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BROADENING EDUCATIONAL PATHWAYS TO STEM EDUCATION THROUGH ONLINE TEACHING AND LEARNING DURING COVID-19: TEACHERS' PERSPECTIVES

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Abstract. *COVID-19 posed formidable challenges to the teaching and learning of subjects with abstract concepts such as Science, Technology, Engineering and Mathematics (STEM). The study explored how STEM teachers transformed their pedagogical practices as an integral part of the transition to online teaching and learning in response to COVID-19 and further examined the effectiveness of online teaching and learning. The study adopted an exploratory descriptive survey design and involved purposively selected STEM teachers from schools operating under the auspices of the Association of Muslim Schools. The Technological Pedagogical Content Knowledge (TPACK) framework underpinned the study. Quantitative data was collected through the administration of a Likert scale instrument. Data was analysed using inferential and descriptive statistics. Findings revealed that COVID-19 essentially compelled teachers to make a transition to online teaching and learning resulting in a concomitant profound impact on their pedagogical practices. Teachers provided various perspectives on the key modalities adopted to navigate online teaching and learning on virtual platforms in an attempt to ensure sustainable, equitable and inclusive teaching and learning. Implications for broadening educational pathways to STEM education through online teaching and learning on virtual platforms and sustainable teacher professional development on technology integration in teaching and learning are discussed.*
Keywords: *COVID-19, online teaching, pandemic, pedagogy, STEM, teaching practices*

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Introduction

The COVID-19 pandemic posed unprecedented and enormous challenges to teaching and learning. The prevalence of COVID-19 pandemic critically exposed existing socio-economic disparities in South Africa in particular. These socio-economic disparities permeate various sectors of the economy and the basic education sector is no exception. While the COVID-19 pandemic is a fundamental challenge of global proportions, it provided a meaningful opportunity to rethink key modalities through which education is provided. In addition, the COVID-19 pandemic compelled teachers to fundamentally transform their pedagogical practices as part of the transition to online teaching and learning on virtual digital platforms. Mulenga and Marbán (2020) posit that the pandemic served as a game changer in terms of the transformation of pedagogy across the globe. The South African government declared a state of National Disaster in response to COVID-19 pandemic during March 2020. The advent of the Fourth Industrial Revolution provides opportunities for teachers to engage in extensive systematic professional development to facilitate a move towards mandatory blended learning (Avgerinou & Moros, 2020). However, the COVID-19 pandemic forced in-service teachers to embark on an arduous task to develop their skills required to navigate online teaching and learning on virtual digital platforms on an ad hoc basis. This study explored teachers' perspectives in relation to broadening educational pathways to STEM education through online teaching and learning during COVID-19 pandemic.

The Association of Muslim Schools

The Association of Muslim Schools (AMS) was formed in 1989. The association was essentially established as a national body for Muslim private schools across South Africa. The association witnessed significant growth in the establishment of private Muslim schools in South Africa since the 1990's (Adam, 2004). This significant growth necessitated the establishment of

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regional bodies to service the needs of schools within provincial jurisdictions (Adam, 2004). The association also caters for schools classified as Section 14 Schools (i.e., public schools on private properties or previously known as state added schools) (Adam, 2004). The vision and mission of the Association of Muslim Schools are to assist schools to advance and promote values of encouragement and co-operation between schools, organise activities within AMS affiliated schools, and to deliver the highest standards and quality of Islamic-based education. The Association of Muslim Schools regularly hosts seminars and professional development workshops for teachers practising within its affiliations. One of the defining key features of AMS schools is the pro-active move towards technology-enhanced teaching and learning. Although governed by an independent board, not every school within the association operates with the same level of strength in terms of financial resources. Consequently, the support offered to teachers on technology integration in teaching and learning is not standardised.

The Impact of COVID-19 Pandemic on Teaching and Learning

The COVID-19 outbreak in the latter part of 2019 rapidly escalated to a pandemic of global proportions. The outbreak was subsequently declared a global pandemic by the World Health Organization (WHO, 2020). To slow down the rapid spread of this virus, countries including South Africa declared a state of National Disaster culminating in a national lockdown characterised by the imposition of strict measures such as social distancing, banning social gatherings, working from home and closure of schools and universities. According to UNESCO (2020a) and UNICEF (2020), in excess of 1.5 million learners in schools and universities globally were affected by the closure of institutions as a result of COVID-19 pandemic.

South African universities migrated to online remote teaching in response to the pandemic. Universities negotiated with service providers to secure data for students and zero-rating of online platforms. The COVID-19 pandemic critically exposed the socioeconomic disparities characterising the higher education landscape and the basic education sector. While historically white universities implemented online teaching and learning on virtual digital platforms, historically black universities encountered fundamental challenges in terms of infrastructure and financial resources. On the basic education front, affluent private schools made a seamless transition to online teaching and learning while a substantial number of under-resourced schools lost vast amounts of teaching time.

The phased-in re-opening of schools in South Africa led to a spike in infections. Civil society organisations including teacher unions put considerable pressure on the South African government to reconsider the re-opening of schools in the light of the spike in infections. This call was acceded to and schools were closed for a month. Public schools were in a precarious predicament due to lack of capacity to make a transition to online teaching and learning. In recognition of this structural problem, Bozkurt and Sharma (2020) concur that the global education system is in a crisis and the move to online remote teaching has been put into place with very little understanding of the fundamentals involved. Distance online education has been a choice of study that has evolved over time as an interdisciplinary field with growing popularity (Bozkurt, 2019a, 2019b; Zawacki-Richter, *et al.,* 2020). The COVID-19 pandemic has made remote online teaching obligatory for teachers (Bozkurt et al. 2020). Consequently, the pedagogical practices adopted by teachers as key agents of educational change required immediate mandatory change.

Although a specific focus on the pedagogical skills of teachers is vitally important, there is a need to also focus on teachers' perspectives in relation to broadening educational pathways to STEM education through online teaching and learning during COVID-19 pandemic. Teachers across the globe are the most critical intellectual resources of any school and are facing financial, physical, and mental struggles due to COVID-19 pandemic (Vu et al. 2020). In the schooling sector, fixed learning schedule and learners remaining in their classes with teaching specialists moving between classes make the transition to remote or online learning space more difficult (Basilaia & Kvavadze, 2020).

While there are several forms of online tools that can be used to facilitate teaching and learning process, it remains to be seen if the transition to remote learning or online learning is in fact a move towards the traditional method of teaching (Allen et al. 2020). This fundamental irony associated with the transformation of teaching and learning within the context of the Fourth Industrial Revolution is noted by Biesta (2019) who argues that "some of the most popular technology-mediated forms of education such as TED talks, Massive Open Online Courses (MOOCs) and the numerous professional and amateur instructional videos on YouTube are all staged in traditional ways, with someone talking and explaining so that others can watch, listen and learn" (p.55). In response to the COVID-19 pandemic, the Chinese Education Ministry immediately implemented a flexible online learning programme called the "Disrupted classes, Undisrupted Learning" (Huang et al. 2020).

As teachers make the transition to online teaching and learning as an inevitable reality, there is a crucial need


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to demystify the nature of technology integration in its broadest sense. Perienen (2020) points out that extensive use of technology by mathematics teachers capacitates them for the remote or online space. Niess (2006) and Zelkowski, Gleason, Cox and Bismark (2013) concur that when teachers have foundational and practical competence to innovatively utilise technological tools, then effective teaching and learning can take place. It is important to point out that remote or online learning is not a predominant practice in every country. For instance, online learning is still very new, and teachers are novices in relation to this domain in the Philippines (Talidong & Toquero, 2020). The inevitable reality is that pedagogical practices adopted by teachers when navigating fundamental challenges associated with online teaching and learning on virtual digital platforms would certainly be severely tested as they embrace a "new normal".

STEM Teaching and Learning

Skills development remains a key facet in terms of the realisation of sustainable growth in various sectors of the economy. This development hinges to a large degree on the demonstration of competence in key knowledge areas such as STEM subjects. Concerted efforts are required to bring about a fundamental transformative change through meaningful enhancement of human capital development as a key strategic priority for instilling South Africa's global competitiveness. South Africa makes substantial budgetary commitments towards the provision of quality education, yet the basic education system is characterised by inadequate matriculation pass rates particularly in gateway subjects such as mathematics and science (Coetzee, 2008; Naidoo, 2004). The 2015 Trends in International Mathematics and Science Study (TIMSS) painted a gloomy picture about the overall performance of South African grades five and nine learners in mathematics and science. Mapaire (2016) argues that promulgated educational policies are not responsive to the critical need to improve learner performance in mathematics in South Africa.

There is a critical need to broaden educational pathways to STEM education within the broader South African context. However, the COVID-19 pandemic posed unprecedented and formidable challenges to STEM teaching and learning in a global sense. The COVID-19 pandemic provides exciting opportunities to make a transition to online teaching and learning in keeping with the advent of the Fourth Industrial Revolution. In fact, the pandemic has the potential to accelerate the penetration of the Fourth Industrial Revolution in various critical areas of human endeavour. Bao (2020) asserts that COVID-19 pandemic compelled teachers to embrace online teaching and learning through utilisation of digital platforms. In support of this notion, Daniel (2020) posits that COVID-19 pandemic poses enormous challenges to educational systems which have relied heavily on contact teaching. Digital migration to online teaching and learning may potentially be a panacea for the fundamental challenges associated with the prevailing pandemic (Mondol & Mohiuddin, 2020). The transition to online mode of delivery provides exciting research opportunities to explore pedagogical practices adopted by teachers when integrating digital technologies within the context of STEM teaching and learning.

Research Problem

Meaningful enhancement of human capital development through broadening educational pathways to STEM education remains a key strategic imperative within the broader South African context. Coherent realisation of this imperative hinges to a large degree on the provision of quality education for all. However, the COVID-19 pandemic posed formidable challenges to the South African education system. These challenges relate to availability of infrastructure as well as the adequacy of teachers' professional competence to fully embrace pedagogic innovation as an integral part of digital transformation. According to Onyema et al. (2020), COVID-19 pandemic created multiple problems for the education sector which essentially culminated in decreased educational opportunities for learners coming from underprivileged socio-economic backgrounds. In addition, the integration of emerging technologies in education has become inevitable as a consequence of the constantly changing learning environment, demands for flexibility in methodology, and the need to enhance creativity and innovations in learning (Onyema, 2019). One of the key pedagogical affordances of technology integration in education is the provision of meaningful opportunities to transform teachers' pedagogical practices from traditional approaches that often place them as dispensers of knowledge to a more flexible approach where they act more as facilitators, mentors and motivators to inspire learners to participate in the learning process (Onyema & Deborah, 2019). Furthermore, the use of appropriate educational technologies increases accessibility to learning resources and multiple learning approaches to meet the need of diverse learners (Onyema et al., 2019). Building a resilient education system for

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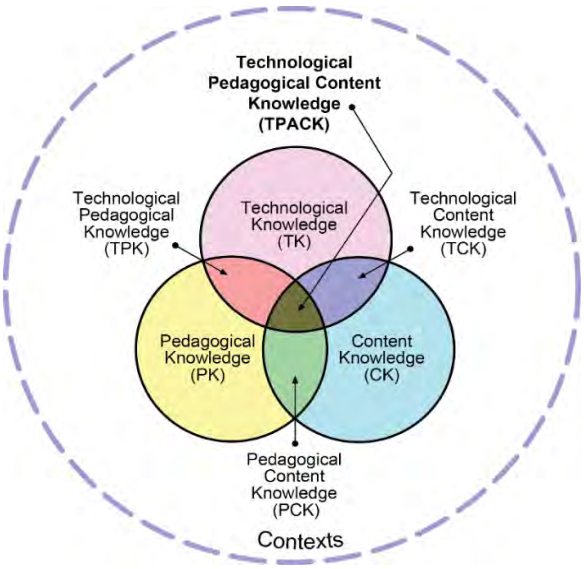
equitable and sustainable development requires teachers as key agents of educational change to seamlessly make a transition to online teaching and learning. Yet, migration to online teaching and learning proved to be an extremely difficult and complex undertaking for teachers particularly during the COVID-19 pandemic (Madeline, 2020). This problem is further exacerbated by lack of access to technology or good internet connectivity (UNESCO, 2020b). In recognition of the complexity of the highlighted problem, this research study examined teachers' perspectives on the extent to which educational pathways to STEM education can be broadened through online teaching and learning during COVID-19 pandemic.

Theoretical Framework

The study is underpinned by technological pedagogical content knowledge (TPACK) proposed by Koehler and Mishra (2009) as the underlying theoretical framework. The TPACK framework emphasises the interaction between pedagogical knowledge, content knowledge and technological knowledge (Koehler & Mishra, 2009). In addition, the TPACK framework advocates that learning can be facilitated when technology is used to complement teaching using appropriate pedagogical approaches (Koehler & Mishra, 2009; Swallow & Olofson, 2017). TPACK is defined by Koehler et al. (2013), as "the basis of effective teaching with technology requiring an understanding of the representation of concepts using technology" (p. 16). In essence, the TPACK framework delineates the intersection between technological knowledge, content knowledge, pedagogical knowledge, and pedagogical content knowledge. As a theoretical lens, TPACK essentially served to provide insightful elucidation into the nature of key research findings emanating from the empirical investigation. The TPACK framework is illustrated in figure 1 below.

Figure 1
The Components of the TPACK Framework (Koehler & Mishra, 2009)



Research Purpose

The study sought to explore teachers' perspectives in relation to broadening educational pathways to STEM education through online teaching and learning during COVID-19 pandemic. The empirical investigation was accordingly guided by the following research question:

How can educational pathways to STEM education be broadened through online teaching and learning on virtual digital platforms during COVID-19 pandemic?

To answer the main research question, the following sub-questions were formulated.

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- How is the information and communication technology (ICT) used by STEM teachers as an integral part of online teaching and learning during COVID-19 pandemic within the South African context?
- What is the nature of teaching practices adopted by STEM teachers to navigate fundamental challenges associated with online teaching and learning on virtual digital platforms?
- What are STEM teachers' perceptions about online teaching and learning?
- What are STEM teachers' perceptions about the efficacy of assessment practices adopted during online teaching and learning?

Research Methodology

General Background

The study adopted an exploratory descriptive survey design. Exploratory descriptive survey design is the determination and description of the situation and comparing how sub-groups view a certain issue (Gay, Mills, & Airasian, 2011). According to Burns and Bush (2006), exploratory research design provides opportunities for gathering information in an informal and unstructured manner. Exploratory research helps a researcher to build understanding about the problem of the research. In addition, exploratory research design is not limited to one specific paradigm as it may use either qualitative or quantitative approaches. Exploratory research design was appropriate as the researchers sought to determine and compare the online teaching and learning experiences of STEM teachers at AMS affiliated schools (Creswell, 2014).

Sampling

According to Muijs (2004), population refers to the complete set of individuals we want to generalise. A purposive sampling method was used to select the participants. 45 STEM teachers from the Association of Muslim Schools were purposively selected on the basis of the abstract nature of the subjects they teach and the need to explore the effectiveness of the transition to online teaching and learning without prior teacher professional training in online mode of delivery.

Data collection

Quantitative data was collected by conducting a web-based survey. The survey allowed the researchers to decide on the sample and questions to be asked (Creswell, 2014). A web-based survey was used as the AMS schools are located in various provinces in South Africa. The use of a web-based survey was also necessitated by the prevailing spike in COVID-19 infections at the time. The survey instrument covered the following constructs: use of ICT by STEM teachers during lockdown in the Republic of South Africa (RSA), STEM teachers' online teaching practices, teachers' perceptions about online teaching and learning and teachers' perceptions about the efficacy of assessment practices adopted during online teaching and learning. The online survey questionnaire was a Likert scale instrument. Each response used the five-point Likert scale for which answers ranged from 1 = "strongly agree" to 5 = "strongly disagree".

The use of Google Forms was preferred for conducting an online survey as the schools were familiar with this product as it comes with the G Suite Educational package. Google Forms has software embedded in it that allows it to generate results and report them back to the researchers as descriptive statistics or as graphical information. The results could be downloaded into an Excel spreadsheet for further analysis. The online survey was created and disseminated to AMS affiliated principals in the following provinces: Gauteng, Northern Cape and KwaZulu-Natal. The cover email contained a unique URL which directed the participants to Google Forms to complete the online survey. Respondents completed the survey online and the researchers received the information as soon as respondents clicked submit. Follow-up phone calls to principals were made to ensure a high response rate.

Data Analysis

Data was downloaded to an Excel spreadsheet from Google Form. SPSS Version 25 was used to analyse quantitative data. Data was analysed using inferential and descriptive statistics.

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Reliability and Validity

Reliability was achieved by ensuring that questions elicited the same type of information each time they were used under the same conditions. The survey instrument was first piloted with a group of STEM teachers to establish its reliability. The internal reliabilities of the instrument were evaluated by calculating Cronbach's alpha for each item. Cronbach's alpha is used as an indicator of scale reliability or internal consistency (Taber, 2017). This is the degree to which the items that make up the scale are all measuring the same underlying attribute (Pallant, 2007). As an important measurement, validity is concerned with the specific outcome to be measured and unique to the process (Creswell, 2014). Validity was achieved through representativeness of the sample and by ensuring that questions asked served the intended purpose.

Ethical Considerations

Permission to conduct the research was obtained from the National Offices of the Association of Muslim Schools. Official correspondence was then sent to the regional offices. Official correspondence explained the purpose of the study and who the subjects on the study would be. Informed consent was received from both offices allowing data to be collected. Ethical protocols pertaining to the execution of the research were strictly adhered to. The respondents remained anonymous and the only information collected was the schools' name and region.

Research Results

The study explored teachers' perspectives in relation to broadening educational pathways to STEM education through online teaching and learning on virtual digital platforms during COVID-19 pandemic within the South African context. The research findings are presented in terms of the key constructs investigated, namely: use of ICT by STEM teachers during the lockdown period in the Republic of South Africa (RSA), STEM teachers' online teaching practices, teachers' perceptions about online teaching and learning and teachers' perceptions about the efficacy of assessment practices adopted during online teaching and learning. Table 1 below depicts distribution of responses on the use of ICT by STEM teachers during the lockdown period in RSA. The specifications for the Likert scale are as follows: Strongly Agree = SA, Agree = A, Neutral = N, Disagree = D, Strongly Disagree = SD.

Table 1
Distribution of Responses - Use of ICT by STEM Teachers during the Lockdown Period in RSA

Items	Frequency of responses				
	SA	A	N	D	SD
I am confident when it comes to using ICT in general	8	24	11	1	0
I was confident using ICT's in my online teaching	8	20	14	2	0
I had to learn how to integrate technology into my online teaching	8	28	5	2	0
I had to learn/develop myself on how to best support my students during online learning	12	23	6	1	1
I understood the role of ICT in education prior to COVID-19	11	19	12	2	1
I find the use of ICT and online teaching more effective than face to face interaction with students	1	5	7	21	11
When teaching online I know exactly how to link relevant videos/images to my lessons	9	22	11	1	2
ICT was used extensively in my teaching prior to COVID-19	3	12	12	14	4
I am in need of professional development for online teaching and learning	7	15	13	9	1

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As reflected in Table 1 above, the participants demonstrated positive disposition about their confidence to use ICT tools when navigating fundamental challenges associated with online teaching and learning on virtual digital platforms during the lockdown period in South Africa. While the transition to online teaching and learning was imposed by the prevalence of COVID-19 pandemic, the teachers were largely confident to embrace virtual digital platforms to provide instruction to learners. The COVID-19 pandemic appeared to provide meaningful opportunities for STEM teachers to undertake a digital migration to online teaching and learning in keeping with the advent of the Fourth Industrial Revolution. In addition, the pandemic has the potential to accelerate the penetration of the Fourth Industrial Revolution in various critical areas of human endeavour and the basic education sector is poised to benefit immensely from this digital transformation. As a complex dichotomy, the advent of the Fourth Industrial Revolution poses enormous challenges while providing practical pedagogical benefits for STEM teaching and learning within the broader South African educational context. While the need to integrate technology as a catalyst for pedagogic innovation in STEM teaching and learning is paramount, considerable attention ought to be devoted to meaningful teacher professional development on the effective utilization of appropriate information and communication technology tools.

The distribution of responses on STEM teachers' online teaching practices is provided in Table 2 below. The participants demonstrated ambivalence about their professional competence to use innovative pedagogical strategies during online teaching and learning. The teachers relied heavily on their subject matter knowledge to navigate fundamental challenges associated with the provision of instruction on virtual digital platforms. While teachers' professional competence to identify and employ appropriate pedagogical strategies during online teaching and learning was shaky, they demonstrated a fundamental appreciation of practical pedagogical benefits that accrue from the implementation of online teaching and learning. These pedagogical benefits include the provision of meaningful opportunities to demystify abstract concepts and provision of meaningful platforms to use extensive content knowledge to foster effective teaching.

However, the teachers highlighted various challenges that impede meaningful enactment of their professional practice. These challenges include inability to deliver creative and inclusive lessons, inability to develop scientific skills through active learner engagement, difficulty to cater for all learning styles, difficulty to teach STEM topics online, and difficulty to teach the scientific process online. The development of meaningful conceptual understanding hinges to a large degree on teachers' professional competence to transform subject matter knowledge through sustainable enactment of contemporary pedagogic approaches such as inquiry-based learning. The transition to online teaching and learning provides opportunities for teachers to critically reflect on their pedagogical content knowledge as a critical means to navigate the provision of instruction on virtual digital platforms. It is imperative to implore teachers as key agents of educational change to become reflective practitioners in order to fully embrace innovative opportunities to fundamentally transform their pedagogical practices.

Table 2
Distribution of Responses – STEM Teachers' Online Teaching Practices

Items	Frequency of responses				
	SA	A	N	D	SD
My content knowledge is extensive	9	26	10	0	0
An extensive content knowledge helps a teacher to teach more effectively online	16	23	3	2	1
As a teacher I am able to articulate abstract concepts effectively during online teaching	3	25	14	2	1
Online teaching allows me more time to prepare for my lessons	2	12	17	8	6
With online teaching I can be more creative in my lessons	2	15	13	12	3
I am able to cater for all learning styles during online teaching	1	11	16	14	3
Online teaching made my lessons more inclusive	1	10	18	12	4

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Items	Frequency of responses				
	SA	A	N	D	SD
Online teaching had all my learners engaged in the session	1	6	16	15	7
STEM topics were easily taught using online teaching	1	15	20	8	1
Scientific skills are easier to develop in students using online teaching	1	7	14	22	1
Your teaching strategies involved more lecturing during online teaching	5	20	15	5	0
Teaching the scientific process through online teaching is effective	0	11	18	12	2
I am able to conduct STEM related task effectively using online teaching	0	13	23	8	1

Table 3 below provides distribution of responses on teachers' perceptions about online teaching and learning. The participants identified various challenges that render the implementation of online teaching and learning on virtual digital platforms an arduous task. These challenges include prohibitive data costs, amount of time taken to create presentations, lack of professional support needed to navigate the virtual digital platforms, and technical difficulties experienced with the utilisation of ICT tools. The challenges highlighted in this regard underscore the need to provide sustainable teacher professional development on the utilisation of ICT tools. The realisation of this key strategic imperative would serve to pave the way for teachers to develop professional capacity to broaden educational pathways for STEM education through online teaching and learning on virtual digital platforms. At another pragmatic level, teacher professional competence on the utilisation of ICT tools would serve as a critical basis to harness opportunities associated with the advent of the Fourth Industrial Revolution.

Table 3
Distribution of Responses - Teachers' Perceptions about Online Teaching and Learning

Items	Frequency of responses				
	SA	A	N	D	SD
Creating presentations/content for online teaching was easy	2	14	12	9	7
Creating presentations/content for online teaching took a lot of my time	16	21	5	3	0
With online teaching I had more personal time	3	9	12	11	10
Online teaching is more cost effective for me as a teacher	2	14	15	9	5
Online teaching has resulted in me being more mentally exhausted	11	11	11	11	1
Online teaching has resulted in me being more physically exhausted	7	12	12	14	0
My SMT is very support to us as teachers during the online.teaching and learning phase	7	17	14	4	3
There was a special team on standby to assist with all technical problems during online teaching at my school	8	11	15	7	4
Online teaching has proven to be more satisfying for me as a teacher at an AMS affiliated school	4	12	18	8	3
Data costs for online teaching and learning was covered by my institution	3	7	15	9	11

Distribution of responses on teachers' perceptions about the efficacy of assessment practices adopted during online teaching and learning is depicted in Table 4 below. The participants expressed reservations about the efficacy of assessment practices adopted during online teaching and learning. This grim reality can be attributed to

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inadequate professional competence on the utilisation of ICT tools. The participants' disposition about the efficacy of assessment practices adopted during online teaching and learning reflected lack of professional versatility when providing instruction through virtual digital platforms. The significance of the role of assessment in teaching and learning cannot be over-emphasized. Thus, there is a critical need to develop teachers' professional capacity to use assessment effectively on virtual digital platforms to ensure a coherent realisation of envisaged learning outcomes.

Table 4
Distribution of Responses – Teachers' Perceptions about the Efficacy of Assessment Practices Adopted during Online Teaching and Learning.

Items	Frequency of responses				
	SA	A	N	D	SD
Monitoring student progress is easier	0	4	14	19	8
I am able to attend to give each student the individual attention required as done when face-to-face	1	9	6	20	9
Assessments are easier to conduct with online teaching	0	6	12	19	8
Students display greater degree of understanding abstract STEM content when taught online	0	4	20	18	3
Assessments conducted using online teaching are more meaningful	0	3	19	19	4
My students effectively collaborated during online learning	1	6	25	10	3
Online learning allows for all students to progress	1	13	15	11	5
Students are able to grasp abstract concepts more effectively when taught online	0	7	18	15	5

As indicated earlier, the findings in this inquiry are presented in terms of the key constructs investigated. The mean values for the constructs investigated are provided in Table 5 below. The mean values indicate that the participants were largely concerned about their general professional competence with regard to online teaching and learning ($M = 2.0$) and lack of professional confidence with meaningful enactment of adopted teaching practices on virtual digital platforms ($M = 2.6$). These highlighted key issues ought to be adequately addressed through provision of sustainable teacher professional development opportunities.

Table 5
Mean values for constructs investigated

Construct	Mean	Cronbach's alpha
Use of ICT by STEM teachers during lockdown period in RSA	1.8	.66
STEM teachers' online teaching practices	2.6	.75
Teachers' perceptions about online teaching and learning	2.0	.69
Teachers' perceptions about the efficacy of assessment practices adopted during online teaching and learning	1.6	.63

Discussion

Broadening the educational pathways to STEM education remains a key strategic imperative in a global sense. STEM education enhances not only students' learning achievement (Guzey et al. 2016; Mathis et al. 2018) but also authentic problem-solving skills (Bybee, 2010; Sanders, 2009). In addition, STEM education fosters individuals' enjoyment of STEM subjects and pursuance of STEM careers (Stevens et al. 2016; Vennix et al. 2018). The transition

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to online teaching and learning became an inevitable reality for STEM teachers as a result of COVID-19 pandemic. The teachers largely embraced the use of ICT tools as an integral part of online teaching and learning. However, they expressed concerns about their general professional competence to implement online teaching and learning and lack of professional confidence with meaningful enactment of adopted teaching practices on virtual digital platforms. These sentiments can be attributed to the fact that teachers' perceptions have a significant impact on instructional design and implementation (Wang et al. 2011). In addition, teachers who have different educational levels have dissimilar personal perceptions by virtue of differences in instructional models among scholastic levels (Warren & Plerson, 1994).

The participants demonstrated ambivalence about their professional competence to employ innovative pedagogical strategies during online teaching and learning. The transition to online teaching and learning posed formidable challenges to teacher professional practice. Teaching practices in particular have been found to be strongly affected by teachers' perceptions (Park et al. 2016; Thibaut et al. 2018). According to Robinson et al. (2020), strategies and practices such as flexibility with course requirements, promptness, clarity of communication, multiple points of contact, personal connections, reciprocity of caring, and students' centred design and teaching practices have shown potential in nurturing and maintaining a climate of care online. The realisation of this key strategic imperative requires the design of emergency remote education curricula that do not stop at content delivery and assigning tasks for assessment purposes, but that intentionally create spaces for learners to learn together in small groups (social constructivism) to reimagine digital forms of informal social spaces that help make school enjoyable for students and help build their social and cultural capital (Bali, 2020).

The participants identified various challenges that render the implementation of online teaching and learning on virtual digital platforms an arduous task. These challenges include prohibitive data costs, amount of time taken to create presentations, lack of professional support needed to navigate the virtual digital platforms and technical difficulties experienced with the utilisation of ICT tools. The prevalence of these challenges appeared to hamper meaningful online teaching and learning that is geared towards the maximisation of students' academic experiences. Popovici and Mironov (2014) posit that students are deeply aware of the changes brought about by the digital technologies and their impact on the learning process. The participants' disposition about the efficacy of assessment practices adopted during online teaching and learning reflected lack of professional versatility when providing instruction through virtual digital platforms. Liberman et al. (2020) contend that formative assessment during COVID-19 pandemic is crucial as teachers need to understand whether students are absorbing the content that is delivered to them in different formats. There is a critical need to develop teachers' professional capacity to effectively use pedagogically valid assessment practices on virtual digital platforms to ensure a coherent realisation of envisaged learning outcomes. The realisation of this goal hinges to a large degree on careful identification of teachers' professional needs in relation to meaningful implementation of online teaching and learning on virtual digital platforms.

The impact of COVID-19 pandemic on teaching and learning compels teachers to be reflective practitioners with professional capacity to embrace pedagogic innovation. Concerted efforts are required to provide support for teachers to smoothly navigate fundamental challenges associated with the implementation of online teaching and learning going forward. Miller (2020) asserts that in addition to the profound and global impact of the pandemic on our social, economic, and political lives, COVID-19 has also affected individuals both emotionally and psychologically. There is thus a critical need for efforts to support individuals and institutions varying from sharing ideas, advice, and resources to providing strategies and guidelines (Archambault, & Borup, 2020; Chiodini, 2020).

Interpretation of Key Findings in Terms of the Adopted Theoretical Framework

As indicated earlier, the study is underpinned by technological pedagogical content knowledge (TPACK) proposed by Koehler and Mishra (2009) as the underlying theoretical framework. The TPACK framework emphasises the interaction between pedagogical knowledge, content knowledge and technological knowledge (Koehler & Mishra, 2009). The teachers relied heavily on subject matter knowledge when navigating the pedagogical challenges associated with the provision of instruction on virtual digital platforms. However, the teachers demonstrated inadequate professional competence with meaningful enactment of adopted teaching practices. This implies that teachers found it increasingly difficult to harness their pedagogical content knowledge as a means to provide pedagogically sound instruction. While the teachers expressed fundamental appreciation of the opportunities provided to use ICT tools as part of online teaching and learning, they bemoaned lack of appropriate professional

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support required to navigate technical difficulties experienced with the utilisation of ICT tools. There is a need to enhance teachers' technological knowledge as key agents of educational change, to create innovative opportunities to maximise the effectiveness of instruction on virtual digital platforms.

Conclusions

The COVID-19 pandemic had a profound impact on pedagogy across the globe. While the teachers embraced the transition to online teaching and learning, there is a need to alleviate formidable challenges hampering the provision of instruction on virtual digital platforms. The teachers expressed fundamental appreciation of the opportunities provided to use digital technologies as an integral part of online teaching and learning. There is a crucial need to provide sustainable teacher professional development on the utilisation of digital resources within the context of changing fortunes associated with the advent of the Fourth Industrial Revolution. While private schools are better placed to take advantage of the key pedagogical affordances of online teaching and learning, significant strides ought to be made to ensure that public schools are equally poised to embrace the prevailing digital transformation.

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