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STEM Teachers' Use Of Technologies For Online Practical Work During COVID-19

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Abstract

Practical work is an indispensable part of science, technology, engineering, and mathematics education. The transition to remote online teaching during COVID-19 deemed it necessary for practical work to be undertaken virtually and teachers had to use new strategies to engage learners in practical work. In South African schools, many teachers and learners cope with poorly resourced laboratories. The argument advanced in this paper is that virtual platforms can resolve the lack of physical resources and provide equitable learning opportunities for learners, provided teachers and learners are trained to use technology. This research answered the following question: What are STEM hons students' experiences using technology during online practical work during COVID-19 conditions? The location of the study was Richwood Teacher Training Institution in, South Africa. Thirty-six STEM Hons students were the participants of the study. Data was collected via reflective journals and semi-structured interviews. The findings suggest that conducting practicals via virtual laboratories, simulations, and field trips helps obviate the lack of resources and provides epistemic access to learners to quality learning materials and activities. Virtual practicals allowed female learners to experience all process skills, prevented the epistemic exclusion of female learners and addressed issues of social justice. Hands-on practical work can be conducted virtually, and learners can experience a variety of process skills. The novel findings of this study illustrate how to enact STEM teaching in developing countries, address issues of equity and leverage technology to enhance practice in STEM subjects post-COVID.

Keywords: Digital use divide, epistemic access, experience, hands-on practical work, virtual laboratories, resources, training.

Introduction

Practical work is an indispensable part of STEM subjects. It can be conducted in laboratories, classrooms, workshops or field trips. Practical work requires specimens, chemicals, and functional equipment, and thus, it is very costly (Reid & Shah, 2007). Without such resources, high cognitive demands are made on teachers who are expected to improvise and innovate during practical work. When teachers in such schools lack the inner resources to be innovative, learners do not engage in practical work and are epistemically isolated and excluded. Teachers in schools that lack resources for practical work are also epistemically excluded from teaching the various process skills. Practical work allows learners to engage in hands-on and mind-on activities linked to real-life situations. Practical work is used to develop learners' basic and higher-order process skills, critical thinking, problem-solving, collaboration, teamwork, communication and an understanding of the nature of STEM subjects (Singh-Pillay, 2023). Some teaching strategies employed during practical work include experiential learning, project-based learning, experimentation, hypothesis testing, fieldwork, inquiry-based learning and problem-based learning (Moore et al., 2020). While face-to-face practical work was impossible due to the transition to remote online teaching, many technological tools were made available to teachers via the Internet of Things (IoT) and the Web of Things (WoT) to create stimulating and engaging learning environments for practical work during the COVID-19 pandemic, (Naidoo, 2022). With regard to the aforementioned point, Makamure and Tsakeni (2020) noted that teachers were uncertain about how to conduct practical work online, and consequently, practical work was abandoned. Thus, the argument advanced in this paper is that technology is a medium to advance the relationships between educators and students and students and students, rethink the design of lessons, use new pedagogies and provide equitable learning, provided teachers are trained to use technology. Training in the use of technology is crucial to addressing the digital use divide, that is, how efficiently and meaningfully a person uses technology to support teaching and learning and access to high-quality learning experiences. If teachers are not trained in the use of these technologies, then they cannot transition to online teaching or engage learners in practical work online. Furthermore, the transition to online teaching is seen as an avenue to espouse the curriculum in a way that would improve the learning opportunities for all students, ensuring equal participation and learning opportunities. In other words, the online platform is construed as a platform to re-envisage or reimagine the facilitation of practical work where students are not subjected to epistemic isolation and exclusion. For example, in STEM classrooms in particular South African contexts, students are isolated and othered when they cannot engage in practical work due to a lack of resources. Ramnarain (2020) explained that in South Africa, in rural settings, practical work is still lacking, and learners are denied the opportunity to develop process skills and clarify abstract content. Recent research on particle work via systematic literature reviews by Tsakeni (2022) and Alangari (2021) points to the facilitation of STEM practical work in remote classrooms; Lal et al. (2018) reported that face-to-face practical work is favoured over distance education options. Mikeska et al. (2022) explored pre-service teachers' teaching practice in virtual classrooms with avatars in place of learners. Abriata (2021) reported on online learning and using household reagents for experiments in natural science and chemistry. Bozkurt and Sharma (2020) noted that many countries were ill-prepared for emergency remote teaching during the COVID-19 pandemic. There is a gap in practice-led research on remote online practical work conducted during online teaching under COVID-19 conditions. This paper explores STEM hons students' experiences using technology for online practical work under COVID conditions and responds to the question: What are STEM hons students' experiences using technology for online practical work under COVID conditions? The novelty of this research is that it illuminates how technologies can be used to engage learners in practical work in many African countries plagued by resource-poor laboratories. The findings will add to the literature on practice-led research on remote online teaching and learning of practical work, regarding strategies used and learning opportunities in the absence of an equipped laboratory. Further, it will provide information on how technology can be used to provide equitable learning experiences for students and diminish the gap in terms of epistemic access and social justice.

Literature review

Benefits of practical work

Practical work has many benefits in STEM classrooms, such as developing manipulative skills, observational skills, and higher-level cognitive processes such as interpreting, analysing, evaluating, hypothesising, problem-solving, critical thinking, improving understanding of abstract theoretical concepts, methods of scientific enquiry, independent learning, team work /collaboration and develop expertise in using it (Bybee, 2013). Teachers can use practical work to provide learners experiential learning opportunities to develop the aforementioned skills. Semali (2020) asserts that practical work can scaffold learners' understanding of abstract STEM concepts by bridging the gap between what is learned in class and what occurs in real life. Learners/ students also learn about laboratory safety and the safe use of materials and equipment.

Remote practical work

Practical work provides a valid environment for face-to-face, hands-on laboratory activities, field trips or virtual online activities (Lal et al., 2018; Akuma & Callaghan, 2019). Virtual laboratories, demonstrations, and virtual field trips are some tools that can be used to conduct virtual practical work (Truchly et al., 2018). In a virtual laboratory, learners have the opportunity to perform investigations, manipulate variables, record observations, analyse data and draw conclusions (Ghergulescu et al., 2018) provided that both learners and teachers are trained to use these technologies (Bada & Jita, 2021). Within the South African context, virtual laboratories are an invaluable resource for schools lacking fully equipped and functional laboratories (Ramnarain, 2020). Learners can access these web-based applications via smartphones (Fan et al., 2021; Chu et al., 2021). According to Ketelhut and Nelson (2010), learners learn equally well in physical and virtual laboratories. The implementation of remote STEM practical work has been well supported by digital technologies prior to COVID-19 (Goldie, 2016; Siemens, 2004). Thus, our initial augment prevails a technology-enabled environment will allow students to access experiential learning, engage in practical work via simulations, virtual field trips, manipulations, hypothesis testing, inquiry-based learning, develop process skills and 21st-century competencies and resolve issues of lack of resources, laboratory safety, epistemic access and social justice. More so, it will allow learners to access materials equivalent to those in better-resourced schools.

Furthermore, engaging in practical work virtually will obviate any form of discrimination female students encounter, as they do, when practicals are conducted physically in a laboratory. Studies (Akala. & Divala, 2016; Martin & Barnard,2013) report the discrimination female students encounter during practical work. These scholars noted that female students are forced to take on the role of timekeeper and recorder of results and observations during practical work, while male students are responsible for setting up, manipulating apparatus and conducting the practical. This means that conducting practicals virtually helps address issues of gender discrimination and epistemic access.

Teaching Strategies Used During Practical Work

Practical work is an inherent component of STEM subjects. Teaching strategies used to engage learners in practical work include inquiry-based learning, problem-based learning, project-based learning, experiential learning, experimentation, hypothesis testing and fieldwork (Lunetta et al., 2007; Kibirige & Maponya, 2021). With the transition to remote online teaching, there is a need to gain a deeper insight into STEM teachers' experiences using these technologies during practical work.

Theoretical framework

Technology-enabled environments, in STEM classrooms increased during online teaching under COVID-19 conditions (DeCoito & Estaiteyeh, 2022). With training on various technologies, students (less experienced in using technology) could tap into resources locally and globally from anywhere, at any time, and participate in a virtual community of practice. Such participation will enhance students' engagement and provide support for students to try higher-order activities/tasks (Shaw et al., 2022). Moreover, Barrot et al. (2021) assert that by participating in a virtual community of practice, students from disadvantaged backgrounds will be afforded equity of access to high-quality learning materials, opportunities to collaborate and personalised learning opportunities.

Methodology

Materials and Method

General Background

Mertens (2020) asserts that in qualitative research the focus is on the inner experiences of participants and how meaning is formed. This qualitative case study, which embraced the interpretative paradigm, explored STEM hons students' experiences using technology for online practical work under COVID conditions. According to Cohen et al. (2018), the interpretive paradigm is espoused by researchers when they want to describe and make sense of social phenomena from the participant's perspective. Data was collected at the Richwood teacher training institution in South Africa from STEM students enrolled for their Honours degree in 2019 and 2020. The appropriate gatekeepers were consulted and grated permission to conduct this study. All ethical protocols were observed.

Participants

Thirty-six STEM students (20 males and 16 females) registered for their Bachelor of honours degree were requested to participate in this study. These students are practising teachers of STEM who engaged in online teaching at their respective schools. Most of these participants teach at under-resourced or poorly-resourced schools in Kwa Zulu Natal, South Africa. As part of their honour’s degree, they were trained to use various technologies, including their cell phones and APPS (virtual laboratories, simulations, virtual trips, Google Dictionary) to engage in online practical work and teaching. Within the South African context, more than 97,2% of the population have cell phones (Stats SA, 2023). Thus, the cell phone is an invaluable teaching and learning resource. Participants were briefed about the research aims, voluntary participation, confidentiality and anonymity.

Instruments

Reflective journals and semi-structured interviews were used to collect data. Before data could be collected participants selected a number from 1 to 36 as a pseudonym. The selected number was recorded by both the participant and the researchers. These selected numbers from 1 to 36 were allocated to the respective participants' reflective journals and interview transcripts. Participants were briefed on maintaining a reflective diary. The brief was to reflect on their experiences using technology during online practical work under COVID conditions.

The individual semi-structured interview was of twenty minutes duration. The interviews were audio recorded. The interview focused on the participants' experience and knowledge of using technologies for practical work, the teaching strategies they used to engage learners in practical work, the activities learners engaged in and whether issues of social justice and access were addressed during online practical work. The audio recordings were transcribed verbatim and sent to participants for member checking. Cohen et al. (2018) state that member checking allows participants to validate and verify data and confirm if it resonates with what was captured during the audio recording, to increase the credibility of the data.

Data Analysis

The reflective journals and the interview transcripts were subjected to thematic analysis. Data obtained by both instruments were read and re-read to note patterns, convergences and divergences before coding could begin. Transcripts were read horizontally and vertically in order to group segments of text together before coding could begin. Coding was inductive the codes emerged from the data, and key themes were identified and reviewed.

Trustworthiness

To ensure the trustworthiness of the data, data was generated from multiple participants from which the findings were drawn.

Finding and discussion

Data from the reflective journals and interviews were used to answer the research question: What are STEM hons students' experiences using technology for online practical work under COVID-19 conditions? Four themes emerged, viz, bridging the digital use divide, virtual practical work obviating the lack of resources, virtual practicals facilitating epistemic access and social justice, and hands-on practical activities. Each theme is discussed below.

Bridging the digital use divide

The training participants received to use different technologies in their teaching of practicals boosted their skills and confidence, as is visible in the excerpts below:

Technology is the way forward, it is essential to use in teaching and engaging learners in practicals. I am a mature lady from a disadvantaged background. At first, I was not confident using technology, but with the training and practising what was learned, I am motivated and eager to try these new technologies and digital pedagogies in my classes. I look forward to doing practicals virtually, I have trained my learners to use the APPS via their cell phones. Technologies are an essential part of my life now. P9, reflective journal.

I am pretty comfortable using technologies in my teaching, especially for project-based and problem-based teaching. I trained learners to use particular apps on their cell phones-they all have cell phones. I find my learners busy during the breaks on their cell phones manipulating variables, forming hypotheses, and problem-solving. Teaching them how to use the APPS for learning has sparked a sense of camaraderie and teamwork among the learners. P34 reflective journal.

Knowing how to use the appropriate technologies has brought the fun back into teaching and learning; I am enthusiastic, my learners are excited, and they are eager to learn. I teach at a rural school; these kids have the latest smartphones but do not use them for learning. I trained my learners to use their smartphones for learning and gaining access to online resources and practical work activities. Learners are now using their smartphones not just to read what is posted on Facebook and Twitter, watch TiKtok, type assignments or complete online worksheets at home. but also, to access learning. P12, interview.

What comes to the fore via these excerpts is that initially, some participants (for example, P9, 12, 34) had basic digital literacy. Participants' digital (ill)literacy influenced how they used technologies and contributed to their digital use divide. Participants' digital use divide is a social justice issue linked to gender, age and locale, all impacting how they use technology. This finding aligns with Starkey et al. (2017) study, which reports that age and locale place people at a (dis)advantage in using digital technologies and contribute to the digital use divide. It is also evident that with training and engaging in active learning with technology participants gained experience, confidence, knowledge of the technologies that could be used during practical work in STEM subjects and skills needed to integrate the relevant technologies in their teaching. Research by Pongsakdi et al. (2021) confirms that teachers trained to use technologies gain confidence, skills, self-efficacy and knowledge and develop positive attitudes toward integrating technologies into their teaching. The training received by participants in using various relevant technologies was used to bridge the digital use divide among their learners. This means that teachers who incorporate technologies during practical work could enhance and transform how their learners use technologies for learning, thus diminishing the digital use divide and digital illiteracy among their learners. By integrating technologies into their teaching of practical work, participants experienced a paradigm shift. They became (re)motivated and eager to engage learners in practical work. They saw teaching as an exciting, fun activity. This paradigm shift (re)kindled hope in the participants during the gloom of the pandemic.

Virtual practical work obviating the lack of resources

Many STEM teachers and learners in KwaZulu Natal are unable to engage in practical work due to under or poorly-resourced laboratories, as can be seen in the excerpts below.

Doing practical work virtually is a blessing, I do not have to stress about borrowing equipment from other schools or begging the principal for money to buy chemicals or specimens. All my learners have smartphones so doing practicals virtually is not a problem. On the virtual platform, every learner can engage in practical, and develop process skills and critical thinking. Also, a learner can do the practical many times without wasting chemicals as they could access the internet, P17, reflective journal.

I teach at a rural school, there is no laboratory, equipment, chemicals or specimens needed to conduct practicals. Learners could not engage in practical work. It was so challenging to teach abstract concepts in chemistry without practical work. After learning about and being trained in PhET simulation and virtual laboratories, it is so easy to do practical work when needed to explain complex concepts and link theory to real-life problems. Connectivity was not a problem, P20, reflective journal

Conducting practicals in virtual laboratories is a breeze; there is connectivity, and all learners have smartphones. I do not have to stress about chemicals running out or safety issue, P11, interview

The multiple benefits of conducting practicals virtually are evident in the above excerpts. The above findings align with Aliyu and Talib's (2019) study, which shows that without a laboratory or chemicals and functional lab equipment (Rani et al., 2018), learners can still engage in practical work and develop the required process skills. Regarding contextual realities, most participants taught at historically marginalised schools in rural areas that lacked fully equipped laboratories and thus could not engage learners in hands-on practical activities. These historically structured arrangements set boundaries for teachers' and learners’ access to resources, learning and success. Put simply, this means that marginalised groups of people face epistemic exclusion (Badat, 2020). The above contextual reality was also noted by Ramnarain (2020), who explained that in South Africa, in rural settings, practical work is still lacking, and learners are denied the opportunity to develop process skills and clarify abstract content. The carryover effect of such structured arrangements of the apartheid continues to prevail in a democratic South Africa. As such, both teachers and learners in rural schools contend with different forms of epistemic exclusion and isolation. With the virtual platform for practical work, connectivity, and smart devices, teachers teaching at rural schools do not have to contend with epistemic and social injustices associated with teaching in rural schools, such as lack of resources and begging for resources to engage learners in practical work. The virtual platform for practical work, accessed via the Internet, releases teachers from the added responsibility of improvising and innovating when resources for practical work are unavailable and opens up opportunities for them to access materials and practical activities (Kefalis & Drigas, 2019).

Virtual practicals facilitating epistemic access and social justice

Conducting practicals virtually addressed issues of epistemic access and social justice as is visible in the excerpts below:

My female learners enjoy doing practicals virtually because. they get a chance to conduct practicals, control variables, and manipulate apparatus. Boys are not dominating them like when practicals are conducted face to face in the lab. P22, reflective journal

When practicals were done physically, they were done as group work due to a lack of equipment and chemicals. Boys would boss the girls, set up and conduct the practical. It is a norm at school, and also a social expectation, that boys are called to do important duties. On the virtual platform, the girls are thriving. They are conducting the practicals themselves they have formed science clubs. I can see a difference in their attitude, and their performance has improved. P15, reflective journal.

The data reveals the gendered nature of practical work when conducted face to face, where male learners dominated the process, thereby relegating girls to passive activities of observations and recording results. This finding is consistent with that of studies conducted by Board (2018), Archer et al. (2020) and Wieselmann et al. (2020), which emphasise the tendency of male learners to dominate in classrooms verbally and in inquiry-based activities. Moreover, the prevailing contextual reality of face-to-face practicals, where female learners are epistemically isolated and excluded from practical work due to a lack of resources, (un)acceptable school norms, and (voiceless) teachers, is conspicuous. The findings reveal that by engaging in practical work virtually, female students had the opportunity to engage in mind-on and hands-on activities and develop basic and higher-order process skills. Thus, the virtual practical activity becomes more inclusive. It addressed the challenges female learners encounter in terms of epistemic isolation /exclusion, gender discrimination, participation and performance. In other words, conducting practicals virtually improved the in-class experience of female learners epistemically, cognitively and socially.

Hands-on practical activities

STEM Hons participants used technologies to engage learners in hands-on practical activities as is evident in the testimonies below:

Learners are now using their smartphones not just to read what is posted on social media, type assignments or complete online worksheets at home. but also, to access learning. They use Apps to manipulate objects and draw 2D and 3D diagrams of mechanical assemblies. Learners could not manipulate objects mentally, but now, with technology, they all can manipulate objects virtually, section them and draw the correct projection. This is amazing P13 interview.

Students are expected to design a toy box for their NS-TECH project. Through this project-based task, learners adopted the design process, used infographic apps to create designs for the toy box, collaborated with peers, evaluated and refined their toy box, and presented their designs to the class, P35 reflective journal

Using their smartphones, I took my learners on a virtual field trip to the beach to learn about aquatic ecosystems. They loved the experience they could manipulate the size of the waves and the strength of the current and see how it affected the aquatic plants and animals. Learners made observations, gathered information on biotic and abiotic factors, made deductions about the adaptations of aquatic organisms, and constructed food chains and webs. Each learner was actively engaged. I have observed that learners are using these technologies and virtual labs on their own to learn and are asking more questions in my life sciences class, P11, interview.

The above data highlights that teachers in this study used Virtual reality (VR) tools such as simulators, virtual laboratories, and virtual field trips, among other tools, to create the experiential learning needed to develop process skills in learners. This finding concurs with that of Truchly et al. (2018), which noted the VR tools teachers can use to engage learners in virtual practicals. The variety of activities in which learners were actively involved included field trips, experiments, investigations, internet searches, laboratory work, the building of models, designing, drawing, and simulations. The learners engaged in virtual practical work to manipulate variables, record, take measurements, make predictions, analyse data, make deductions, create, design, develop explanations, link theory to real-life contexts, communicate, think critically, problem-solve, collaborate, innovate and draw conclusions. This finding concurs with Chernikova et al.'s (2020) study, which exemplifies that a virtual platform can support experiential learning during practical work, demystify abstract concepts, and acquire process and 21st-century skills. In their study, Ghergulescu et al. (2018) noted improved mental traits such as creative thinking, fluidity, originality, and flexibility in learners who conducted practical work in virtual laboratories. Further, it can be inferred that if teachers are trained and knowledgeable about the relevant technologies and the accompanying pedagogies, their use of digital devices will increase, and their practice will change (Lestari & Supahar, 2020). The finding of this study confirms that practical work in virtual environments also helps in achieving key learning outcomes in STEM subjects.

Conclusion

This study explored STEM hons students' experiences using technology for online practical work under COVID-19 conditions. The finding reveals that participants could bridge the digital use divide for themselves and their learners with training. Bridging the digital divide use allowed for improved digital literacy and greater epistemic access, improved confidence levels and reignited motivation in teaching and learning. Kelly et al. (2020) noted that teachers who encountered positive experiences in the use of technology were able to link the application of knowledge to real contextual issues. Furthermore, the findings reveal that without laboratories and reagents, innovative active learning can occur on a virtual practical work platform where learners can develop complex process skills and 21st-century skills. This finding dispels the age-old cry that fitted laboratories are needed to be able to conduct practical work. The findings on practical work are noteworthy. They demarcate a path that could be taken to deal with the perpetual obstacles facing many rural and under-resourced schools in South Africa in terms of limited financial and infrastructure resources for laboratories. Ramnarain (2020) and Bantwani (2017) assert that in rural schools, the teaching and learning of science subjects are affected by the lack of fully fitted and functional laboratories. Some values of virtual practical work are safety, the absence of faulty lab apparatus and teachers being free of the challenges of sourcing materials for practical work and being forced to innovate and improvise. The findings also illuminate how engaging learners in virtual practical work enhanced female learners' participation in practical work and allowed them to perform all tasks and develop relevant process skills. The findings of this study elucidate the types of practical work learners engaged in virtually and the kinds of process skills they experienced. The findings advocate for leveraging technologies to address epistemic exclusion learners still encounter during STEM teaching and learning. Bridging the digital use divide and conducting practical work virtually have brought about epistemic access and justice and restored hope for the post-COVID era in South African classrooms.

Recommendations

Further research is needed in rural settings on the use of PhET simulations to conduct practical work, promote understanding of difficult concepts, develop process skills and 21st-century skills. It is necessary to obtain deeper insights into the hidden gendered STEM curricula during practical work and its impact on students' interest in STEM subjects, self-efficacy and teacher support. Given the context of the study and its focus on STEM subjects, the findings of this study may not be easily applied to other disciplines. However, limitations are also opportunities for further research. The research could be extended to other disciplines and different contexts and the sample size could be increased to examine the variations related to, for example, the disciplines and contexts.

Using technologies to maximise teaching and learning opportunities is not a skill teacher can pick up on their own in practice. Professional development for pre and in-service teachers is needed on how to use technologies to support learning during practical work and to address epistemic exclusion learners encounter via the curriculum and how these could be addressed via gender-responsive STEM teaching and bridging the digital use divide.

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