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South African Postgraduate STEM Students' Use of Mobile Digital Technologies to Facilitate Participation and Digital Equity during the COVID-19 Pandemic

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Abstract: The transition to online mobile teaching and learning during the COVID-19 pandemic required more than access to mobile digital technologies, particularly in South Africa, a country trying to address the injustices and inequalities of the pre-democracy period. The argument advanced in this research is that the transition to online mobile teaching and learning could be used as leverage to promote active participation, quality inclusive learning, develop relevant and responsive content and achieve mobile digital equity. This interpretative case study was conducted at a South African teacher-training institution. The primary aim of this study is to explore the following question: How did postgraduate STEM students use mobile digital technologies to facilitate teaching and learning under COVID-19 conditions? Data was obtained from 20 purposively selected postgraduate STEM students enrolled for their Bachelor of Education honours degree. They participated in online discussion forums and maintained reflective journals. Due diligence was taken to ensure all the required ethical protocols were observed. Mishra and Koehler's Technological Pedagogical and Content Knowledge (TPACK) model framed this study. The constructs of the model were used during the analysis of data. The findings highlight that mobile digital technologies were used for translanguaging, supporting students in developing disciplinary science understanding through exposure to practical work and linking cross-cutting concepts in STEM subjects. The findings of this study are significant as they indicate how to operationalize STEM teaching in developing countries; how to address issues of access and social justice; and how to leverage mobile technologies to improve practice in STEM subjects, post-COVID.

Keywords: access; digital equity; mobile digital technologies; mobile online teaching and learning; participation

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1. Introduction

During the COVID-19 pandemic, remote online mobile teaching and learning were introduced, globally, to ensure that education continued. The transition to online mobile teaching and learning did not alter society's expectation of education institutions to provide their students equitable, quality education and life-long learning opportunities so that they can become critical responsible citizens capable of solving contextual problems in their local. Moreover, higher education institutions were still expected to contribute to the knowledge economy while transitioning to online mobile teaching and learning. The expectations mentioned above, embrace the targets of sustainable development goal 4 of Agenda 2023, which can be achieved via effective teaching and learning environments and innovative teachers/educators. The novelty of this research is that it highlights how digital technologies can be used to address issues of social justice and equity that continue to plague many countries in Africa. It illuminates the breakthrough in using the learners' diverse linguistic backgrounds as a resource to access learning, and increase participation and engagement in STEM classrooms.

The transition to online mobile teaching and learning requires more than access to mobile digital technologies. It also requires knowing how to innovatively use them as resources during the teaching and learning process [1]. Naidoo and Singh-Pillay [2] posit that to embark on online mobile teaching and learning, training in the use of mobile digital technologies is quintessential for both students and lecturers. They argue that such training is key to learning to use mobile digital technologies to solve problems and develop complex cognitive skills, such as analysis, synthesis and evaluation of ideas and information, to create or develop new ideas and new ways of representing information. Put simply, they assert that training in the use of mobile digital technologies is vital to provide equitable, quality education and life-long learning opportunities. During online mobile teaching and learning portable mobile technologies such as cell phones, tablets, laptops, I-Pads and ICT (computers) were indispensable tools [3]. Thus, acquiring mobile digital competencies is no longer a nice-to-have skill but a necessity, and achieving mobile digital equity, especially in developing countries, is the ultimate goal. Mobile digital equity means that all students, irrespective of their socioeconomic and cultural background, locale or history, can participate and engage with mobile digital technologies to improve their opportunities in life. In this study, participation is envisaged as being able to make meaning and critically engage with epistemic content/activities to apply them to solve contextual problems. It extends beyond having mobile digital tools and connectivity access to the content and activities. In other words, mobile digital equity is a social justice issue that addresses the digital divide and participation gap. Therefore, mobile digital equity is seen as leverage for socioeconomic growth, sustainability and a pre-requisite for social justice. Effective and innovative use of mobile digital technology in higher education institutions can contribute to mobile digital equity when systemic barriers to learning materials are removed.

The argument advanced in this research is that digital equity goes beyond merely having access to mobile digital tools and connectivity and replacing standard worksheets with electronic material. It entails access to meaningful, high-quality, and culturally relevant content and access to educators and teachers who know how to use mobile digital tools and resources innovatively. So that the mobile digital divide in terms of access to quality learning material and equity diminishes. Recent research [4] points to integrating sustainable development in higher education under face-to-face teaching and learning conditions. However, there is a paucity of research on providing equitable, quality education and life-long learning opportunities for students, which aligns with the targets of sustainable development goal 4 of Agenda 2030 during online mobile teaching and learning under COVID-19 pandemic conditions.

This qualitative research was conducted at a teacher-training university in KwaZulu-Natal, South Africa. Since achieving democracy 29 years ago, South Africa has been caught between adopting neoliberal policies to keep up with global standards while trying to address the injustice and inequalities of its apartheid era (1948 to 1994). Some of the injustices and inequalities were segregated schools for different racial groups, access to schooling, teaching subjects offered at segregated schools, the language of teaching and learning, poor infrastructure and human resources at school and differentiated funding to schools. These historical inequalities in society continue to reproduce themselves in South Africa's achievement levels in education, as evidenced in the 2019 TIMSS results.

> I am a teacher educator, to postgraduate STEM students enrolled for their Bachelor of Education honour degree, at the Edgemont campus of the university. These students are practising teachers. This research thus responded to the following question: How did postgraduate STEM students use mobile digital technologies to facilitate teaching and learning under COVID-19?

The findings of this research will contribute to the literature on teaching and learning practice-led research, that foregrounds providing quality education, and address issues of equity and participation during online mobile teaching under COVID-19 conditions. The findings provide insights into how mobile digital technologies can first address the disjuncture between the language of teaching and learning and the learners' home language, thereby addressing issues of equity, social justice and inclusiveness. Second, the findings illuminate how quality learning and practical work can be conducted without resources and access to equipped laboratory. Third, the findings show how mobile digital technologies can link cross-cutting concepts in STEM subjects to promote integration, application and quality life-long learning.

2. Literature Review

2.1. Mobile Digital Education

Casillas-Martín et al. [5] argue that mobile digital education involves the innovative use of mobile digital tools and devices to transform teaching and learning activities. The goal is to provide high-quality education and equip students with skills such as problem-solving, critical thinking, creativity, teamwork, communication and life-long learning so students can adapt to the ever change skill required in the world of work [6,7]. Thus, mobile digital education is not just a term but an innovative way of facilitating teaching and learning via mobile technologies to provide inclusive, equitable and quality life-long learning and education or meeting sustainable development goal 4 [8,9].

2.2. Educational Innovation

The term innovation is intrinsically interconnected to the idea of a change in educational practice in terms of novelty and transformation to improve educational processes [10]. In other words, the emphasis shifts from memorization, rote learning, teacher centeredness towards active learning, critical thinking, problem-solving, student-centeredness, self-regulation, deep learning, and collaboration. Mobile digital education, coupled with innovation, can address issues of equity, inclusiveness, and social justice and contributes to education for sustainability, fostering critical thinking, problem-solving, application of learning to solve contextual problems, responsible citizenship collaboration, teamwork, and life-long learning.

2.3. The Use of Mobile Digital Technology for Access, Equity and Social Justice

2.3.1. The Efficacy of Mobile Digital Devices in STEM Teaching and Assessment

Studies by DeCoito and Richardson [11] emphasise the advantages of mobile digital web-based tools for engaging learners in inquiry-based learning, enhancing their scientific literacy exposing learners to virtual laboratories, simulations, modelling software, data logging for data collection, manipulation of variables, collaborative online environments and virtual field trips. The study above illuminates how mobile digital tools can be used in STEM classrooms to allow students to visualise processes better, connect cross-cutting concepts, engage in problem-solving, apply learning to different contexts, collaborate, organise data for graphing and manipulate variables if teachers are trained to use their technologies in their teaching.

Mobile digital technologies can also be used for online assessments. Barril [12] emphasises that teachers must be trained to create online assessments catering to learner diversity by including interactive quizzes, higher-order activities, opportunities for collaboration, and innovative assessments that can reduce boredom and increase interaction with course material such as projects, portfolios, self-assessments and peer evaluations. Equally crucial during online assessments is prompt feedback from the teacher that is corrective and precise to help learners achieve greater conceptual understanding and application of concepts and improve their performance [13]. A further advantage of mobile online teaching and learning is that learners can access study materials anytime and anywhere.

2.3.2. The Use of Mobile Digital Tools to Overcome Language Barriers in STEM Teaching and Learning

In many post-colonial contexts in the South, for example, South Africa, Zimbabwe, Kenya, Uganda, Tanzania, and Mauritius, the language of the colonizer is still dominant and is entrenched as the language of teaching and learning via national language policies [14,15]. Thus, in these contexts, STEM teachers have a trio of responsibilities in their classroom, that is, to teach STEM nomenclature and discourse, teach STEM content in English, which is the language of teaching and learning (LOLT) and deal with the learners' home language [16]. STEM teachers thus need to understand and be proficient in the STEM language used to execute this additional role of being language teachers.

Learners entering STEM classrooms are sociocultural beings who carry their sociocultural background, impacting their learning. Mokiwa [17] assert that language has influenced poor learner achievement in STEM subjects, especially for learners whose home language is not English. To exacerbate the languages dilemmas learners encounter in STEM subjects, it must be noted that textbooks and resource materials are written from a Western viewpoint, which can shape the use of vocabulary, examples, and phrases that may not be common or easily understood by a learner, or teacher, from an African language background. Furthermore, STEM teachers lack the tools and knowledge to support multilingual learners with the challenging language demands of the STEM classroom.

The mismatch between the LOLT (including the language used in textbooks and resource materials) and the learners' home language poses challenges or barriers to learners' engagement and uptake of STEM subjects. Furthermore, this mismatch raises serious questions about how the diversity of languages in the local society/community is reconciled during online mobile teaching and learning of STEM. Second, how can ICT teach learners to read and write STEM text, acquire STEM knowledge and skills and understand STEM content? Moreover, third, how can ICT be used to assist learners in using their home language to promote proficiency and conceptual development in STEM subjects?

Studies by [15,18] highlight the benefits of using translanguaging pedagogy to address the language barriers multilingual learners encounter in the STEM classroom. García, Johnson, and Seltzer [19] assert that for teachers to embrace translanguaging in their STEM classroom, they must use the learners' home language as a resource to leverage learning. This means that the design of lesson plans and assessments should integrate the learners' in-school and out-of-school language practice and that STEM teachers should be able to make shifts in their instructional plan based on learner feedback. With its Google voice-typing and dictionary features, Google Classroom (8.0.163.10.90.1) can support STEM teachers in modifying their current teaching to promote translanguaging and scientific disciplinary literacy, provided they are trained to use these digital and ICT resources. The dictionary and voice-typing feature effectively scaffold multilingual learners' use of academic vocabulary. Voice typing can support multilingual learners' engagement in the argumentation required for scientific learning by recording their spoken words without additional spelling and grammatical challenges.

2.3.3. The Use of Mobile Digital Tools to Conduct Practical Work and Develop Process Skills

Practical work and demonstration undergird the teaching and learning of STEM subjects. The transition to online mobile learning meant laboratories could not be used for practical work. However, Aliyu and Talib [20], posit that STEM teachers can engage learners in practical work on a virtual platform without a physical presence in a laboratory. Rani et al. [21] argue that on a virtual platform going on a field trip, the resource limitations of a real lab and the availability of reagents and functional lab equipment are overcome. These findings show how experiential learning on practical work can occur on a virtual platform and that virtual practical work is vital to support students in understanding abstract concepts and acquiring process skills and 21st-century skills. The above finding illustrates that if teachers are empowered to use different technological digital options, their teaching practice will change and they can use software applications for practical work, develop process skills and facilitate deep learning [22]. These studies have implications for STEM teachers' practice of conducting practical work in South Africa (or any developing country), especially in resource-constrained schools that lack laboratories, functional equipment, and funds to purchase reagents or specimens. Bantwini [23] found that teaching STEM subjects in most rural classrooms lacked practical activities that promote deeper learning of science content and that the classroom environment was impoverished for STEM teaching and learning. Virtual practical work can occur as and when needed. It is safe (no danger of ill functional equipment), allows for the development of process skills and 21st-century skills, facilitates the teaching of difficult and abstract concepts and obviates the limitation of resource constraints.

3. Theoretical Framework

Mishra and Koehler's [24] technological pedagogical and content knowledge, or TPACK model, framed this research. The TPACK model theorises the relationship between blending pedagogical, content and technological knowledge. It is a holistic model as it illuminates the interconnected relationship between technological knowledge (TK), pedagogical knowledge (PK) and content knowledge (CK) for effective teaching with technology across subject disciplines, as reflected in Figure 1 below.

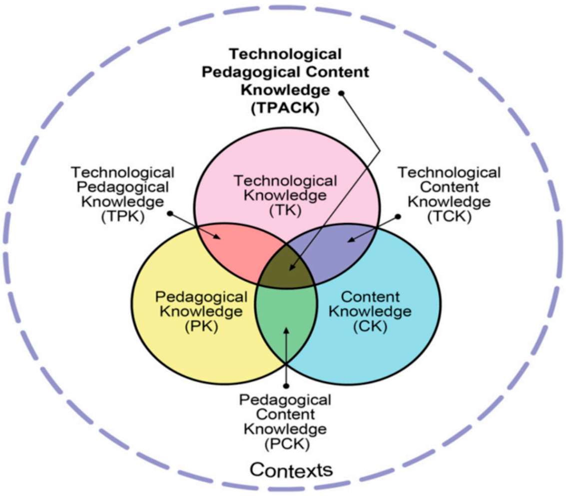

Figure 1. The components of the TPACK framework (graphic from [24]).

TK is knowledge about the use of technology for example ICT, mobile phones, Zoom, and Microsoft Teams, in teaching and learning [25]. It also entails knowing about online presence, ethics, cyber safety and managing personal data. This knowledge is used to collaborate and create online networks and virtual environments.

Technological content knowledge (TCK) refers to the knowledge of how technology works and how it can be used to create new representations for specific content.

Technological pedagogical knowledge (TPK) involves having in-depth knowledge of different technologies and their 'fit for purpose' for teaching different topics in the curriculum, class management and lesson designs [26]. This means that teachers understand that using a specific technology can change how learners practice and understand concepts in a specific content area. This includes knowing how to teach with and through technology creatively. Teachers with strong TPK can make informed decisions about digital resource use and improve their teaching effectiveness. For example, technologies such as Google Classroom and Google Dictionary (4.1.8) can be used to embrace a translanguaging pedagogy in a STEM class that has multilingual learners. Virtual labourites can be used for practical work, simulations, and field trips.

TPACK comprises the knowledge teachers require to integrate technology into their teaching in any content area while using discipline-content-appropriate pedagogy [27]. Teachers have insightful know-how of the interface among the three knowledge components (CK, PK, TK) that impact their teaching practice. TPACK is an operational competence; its success relies on the capabilities of teachers within each domain and their ability to be flexible.

4. Materials and Methods

4.1. General Background

This qualitative study was conducted at a teacher-training institution in KwaZulu-Natal, South Africa. The institution offers undergraduate and postgraduate programmes for pre-service and in-service teachers (practising teachers). An interpretative paradigm was adopted to gain insights into how postgraduate STEM students use mobile digital technologies to facilitate teaching and learning under COVID-19 conditions. Data was collected in semester 1 of 2021 during the COVID-19 pandemic.

Participants

In total, 20 postgraduate STEM students enrolled at Edgemount University for their Bachelor of Honours degree (research in technology module) participated in this study. Participants were purposively selected. The criteria for their selection were that they had to be practising teachers of STEM subjects and registered for the B. Ed Hons degree. All ethical protocol was observed regarding gatekeeper permission to conduct research, informed consent, the right to withdraw from the study, assurance of confidentiality and anonymity.

4.2. Instruments

Electronic data generation methods were used due to the pandemic conditions. Three online interactive discussion forums and an electronic reflective diary were used to generate data. The advantage of interactive online discussion forums is that it promotes dialogue, and allows for probing of responses, reflection, knowledge construction, and self-assessment. Three online discussion forums were scheduled. The first was during the first week of lectures, the second towards the middle of the semester, and the third during the last week. The online discussion forums addressed the following key questions: How were mobile digital technologies used to address SDG goal 4? How has the use of mobile digital technologies impacted their teaching practice? The discussion forums included the following sub-questions: What are your experiences using mobile digital technologies to address issues of equity, social justice and inclusiveness regarding the LOLT and the learners' home language? How were mobile digital technologies used to ensure quality education without access to resources and laboratories? How were mobile digital technologies used to promote life-long learning opportunities regarding integrated STEM learning and applying learning to contextual issues? Changes encountered in their TK, TCK, TPK and TPACK? What steps can be taken to improve your experience using mobile digital technologies for online teaching and learning? Have your experiences of online mobile teaching and learning influenced/shaped your teaching of STEM subjects?

Participants were briefed on how to maintain an electronic reflective diary. They were asked to record the challenges they encountered with using mobile digital technologies to address SDG 4 and the opportunities afforded by using mobile digital technologies to address SDG 4 in STEM teaching and learning.

All 20 postgraduate STEM students participated in the three discussion forums and maintained an electronic reflective diary. Prior to the collection of data, students chose a pseudonym, P1 to 20 that they used in the discussion forum and for their electronic reflective journal. The data from the discussion forum, which was already in text format was collated before analysis could begin. The limitation of the small sample size in qualitative research prevents the generalisation of results.

4.3. Data Analysis

The transcripts texts were sent to participants for respondent validation to check if their responses were accurately captured [28]. The data from the discussion forum and reflective journals were read and re-read carefully before inductive coding could begin. Codes emerged from the data. Similar codes were regrouped into themes. The assigned codes are reflected in Table 1.

Table 1. Showing categories and codes for discussion forum questions.

Discussion Forum Questions	Category	Codes
How did postgraduate STEM students use mobile digital technologies to facilitate teaching and learning under COVID-19 conditions?	Translanguaging	Home language-LOLT discerptions, mother tongue-LOLT divergence, epistemic access, equity, social justice
	Virtual Practical work	Lack of resources—infrastructure, improved conceptual understanding, manipulation of apparatus, no cost for chemicals
	Integrated STEM learning	Linking cross-cutting concepts, showing links of concepts in chemistry, physics, technology

5. Findings and Discussion

Data from the discussion forums and reflective diaries were used to answer the research question: How did postgraduate STEM students use mobile digital technologies to facilitate teaching and learning under COVID-19 conditions?

Data analysis reveals three themes: translanguaging, virtual practical work, and integrated STEM learning. Each theme is presented and discussed next.

5.1. Translanguaging

STEM subjects have their discourse, which is abstract, difficult to understand and often unrelated to the spoken home language of the learner (more so in the African context). The disjuncture between the language of teaching and learning (LOLT) in STEM classrooms, STEM discourse and the learners' home language impacts learners' epistemic access to information, participation, comprehension and performance. These findings are evident in the testimonies below:

> "My learners whose home language is not English struggle with the terminology in chemistry, life sciences and physics and accessing learning. With training and exposure to Google Classroom, voice typing and Google Dictionary, and Microsoft Translator, I have adjusted my pedagogy and allowed learners to draw on their home language to access epistemic learning in STEM subjects." P18, discussion forum.

> "I adopted translanguaging as pedagogy, I adjusted my lessons and assessments to suit the learners' home language. I have noted an improvement in the performance of learners from diverse language backgrounds and an increase in their participation in science and technology lessons, and engagement with content and activities. This improvement can be attributed to the use of mobile digital technologies and online teaching. Learners' participation and engagement are greater and better when compared to face-to-face teaching." P15, reflective journal.

> "Learning to use technology for translanguaging has benefited my practice. I can teach chemistry and physics confidently by combining content and technology. The voice-typing feature allows learners to switch between languages to describe their scientific observations, and it has enhanced my learner's learning and performance in STEM subjects." P5, reflective journal.

From the above excerpts, it is visible that postgraduate STEM students, experience and exposure to training in the use of Google Classroom, voice typing and Google Dictionary SQ impacted their teaching practice. Their experience using Google Classroom, voice typing, Microsoft Translator (1710) and Google Dictionary allowed them to address the language disjuncture learners whose home language is not English encountered in STEM classrooms. Empowered with TK, TPK and TCK, participants adopted translanguaging pedagogies in their teaching to improve epistemic access, learning and participation. Mobile technologies were used to allow learners to learn content, make sense of abstract, difficult STEM terminology and engage in activities using their home language. The learners' home language was embraced and integrated into the teaching and learning of STEM. The learners' home language was a meaningful part of classroom discourse. For example, when learners were taught the concept of power in physics, they used the Google Dictionary and made reference to the isizulu term to understand the relationship between Amandla (power), phoqa (force) and indawo (area) and perform calculations. Translanguaging allowed learners, whose home language differs from the LOLT to participate in knowledge production and learning and not just be passive participants, who are often times excluded in the learning process due to a language barrier. In a way translanguaging via the use of mobile technologies, supported learner learning involving tasks and concepts that they could not access/complete by themselves. In other words, it extended the learners' zone of proximal development.

This breakthrough in using the learners' diverse linguistic backgrounds to access learning, participation and engagement in STEM classrooms is a significant advantage of online mobile teaching and learning, which would not have been possible during normal face-to-face teaching where chalk and talk dominate. The participants acquired TPACK highlights how their instructional practice evolved due to the effective use of specific technologies. The above findings reveal how technology used for translanguaging allowed for easy movement between the home and school language and the discourse of STEM subjects. They also reveal how technology can foster a humanising pedagogy in STEM classrooms. Technology allows for a humanising experience for learners whose home language is not English, as they can draw on their home language to access and construct conceptual knowledge in STEM subjects. The learners' home language is no longer considered inferior to the LOLT or seen as a hindrance to accessing STEM knowledge/learning. In a way, translanguaging can address the language power dynamics in STEM classrooms (between the LOLT, STEM discourse and learners' home language), access and social justice issues (particularly in Africa).

The finding of this study corresponds with that of [29], who noted that translanguaging improved learners' participation in learning concepts and learners' performance. Moreover, the finding of this study indicates that translanguaging pedagogies allow for the learners' home language to serve as an asset in STEM classrooms that can be used to promote understanding of STEM subjects and scaffold learning. This finding is significant, as it is contrary to [30] study, which indicates that within the South African context in STEM classrooms, learners from diverse linguistic backgrounds struggle with accessing epistemic knowledge and perform poorly in STEM subjects when the LOLT is different. To support her findings Dlamini references South African learners' poor performance in the TIMMS study. Thus, it can be reasoned that translanguaging could be a boon to teaching and learning in STEM classrooms post-COVID, it can be used to address issues of social justice and equity. The findings of this study highlight the practical implications of how translanguaging can support language development, use of scientific discourse, promote higher-order thinking, and conceptual understanding in STEM classrooms whilst creating a more inclusive learning environment for the participation of learners whose native language is not English.

5.2. Practical Work and Twenty-First-Century Skills

Practical work and demonstration undergird the teaching of STEM subjects. The transition to remote online mobile learning meant laboratories could not be used for practical work. As is evident in the excerpts below, participants' experiences of online teaching impacted their teaching practice, and they discovered alternative ways to engage students in practical work and demonstration.

> "I used PhET simulations for experiments and student manipulations to explain difficult abstract concepts, and it works well in physics, math and EGD, It is interactive, with high levels of engagement, which promotes critical thinking, creativity and collaboration among students. Anyway, most of the equipment in the school lab is non-functional and obsolete." P2, Discussion forum.

> "I have taken my life sciences class of 32 learners on a virtual field trip for them to explore, investigate and engage in inquiry-based learning of the biomes in South Africa. A physical field trip would not have been possible during face-to-face teaching learners are extremely poor and would not have been able to pay for the cost of the trip. Learners worked in groups of 4, exploring a particular biome and collating information on the biotic and abiotic components. Learners were required to do a Zoom presentation on their findings on the biomes. Leaners described the virtual field trip as an adventurous learning experience which was free. On the virtual platform, I do not have to worry about equipment, reagents or cost. The resource is always available, as compared to face-to-face teaching. Doing practicals virtually is better; I do not confront the challenges as in the laboratory." P11, Discussion forum.

> "Initially, I pre-recorded videos of myself conducting experiments in the lab, used YouTube videos, and introduced learners to kitchen chemistry while doing the section on acids and bases. I create breakaway Zoom rooms for student discussions. It allowed students to engage in active learning, predict, evaluate, critique the design of their experiment, collaborate and present findings." P19 reflective journal.

On the one hand, the above excerpts show that many strategies were used to engage learners in practical work on the online platform. On the other hand, it silently exposes the opportunity missed to engage learners in practical work during face-to-face teaching in resource-constrained schools and the advantages of mobile online teaching and learning. The practical work learners engaged in was an active learning experience which entailed inquiry-based learning rather than just a recording and observing of the experiment. Students had to investigate, predict, evaluate, develop explanations, communicate, think critically, problem-solve, collaborate, be creative, and innovate. The testimonies confirm that STEM teachers can engage learners in practical work on a virtual platform without a physical presence in a laboratory or field trip or the resource limitations of a real lab [20] and the availability of reagents and functional lab equipment [21]. These findings show how experiential learning pertaining to practical work can occur on a virtual platform and that virtual practical work is vital to support students in understanding abstract concepts and acquiring process skills and 21st-century skills. The above finding illustrates that if postgraduate STEM students who are teachers are empowered with TPK and TCK, their TPACK will flourish, and their teaching practice will change—they will be able to use software applications for practical work, develop process skills and facilitate deep learning [22]. The above findings have practical implications for STEM teachers' practice of conducting practical work post-COVID in South Africa, especially in resource-constrained schools that lack laboratories, functional equipment, and funds to purchase reagents or specimens. Bantwini [23] found that teaching STEM subjects in most rural classrooms lacked practical activities that promote deeper learning of science content and that the classroom environment was impoverished for STEM teaching and learning. The findings confirm that not engaging learners in practical work due to a lack of resources is no longer an applicable reason in the South African context. Virtual practical work can occur as and when needed. It is safe (no danger of ill functional equipment), cost-effective (virtual field trips/excursions are free), can be used even if the teachers themselves lack the skills and/or confidence to conduct practical work [31], allows for the development of process skills and 21st-century skills, facilitates the teaching of difficult and abstract concepts and obviates the limitation of resource constraints.

5.3. Integration of STEM Content Knowledge

STEM subjects are often taught in isolation; however, through the use of mobile digital technology, postgraduate STEM students learnt to link cross-cutting concepts in STEM disciplines with ease, as can be seen in the excerpts below:

> "Using technologies in my teaching has changed how I design my lessons. In my physics lesson, I draw on the design process when engaging learners in project-based learning. For example, in constructing a mechanical arm, learners are expected to use the knowledge of dimensions from mathematics. In this way, I integrate STEM subjects. What helps me is that we have a platform on the discussion forum to share our practice and how we link concepts—what works and what does not. It is a safe, encouraging space, we are not judged we are all learning together." P11, discussion form.

> "I can now link common concepts in STEM For example when I teach acids and bases in chemistry, I link the concepts of neutralisation to life sciences and the use of antacids during indigestion. Learners draw on maths when performing calculations on Ph. Linking concepts in STEM is only possible due to the use of mobile digital technologies." P4, discussion forum.

> "Being empowered with knowledge of mobile digital technologies, and how it is used has changed the way I teach STEM subjects. I no longer think in compartments or teach the subjects in isolation. The use of mobile digital technology has enabled me to see the links between cross-cutting concepts and apply them in my teaching. When teaching about X-ray diffraction in physics, I link it to X-ray machines and the diagnosis of diseases (life sciences) to radioactivity (chemistry) and to contextual issues in the community why it is necessary for pregnant ladies to wear a lead apron when taking an X-ray. I am so glad, I have had the opportunity to be capacitated to engage in online teaching. It has impacted my confidence, material design, pedagogy and how I think of STEM subjects and how they ought to be taught." P15, reflective diary.

The above testimonies expose participants' shift in their confidence to teach with mobile digital technology. Enhancing their TCK, TPK and TPACK impacts their teaching practice. It allows them to teach STEM subjects differently, signalling a change in their practice, which differs from their face-to-face teaching practice. Using mobile digital technology, they can now, change their instructional strategies, and support and guide learning of integrated concepts across STEM, for example linking learning about acids and bases in chemistry to neutralising heartburns during indigestion, via antacids as well as drawing on mathematics when calculating the molar concentration and Ph of solutions. The cross-cutting concepts were used to forge a bridge between the STEM subjects. Consequently, participants no longer treat and teach STEM subjects as discrete isolated units as they did during face-to-face teaching. Kelley et al. [32] aver that changes in knowledge and confidence in the use of technology are vital for teachers to change their pedagogy and successfully integrate STEM concepts in their teaching. Further, it is visible that the discussion forum has created a safe space for participants to share their concerns and triumphs of integrating STEM concepts into their teaching. The above finding resonates with that of [33] study, which asserts that a community of practice is key to allowing teachers to share their practice and deepen their knowledge on pedagogy, mobile digital technologies, integrating STEM concepts and changing how they teach STEM subjects.

6. Conclusions

This research aimed to explore how postgraduate STEM students use mobile digital technologies to facilitate teaching and learning under COVID-19 conditions?

Once the participants TPACK, TK, TC and TPK improved, they reported positive experiences with online mobile teaching. The improvement in participants' TPACK, allowed them greater choices of resources, technologies, planning and designing of tasks to facilitate active learning in STEM disciplines.

Participants used translanguaging pedagogies to bridge the divide between STEM discourse, LOLT and learners' home language. This enabled learners' home language to be an asset in STEM classrooms, one that could be used to create a more inclusive learning environment, promote conceptual understanding of STEM subjects, develop higher-order thinking, scaffold learning and address issues of equity, power and social justice. Based on the findings of this research it can be argued that translanguaging technology can be used as a pedagogical strategy for linking the LOLT, discourse of STEM with the learners' home language. As pedagogy, translanguaging has a place and space to play in the post-COVID classroom, especially in an African context where many learners' home language is different from the Eurocentric LOLT at school. Including translanguaging as pedagogy in the post-COVID classroom would enable learners, whose home language is not English, to forge a connection to the STEM subject matter by understanding what they are able to do with the cultural and language strengths they bring to the classroom. This will enhance the learners' confidence to engage with STEM concepts, learning materials and tasks. Translanguaging allows for the planned and systematic use of the home language of learners with the language of the classroom in order to foster learning and teaching, address language power dynamics, issues of social justice, equity and access to STEM content. These issues have plagued the learning and uptake of STEM subjects by learners whose home language is not English [17]. Proponents of translanguaging [34,35] implore STEM, teachers to challenge learners to draw on their linguistic repertoire for meaning-making in the classroom.

Participants engaged learners in virtual practical work, via PhET simulations. These virtual practicals embraced active learning where learners had to investigate, predict, evaluate, develop explanations, communicate, think critically, problem-solve, collaborate, be creative, and innovate. The findings of this study pertaining to practical work is significant, as it charts a way to overcome the challenges facing rural schools within the South African context in terms of limited financial and infrastructure resources for laboratories. Ramnarain [36] asserts that the teaching and learning of science subjects, in rural schools in South Africa are negatively affected by a lack of fully functional laboratories. A striking feature of conducting practical work virtually is that teachers and learners are able to perform practicals in a safe environment, with functional apparatus and reagents that they would otherwise be unable to perform due to resource constraints. Furthermore, engaging in virtual practical work allows for greater equity of access to quality resources and enables deep learning in learners.

The ability to integrate cross-cutting concepts in STEM disciplines was evident in the participants' practice. The improvement in participants' TPACK allowed them to effectively use mobile digital technology to see the links between concepts in STEM disciplines. The study participants no longer taught or considered STEM subjects as discrete units with fixed boundaries. Their positive experiences of using technology allow for the identification and linkage of cross-cutting concepts and the scaffolding of STEM knowledge and linking the application of knowledge to real contextual issues [32]. In a surreptitious way, the findings of this study bring to the fore the advantages of using mobile digital technology during online teaching and learning. These advantages (translanguaging, practical work and integration of STEM concepts during teaching), have practical implications, in the post-COVID era, for teaching STEM subjects in Africa, for pre-service teacher training and in-service teacher professional development.

The practical implications of using translanguaging as pedagogy in South Africa's (or Africa's) STEM classroom is that the learners' home language is construed as an asset and resource to navigate between the discourse of STEM and LOLT. Learners will be afforded the opportunity to use their prior knowledge and experiences they carry with them to make meaning of STEM concepts (which are often abstract) and be co-constructors of knowledge where they participate in the practice of generating and creating scientific explanations in their own voice. It is important to note that learning STEM involves participation in the culture of STEM and its processes. A translanguaging pedagogy will allow for this participation, engagement with content, development of conceptual understanding and higher-order thinking and consequently not preclude learners whose home language is different from the LOLT, from demonstrating their knowledge and abilities in STEM subjects. For teachers to use the learners' home language as a resource it requires them to adjust their instructional design and activities accordingly. Thus, teachers will need to be capacitated via professional development with professional knowledge of how STEM instruction could be organised to support learners whose home language differs from the LOLT and how to create a more inclusive learning environment.

The practical implication of using virtual practical work to support learners in understanding abstract concepts, deepening their engagement with content and acquiring process skills and 21st-century skills is key in resource-constrained schools. In the absence of fully equipped and functional laboratories, learners have the opportunity to engage in active learner-centred learning, recognize apparatus, manipulate apparatus/variable virtually, and develop competencies in conducting scientific investigations. Based on the finding pertaining to conducting practical work virtually in resource-constrained schools it is pivotal that teachers be trained and capacitated to use mobile digital technologies to engage in practical work virtually.

The findings pertaining to linking cross-cutting concepts and content in STEM subjects have implications for the development of STEM curricula and further professional development for practising STEM teachers.

Moreover, there is a need for pre-service and in-service teacher professional development to ensure that teachers are equipped with the relevant TPACK so they are capable of selecting and using appropriate mobile digital technology to promote deep and meaningful learning with learners.

7. Recommendations

The findings of this study point to the need for further research firstly on the use of translanguaging technology to support student learning and improve learners' performance. Secondly, they point to the need of PhET simulations to develop process skills and 21st-century skills, especially in resource-constrained schools and using technology to integrate stem concepts and understanding. Thirdly, they highlight the need to expand the sample, to include students from other institutions or contexts to provide a broader view of how mobile digital technologies are used in STEM education. Forth, this study requires a long-term follow-up using quantitative methods to provide statistical analysis on the effectiveness of digital mobile technologies in improving student outcomes, participation and digital equity in STEM education in particular and education in general.

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