forson & Vuopala, 2019; Ndlovu & Meyer, 2019; UNESCO, 2021). The availability and use of technology in teaching practices are essential in the COVID-19 era, while it remains essential to research students' preparedness for online teaching and learning (Oladele et al., 2021; Kamaruzaman et al., 2021). These constitute an element to be considered if the goals of STEM education are achieved through online teaching.

The COVID-19 pandemic necessitated an unplanned transition to online teaching and learning. STEM education geared towards acquiring required skills and mindsets for lifelong learning while adopting learning technologies must be adequately evaluated for success. Many countries are committed to improving its quality, considering the importance of STEM for 21st Century economies' development (Hasanah, 2020). Related STEM education studies have been carried out concerning skills needed by teachers at all levels to be intimately familiar with the interrelationships within the STEM disciplines (Breiner et al., 2012); Integrative STEM education is seen as a viable endeavour (White, 2014); the potential of LMS for blended learning with a focus on Moodle (Ndlovu & Mostert, 2018); lecturers' preparedness for transition to teaching online courses (Lichoro, 2015); readiness of students in applying e-learning (Fakinlede et al., 2014; Rasouli et al., 2016) and teacher readiness on technology integration for teaching Mathematics (Qazaq, 2012; Ndlovu & Meyer, 2019) among others. The current COVID-19 pandemic, which has resulted in institutions taking to online teaching and learning, urges students' preparation and experience with STEM instruction to be investigated. This study aims at mirroring students' experiences with online learning to aid improvements where needed. Specifically, the objectives of this study were to:

1. examine students' preparedness for online teaching and learning;
2. examine students' experience with online teaching and learning;
3. assess the quality of lectures deployed via the online platform;
4. find out new skills acquired by students exposed to online teaching and learning; and
5. ascertain if there are significant differences in students' experiences based on selected variables.

The above-stated objectives were further translated to research questions and hypothesis below:

1. What is the level of students' preparedness for online teaching and learning?
2. What are the students' experiences with online teaching and learning?
3. What is the quality of lectures deployed via online platforms?
4. What are the new skills acquired when exposed to online teaching and learning?
5. Is there any difference in students' experience with online teaching for STEM education across gender, age, disciplines and level?

H_{01}: There is no significant difference in students' experience with online teaching for STEM education across gender, age, disciplines and level of study (graduate/postgraduate).

METHODOLOGY

The non-experimental design of the survey research type was adopted for the study. The study population was students in higher learning institutions in the sub-Saharan African region, while the target population experienced online teaching and learning due to the pandemic. A multi-stage sampling procedure consisted of convenience sampling and purposive sampling techniques. Four universities were selected using the convenience sampling technique: one each from Nigeria (West Africa), South Africa, Uganda (East) and Algeria (North Africa) was premised on access, while students from the selected universities were sampled purposively to include STEM education learners. A self-developed questionnaire titled Technology Adoption for Teaching and Learning Questionnaire "TATLQ" was used for data collection. The instrument was developed with the UTAUT model suitable for examining users' ability to accept and adopt new technologies and their experience in the adoption process (Venkatesh et al., 2003). Hinged on this model, the instrument consisted of two sections.

Section one presented brief background information on the study. In contrast, section two consisted of seven loose items with corresponding response formats and three themed items on Student preparedness for online teaching and learning with 14 items, Student experience with online teaching and learning with 21 items and rating the quality of lecture with 11 items on a four Likert response scale of Strongly Agree, Agree, Disagree and Strongly Disagree. The instrument was face and content validated by educational measurement experts. Its reliability was established using the Ordinal Alpha method for determining the instrument's internal consistency applied to the themed items in Sections B. Ordinal reliability coefficients of 0.95, 0.95 and 0.99 were obtained with an overall reliability coefficient of 0.96. The instrument was deployed via Google forms to students in the selected Universities to ensure adherence to the social distancing measure for curbing the spread of the Corona Virus. The collated data were analysed using descriptive of the median and a network chart to answer the research questions and inferential statistics of t-test and Analysis of Variance to test the hypothesis generated for the study, which was implemented in the psych package of R programming language version 4.0.2 software.

RESULTS

Data Handling

Responses to the questionnaire were used to answer the questions/hypotheses posed for the study. Data integrity was ensured by handling the missingness and outliers evident in the dataset. Also, a preliminary analysis was conducted to check for assumptions (such as normality, heterogeneity of variance, and sample size adequacy) that underlie the statistical tools employed in this study. The results from Shapiro-Wilk's test ($W = 0.98$, $p = 0.19$) revealed that the dataset followed a normal distribution, thereby not violating the normality assumption. Levene test ($F = 0.32$, $df = 1,193$, $p = 0.57$) was used to assess variance heterogeneity at a significance level of 0.05; it was remarked that equality of variance existed among the subjects used for this study.

Answering Research Questions

The median statistics describe students' preparedness for online teaching and learning to answer research question one. It provides more information about the sample than the mean, which many researchers in the literature predominantly reported. Also, the measurement scale is ordinal, whereby there is no standard scale on which the difference in each rating is measured. There is a clear order to these categories, but we cannot say that the difference between "strongly agree" and "agree" is the same as that between "disagree" and "strongly disagree." For easy interpretation of the question, a median value less than 2.5 signifies that half of the sample rated the item below 2.5, indicating a 'low level' of participants' preparedness for online teaching. Also, a median value greater than 2.5 signifies that half of the sample rated the item above 2.5, indicating a 'high level' of participants' preparedness for online teaching. Table 1 presents the result.

Table 1
Level of students' preparedness for online and teaching

Statement	Median	Remarks
I have a personal computer	4	High
I have access to the internet	4	High
I have access to an uninterrupted power supply	2	Low
I am experienced with using google collaboration tools	3	High
I have experience participating in zoom meetings before the class starts for the contact session	3	High
I have a functional email address	4	High
I am conversant in using email for communication	4	High
I am used to surfing the internet for required contents	4	High
I have other devices/gadgets for effective participation in online teaching and learning aside from my computer	3	High
I have dedicated enough time to participate in online teaching and learning fully	3	High
I have prepared the cost implication(s) on the data bundle for seamless participation in online teaching and learning	3	High
I have experience in using the chatbot and other facilities of different platforms	3	High
I have used other platforms aside from zoom for meetings before the commencement of class for the contact session	3	High
Learning online sounds like a good idea	3	High

Table 1 presented median values for each item on the scale. It was revealed that most sampled subjects showed high enthusiasm towards items measuring their preparedness for online learning. However, access to an uninterrupted power supply was low, contributing to the participant's level of preparedness. Overall, students were adequately ready and prepared for online learning, especially with the upsurge of COVID-19, which necessitated the teaching-learning process to be migrated online.

Also, research question two was answered using descriptive statistics of the median, and classification of positive and negative was done regarding research question one. The result is presented in Table 2.

Table 2 depicts the values of median descriptive statistics for each item describing students' experience with online teaching and learning. The result showed that participants displayed their experience on each item, measuring the scale above 2.5. They had divergent views on a few items (browsing data and technical availability support during online classes), with a median value below the cut-off of 2.5. The result implies that students'

Table 2
Level of students' experience in online teaching and learning

Statement	Median	Remarks
I am conversant with WhatsApp as a mobile technology	4	Positive
I am skilled in using google forms for taking assessments	3	Positive
I am skilled in using google docs for submitting assessments	3	Positive
The school provided the data I used to join classes	2	Negative
I financed the data used to join online classes	4	Positive
I am skilled in using functions from different platforms while in class	3	Positive
I could resolve my internet issues while connecting to online classes	3	Positive
I had technical support during online classes	2	Negative
I had access to clear and legible presentations during my classes	3	Positive
I had ample time to jot down points during online classes	3	Positive
I had the opportunity to ask questions during online classes	3	Positive
Access to lecture playbacks aided the online learning process	3	Positive
The use of technology hampered my learning	3	Positive
Lecture information was effectively disseminated during the class	3	Positive
I could surf the internet for content to support learning	3	Positive
I took online assessments with ease	3	Positive
I got timely feedback after taking my online assessment	3	Positive
I had direct access to the lecturer before and after classes	3	Positive
I had ease of access to course materials before the class	3	Positive
I had educative and informative interactions and discussions with other students	3	Positive
It improves my self-discipline to work independently	3	Positive

experience with online teaching and learning was largely positive. The positive students' experiences being considered, online teaching and learning generally serve as a responsive model to the emergent needs of the student.

Furthermore, research question three on the quality of lecture deployed was assessed using descriptive statistics to depict high or low quality based on the median benchmark of value less than 2.5 and greater than 2.5 on each item. Table 3 presents the result.

Table 3
Quality of lecture deployed through online teaching and learning

Statement	Median	Remarks
Timely commencement of the lecture	3	High
Access to lecture slides	3	High
Clear presentation of lecture content	3	High
Good communication skills	3	High
Adequate course content coverage	3	High
The lecture was revised before taking the final examinations	3	High
Availability of learning resources to support the class	3	High
Engaging lecture presentations (With suitable images and backgrounds)	3	High
Room for feedbacks	3	High
Contents are disseminated in simple and clear terms	3	High
Support for accomplishing class tasks	3	High
Courteous interaction during online classes	3	High

Table 3 remarked that participants from STEM disciplines rated each item above the cut-off of 2.5. This finding implies that students were satisfied with the quality of online teaching and learning content. Also, their responses might be because lecturers were digitally competent at adapting to their wishes and needs regarding teaching; contents are synchronously deployed and enhance their collaboration, especially during a Covid-19 pandemic.

A network chart of skills acquired during online teaching for STEM education was mapped to answer research question four, as shown in Figure 1.

Figure 1 depicts diverse skills acquired during online teaching for STEM education, some of which were typing, time management, problem-solving, PowerPoint presentation, self-development, online research, self-dependence, note-taking, time management, critical thinking, commitment, using LMS, commitment, animation and editing, internet proficiency and safety, cognitive reasoning, self-discipline, graphic design, listening, and collaboration, among others. This finding reveals that students acquired various skills to cope with online teaching and learning.

Hypotheses Testing

The research hypotheses posed for the study were tested at a significance level of 0.05 after establishing the assumptions of statistical tools, such as independent sample t-test and one-way analysis of variance (ANOVA). Table 4 presents the sample t-test on students' experience with online teaching for STEM education based on gender.

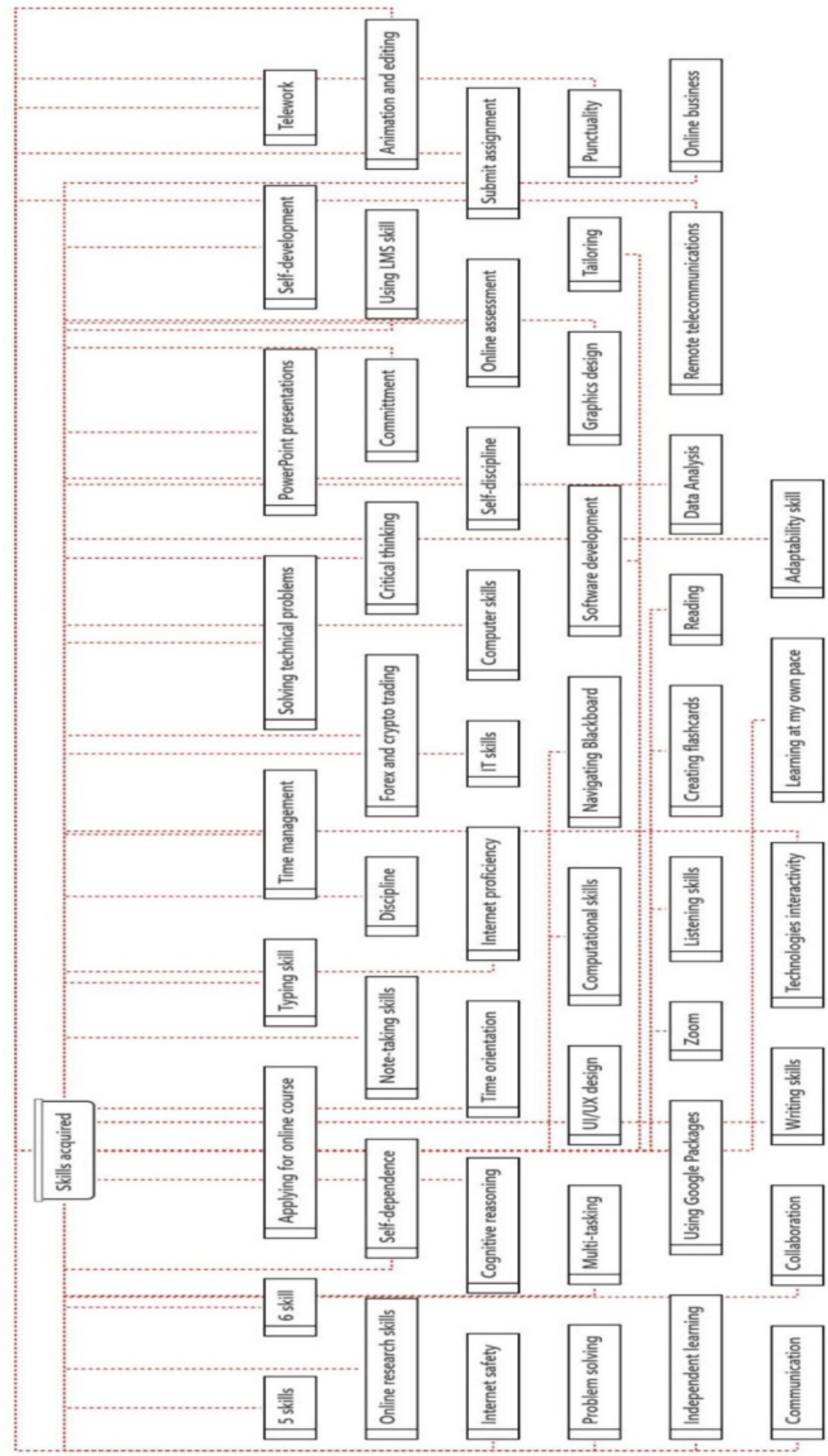

Figure 1. Network of skills acquired during online teaching for STEM education

Table 4
T-test summary of experience with online teaching for STEM education based on gender

Gender	Mean	SD	Statistic	df	P
Male	65.8	9.57	1.98	193	0.04
Female	62.9	10.5			

Table 4 showed that male students across the STEM education had higher mean score of (M = 65.8, SD = 9.57) compare with their female counterparts with (M = 62.9, SD = 10.5). This finding shows that male students had a better experience with online teaching and learning than female students. Also, an independent sample t-test was conducted to assess the observed difference in the students' experience with online teaching; the result yielded a statistically significant difference between the male and female experience with (t = 1.98, df = 193, p = 0.04). Thus, the null hypothesis was rejected. This decision implies that the acquired skills and experience during online teaching differ between male and female students. This outcome might allude to the fact that male students develop more interest in technology-driven teaching than female colleagues.

Also, the hypothesis stated no significant difference in the students' experience with online teaching for STEM education concerning age group was conducted using one-way ANOVA. The result is presented in Table 5.

Table 5
ANOVA summary of experience with online teaching for STEM education based on age group

Age group	Mean	SD	F	df1	df2	p
18-25	65.5	10.05	1.83	3	191	0.14
26-32	61.60	8.94				
33-39	62.60	11.07				
40 and above	62.00	14.28				

Table 5 depicts that age group 18–25 across the STEM education had higher mean score of (M = 65.5, SD = 10.05), followed by 33–39 age group with (M = 62.6, SD = 11.07), next to above 40 with (M = 62, SD = 14.28) and age group 26–32 with (M = 61.6, SD = 8.94) respectively. More so, one-way ANOVA was used to establish whether there was a difference in their mean scores or not. The result remarked a non-statistical significant value with ($F_{3,191}$) = 1.83, p = 0.14). Consequently, the null hypothesis was not rejected. This finding implies that the students' age groups have nothing to contribute to acquiring skills for online teaching for STEM education.

Also, the hypothesis stated that no significant difference in the students' experience with online teaching for STEM education in disciplines was conducted using one-way ANOVA. The result is presented in Table 6.

Table 6

ANOVA summary of experience with online teaching for STEM education based on disciplines

Discipline	Mean	SD	F	df1	df2	p
Engineering	67.80	9.34				
Science	63.60	10.75	0.99	3	191	0.40
Technology	64.00	9.55				
Mathematics	66.90	11.25				

Table 6 remarked that engineering as a discipline had higher mean score of (M = 67.80, SD = 9.34), followed by Mathematics with (M = 66.90, SD = 11.25), followed by Technology with (M = 64, SD = 9.55) and Science with (M =63.60, SD = 10.75) respectively. Meanwhile, one-way ANOVA was used to establish a difference in their mean scores. The result showed that the mean difference was not statistically significant ($F_{3,191}$) = 0.99, p = 0.40). Therefore, the null hypothesis was not rejected. This decision implies that irrespective of the student's discipline has no contribution to experience with online teaching for STEM education.

Furthermore, the hypothesis that there is no significant difference in the students' experience with online teaching for STEM education at the study level was conducted using one-way ANOVA. The result is presented in Table 7.

Table 7

ANOVA summary of experience with online teaching for STEM education based on the study level

Study level	Mean	SD	F	df1	df2	p
Graduate	64.5	10.61				
Honours	62.2	9.66	0.95	2	192	0.39
Postgraduate	65.5	8.98				

Table 7 remarked that postgraduate level had higher mean score of (M = 65.5, SD = 8.98), followed by graduate with (M = 64.5, SD = 10.61), and honours with (M = 62.2, SD = 9.66). However, one-way ANOVA was conducted to compare mean differences. The result showed that the mean difference was not statistically significant with ($F_{2,192}$) = 0.95, p = 0.39). Therefore, the null hypothesis was not rejected. This finding implies that the students' study level has no contribution to experience with online teaching for STEM education.

DISCUSSION

This study aims at mirroring students' experiences with online learning to aid improvements where needed. Considering that COVID-19 was an emergency where online learning was adopted with little or no preparation, the study surveyed students' level of preparedness for online learning as a precursor to their experiences. The study revealed that students were adequately prepared for teaching online, especially with the upsurge of COVID-19, which necessitated the teaching-learning process to be migrated online. This finding may be because the target population of this study were students enrolled in STEM subjects who are conversant with personalisation of learning; problem-based learning; rigorous learning; career, technology, and life skills; school community and belonging; external community; staff foundations; and external factors being the elements of inclusive STEM education (LaForce et al., 2016). This finding aligns with Forson and Vuopala (2019) and Kamaruzaman et al. (2021), revealing that students had a positive attitude towards online learning. Ndlovu and Meyer (2019) stressed that preparedness is a major requirement for meaningful learning in an online environment. Parkes et al. (2015) gave a divergent view that while students were perceived as technology-ready, there is a need for improvement with synthesising ideas, implementing learning strategies, intellectual rationalisations when necessary and collaboration. However, the finding of this study concerning preparedness can be regarded as superseding that of Parkes et al. (2015), considering that it was premised on real students' experiences.

This study also reported a positive experience with online teaching and learning. In essence, online teaching and learning education generally serves as a responsive model to the emergent needs of the student. Learning is now diversified and deployed innovatively through internships and volunteer activities. The positive experiences recorded might come from personal development and exposure to various online teaching platforms such as zoom, Ms teams, blackboard, smart Board, google meet, LMS canvas, and google classroom. Worthy of note are the areas of browsing data and technical support needs during online classes where students' experiences were negative. This finding aligns with Vahidy (2019) and Oladele et al. (2021) that the high cost of the internet and a dart of technical assistance while interacting with online learning platforms have been a major challenge in sub-Sahara Africa. This submission is strengthened by a report on internet penetration in South Africa stood at 64.0% (Kemp, 2021).

Similarly, Adegoke (2017) reported that internet delivery is slower, more unreliable, and expensive and stressed the need to build the internet sector considered critical for development and improved efficiency and productivity gains in the educational sector in Africa. Access to browsing data and related technical support can be the gateway to online learning. These submissions magnify the urgent need for solutions to sustain students' high experience with online teaching and learning fast becoming the new normal.

Furthermore, the findings on students' rating of the quality of lectures deployed via the online mode revealed that they gave lectures a high rating. Their responses might be because lecturers were digitally competent at adapting to their wishes and needs regarding teaching; contents are synchronously deployed and enhance their collaboration, especially during a COVID-19 pandemic. This finding correlates with a study by Junus et al. (2021) that lecturers have strong baseline technical skills to use e-learning platforms for online courses, with quick adaptivity capabilities to using a Learning Management System (LMS). Lecturers are an important factor in teaching as learning is described as a social activity strengthened when an instructor carefully facilitates instruction. Considering the need for carefully designed content to suit students' needs, an effective instructor (in this case, the lecturer) is needed to enhance corrective feedback and encouragement while motivating students to be committed to a given task(s) to achieve the learning objectives. Therefore, a symbiotic relationship between students and lecturers is required to learn the online teaching-learning process (Young, 2006).

Furthermore, the findings from the study revealed that students developed an array of skills from online teaching and learning believed to help enhance the student's academic excellence. While this finding resonates with Forson and Vuopala (2019), preparedness, a major requirement for online learning, is influenced by appropriate strategies for independent learning, such as self-regulation, direction, and motivation (Fakinlede et al., 2014). Conducting online teaching on various courses makes learning more flexible, and they can work at their own pace, promoting better learning for the students. Students cultivate time management, and schedules can be more accurately planned, and one activity will not affect the execution of another. Their online research skills were sharpened as students had more time to get information on topics of interest by reading extensively on the same issue in different parts of the world. More knowledge of the usage of teleconferencing software was also improved during online teaching.

Some soft skills are also improved during the period, such as communication skills, including writing, reading, and speaking skills. Also, problem-solving skills were improved in some students. Some also improve discipline and self-dependency. Of course, these will aid better achievement in their academic endeavour in STEM. This finding revealed that the elements of inclusive STEM education derived by LaForce et al. (2016) were much present in the crop of students surveyed in this study. This finding aligned with Forson and Vuopala's (2019) study, which revealed that students possessed skills relevant to the world of work and life-long learning. Also, information technology skills regarded as necessary to success were improved as some learned data analysis, some went into software development, and some went into building an application. This finding aligns with The Glossary of Education (2014), which stressed that new technologies have diversified learning in a dependent, interdependent and self-paced leveraging of technology. After their studies, these skills will help the students apply knowledge gained in work life. This benefit is particularly important for the 21st Century, which is fast, self-paced, and apt for STEM disciplines to solve real-world problems (Chesky & Wolfmeyer, 2015; Ismail, 2018; Alturki & Aldraiweesh, 2021).

All tested hypotheses were accepted for students' age groups, discipline, and study level except for gender, which was rejected. The non-significance concerning students' age groups, discipline, and study level may result from an array of free technology platforms readily accessible via the internet during the COVID-19 pandemic, which coincided with the Fourth Industrial Revolution (4IR). This assertion is strengthened by Aikman (2017), who submitted that the 4IR waves of transformation systems are empowering and carefully designed solutions to enrich human dignity. Therefore, there is no gain-saying that 4IR is an improvement that engages smart technologies that blear the virtual, visible, and botanical spaces in time (Marwala, 2020). On the other hand, the significance with respect to gender implies that the acquired skills and experience during online teaching differ between male and female students. This finding is congruent with Oladele et al. (2021) that a significant difference exists along the gender divide. This finding reveals a persistent inequity in access, participation, and success in STEM subjects, threatening any nation's ability to a technology-driven economy and close the poverty gaps through education (UNESCO et al., 2015; Tanenbaum, 2016).

CONCLUSION AND RECOMMENDATIONS

This study concluded that online teaching and learning is a plausible direction for STEM education in sub-Saharan Africa. At the same time, internet access and technical support need to be enhanced to improve students' experiences. Some recommendations made based on this conclusion were that the Government should provide enabling business environment for telecommunication companies to subsidise the data cost, data support to higher institutions should be a priority to all societal stakeholders ranging from governmental and non-governmental organisations and civil societies, investments should be increased in the training of technical experts to meet this area of need, and relevant stakeholders should hold the reins of promoting gender equity in technology development, innovation, and problem-solving.

Considering that this study was focused on Technology Adoption for STEM Education in Higher Education while surveying the skills acquired during the COVID-19 pandemic, the quality of these skills concerning producing STEM graduates is essential to the world of work in the 21st Century premised on the fourth Industrial way. As such, assessing the acquired skills would constitute a direction for further research.

ACKNOWLEDGEMENT

The authors would like to thank the universities that approved the survey. We are also grateful to all the students who found the time to fill out this survey.

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