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Technology-based Pedagogy for Mathematics Education in South Africa: Sustainable Development of Mathematics Education post COVID-19

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Abstract: The COVID-19 pandemic has transformed life globally. So too, teaching and learning in higher education have transformed to include technology-based pedagogy and online learning to curb the spread of the contagious Coronavirus. In the era of the 21st century, technology-based pedagogy is important for supporting teaching and learning. In mathematics higher education contexts, coupled with embracing abstract concepts in mathematics, there are different notions of what it means to include technology-based pedagogy during the COVID-19 pandemic. This qualitative study explored 38 postgraduate students' experiences and perceptions of using technology-based pedagogy during the COVID-19 pandemic. These participants were mathematics education students and practicing mathematics teachers at schools in South Africa. The theory of virtual communities of practice framed this study. Participants were invited to two interactive virtual workshops using various technology-based pedagogy during the COVID-19 pandemic. Subsequently, these participants were invited to participate in online interviews focusing on their experiences and perceptions of technology-based pedagogy for learning mathematics education. This study reveals the challenges and strengths of using technology-based pedagogy for learning mathematics education during COVID-19. These results are relevant when considering perceptions, experiences, and implications of technology-based pedagogy for sustainable mathematics education during and post-COVID-19.

Keywords: COVID-19; Higher Education; Hovercam; Mathematics Education; Moodle; Online Learning; Technology-based Pedagogy; Virtual Communities of Practice; WhatsApp

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1. Introduction

Currently, technology is increasingly being used to teach innovatively. In addition, technology is significantly used by society for different daily activities [1]. Also, in the 21st century, in the Fourth Industrial Revolution (4IR) era, there are several discussions on how current educational environments need to be transformed to support and incorporate technology-based pedagogy. Moreover, developments in technology-based pedagogy have provided lecturers with different technology-based tools and interactive online systems to change their education environment. Institutions on a global level are encouraging online, and distance learning, and technology-based pedagogy is key in facilitating online and distance learning. In mathematics education contexts, coupled with embracing the effective understanding of abstract mathematics concepts, are issues of what it means to integrate technology-based pedagogy in mathematics educational environments in the context of COVID-19 and beyond.

In this study, technology-based pedagogy provided lecturers and students with different technology-based tools, devices, and online platforms to discuss content, clarify concepts and enhance knowledge to promote teaching and learning using the Internet[1]. Also, within this study, the technology-based devices used were desktop computers, laptops, tablets, portable document cameras (Hovercam[2]) and cell phones. These technology-based devices supported technology-based pedagogy by using images, pictures, videos, text and audio [2]. Technology-based tools in this study included PowerPoint presentations, websites, online resources and software programmes. Thus, technology-based pedagogy validates online platforms and supports the integration of technology-based tools and devices [3]. Consequently, online platforms assist lecturers when using technology-based resources and tools to upload learning materials online. For example, the Zoom[3] and WhatsApp[4] online platforms are combined software solutions that support technology-based pedagogy.

This study sought to answer one fundamental research question: What are mathematics education students' experiences and perceptions of using technology-based pedagogy during the COVID-19 pandemic. The COVID-19 pandemic resulted in lockdowns worldwide, which has changed how we live our lives. In the 21st century and contemplating the conditions of the COVID-19 pandemic, Higher Education Institutions (HEIs) are using technology-based tools, devices and online platforms to support technology-based pedagogy. Technology-based pedagogy, an approach for using technology-based tools, devices, and online platforms to teach and learn, is effective pedagogy for preventing the spread of the contagious COVID-19 virus [4]. So too, using technology-based pedagogy and online learning are seen as viable pedagogies for sustainable education post-COVID-19.

2. Literature Review

2.1. Teaching and Learning Mathematics Education

Teaching in the 21st century in the Fourth Industrial Revolution (4IR) incorporates progressive strategies in which technology is embedded within people and society [5]. Although we live in a technologically progressive world, many students still cannot use technology-based tools and devices competently [6]. In addition, some students do not have the essential technology-based tools and devices to succeed with technology-based pedagogy. South African students are from different socio-economic backgrounds and have diverse access to technology-based tools and devices. Challenges are complex because students need to constantly acquire new proficiencies to succeed in a technology-based world [7].

Thus, educational environments need to adopt different strategies to prepare students to succeed in this transforming educational landscape [8]. If technology-based pedagogy is going to be used, teacher knowledge and engagement is important to ensure that technology-based devices, platforms and tools are used successfully to sustain education [9]. Professional teacher development is important for transforming pedagogy, evolving

1. The Internet is a connected online system using computer networks which are made up of public, government, private, business and academic computer systems linked by wireless, electronic, and optical networking technologies.
2. The Hovercam is a portable document camera. The Hovercam is connected to the lecturer's computer. This allows the lecturer to teach in real time and display notes and other information on the computer as the lecturer teaches. The Hovercam is able to magnify resources, pictures and images so that they are easier and clearer for the student to see. Lectures can also be recorded using the Hovercam.
3. Zoom is a software app programme which permits one to communicate virtually with peers, family, colleagues, lecturers, tutors, students and friends when communication through face-to-face means is not possible.
4. WhatsApp is a free messenger application (app) programme. WhatsApp allows individuals to use the Internet to send and receive calls, images, pictures, messages and videos. The participating university used WhatsApp unofficially as an online platform for communication between students, tutors and lecturers. This was used prominently during the Covid-19 pandemic.

educational environments, using technology-based tools, and advancing learning outcomes [10]. Also, mathematics teacher education in the 4IR era entails that teachers are sufficiently developed to successfully use and integrate technology-based devices and tools in their educational environments [11]. However, due to the COVID-19 pandemic, HEIs were forced to abruptly transform and use technology-based pedagogy without preparing their lecturers or students sufficiently for this abrupt transformation. This is concerning for students who live in unequal social environments and do not have the essential technology-based tools, devices, and resources to join equally in technology-based educational environments.

2.2. *Technology-based Pedagogy for Mathematics Education*

Technology-based tools and devices are prominent in educational environments, and technology-based pedagogy is progressively being used in educational environments in new ways [12]. In this study, technology-based tools are online platforms and online resources that may be used with technology-based devices, for example, desktop computers, laptops, tablets or mobile phones. These technology-based devices function with images, text, videos, pictures and audio files to scaffold teaching and learning [2]. Research [13] maintains that several online websites and online educational applications are available that can scaffold students' mathematics learning and achievement. In the era of the 4IR during the COVID-19 pandemic, HEIs were compelled to use technology-based tools and devices for distance, online and technology-based pedagogy. Thus, technology-based pedagogy and online learning are a premise for promoting sustainable education post-COVID-19.

Research [14] has revealed that the use of technology-based tools and devices for mathematics teaching has enhanced students' performance. Similarly, technology-based pedagogy for mathematics education may support successful and struggling students [15]. However, within the context of distance and online teaching and learning, for the lecturer to select a suitable technology-based tool to traverse the multiple available technology-based tools is overwhelming. The notion is to choose technology-based tools that are most effective for successful technology-based teaching that scaffolds students' achievement and learning. It is, therefore, the responsibility of the teacher/lecturer to advance technology-based educational environments [16].

Research shows that technology-based tools and devices are changing the role of the lecturer. We need to know more about how best to assist lecturers during this change [12]. The lecturer should use technology-based tools and devices to enhance technology-based pedagogy in the 4IR. The lecturer also needs to consider the implications of the COVID-19 pandemic on teaching and learning. One way of ascertaining the impact of technology-based pedagogy is to find out students' views. Mathematics students can assist by providing their experiences and perceptions of using technology-based pedagogy, tools and devices in their educational environment. These perceptions and experiences are important to promote sustainable mathematics education post-COVID-19.

2.3. *Virtual Communities of Practice Theory*

The theory of Communities of Practice is a social theory of learning, with the community as the central unit of analysis [17]. Communities of Practice (CoP) focus on the experiences of individuals in the CoP [18]. This theory maintains that the CoP is fashioned by individuals who share the learning process with other community members. Virtual Communities of Practice involve a technology component and online platforms, making virtual communities of practice different from the traditional communities of practice [19]. Through collaboration using technology-based tools, devices, online platforms, online resources and the Internet, the traditional CoPs advance to Virtual Communities of Practice

(VCoPs). A Virtual Community of Practice may be described as a community of professionals who share ideas, and meaning-making, thus adding to their knowledge base and improving their professional practice [20].

In this study, as the VCoP under focus worked together virtually, they shared knowledge and developed a community that supported learning and development [21]. The connection between VCoP theory and this study is clarified: VCoP has a shared interest; in this study, the shared interest is the participants' perceptions of technology-based pedagogy for mathematics education during the COVID-19 pandemic. Within VCoP, community members collaborate in activities and critically reflect and discuss the content under discussion [22]. In this study, members of the VCoP used technology-based tools, devices, resources and the Internet to collaborate and learn together. They used the Zoom online platform, WhatsApp and the Hovercam to share ideas, learn together and clarify misunderstandings. Members of a VCoP are professionals; in this study, the members of the VCoP were practising mathematics teachers. Thus, this study focused on using technology-based pedagogy for mathematics education during the COVID-19 pandemic and was suitably framed by the VCoP theory.

3. Materials and Methods

3.1. General Background

This qualitative, interpretive study was located at one South African Higher Education institution during the COVID-19 pandemic. All participants provided their consent to participate in the study. The university's ethics committee approved ethical clearance and gatekeeper access. The study included two interactive online workshops and individual online interviews, which were semi-structured with postgraduate mathematics education students. These participants were also mathematics teachers in South African schools.

3.2. Participants

For this study, thirty-eight postgraduate students were invited to participate. Participants were given an informed consent form. This form explained and described the research design, methods and processes. Positive responses were received from thirty-three students (15 male and 18 female). Six participants who responded positively were randomly selected to participate in the pilot study.

3.3. Pilot Study

To improve the study's dependability, trustworthiness, conformability and transferability, a pilot study was conducted. During the pilot study, some participants lost connectivity during the pilot workshop, and some were unsure about the questions asked during the interview. Experiencing these issues during the pilot study assisted with the planning for the main study. The main study was held during off-peak periods to ensure stable and fast internet connectivity. The interview questions were revised to ensure clarity. These revisions improved the credibility of the research design, methods and instruments.

3.4. Main Study

For the main study, twenty-seven postgraduate mathematic students participated. Data was gathered from two online workshops and online interviews. While 27 participants were present during the workshops, only 15 participants were available to be interviewed due to family, work or personal commitments. Thus, for the main study, seven male and eight female participants were interviewed. Pseudonyms were assigned to each participant. This ensured the participants' confidentiality. The pseudonyms used for this study are shown in Table 1.

Table 1. Interview Participants and their Pseudonyms

Participant	Pseudonym	Participant	Pseudonym
1	Anand	9	Ned
2	Bongani	10	Pretty
3	Cameron	11	Rakesh
4	Glenda	12	Sam
5	Jane	13	Susan
6	Linda	14	Thuli
7	Lungi	15	Tom
8	Nancy		

3.5. Interactive Online Workshops

The two interactive online workshops focused on teaching mathematics education students using technology-based pedagogy in the context of the COVID-19 pandemic. The researcher (lecturer) was the facilitator for the two workshops. Each participant was given additional online notes, resources, website addresses and PowerPoint presentations. The online workshops were conducted via the Zoom platform during the second semester (July – December) of the 2020 academic year. The first online workshop focused on controversial issues in mathematics education and problem-solving. The second online workshop focused on misconceptions in mathematics education and problem-solving. All participants were invited to online interviews at the end of the second workshop. The online interviews were focused on exploring mathematics education students' perceptions and experiences of using technology-based pedagogy during the COVID-19 pandemic.

3.6. Online Semi-structured Interviews

The interview aimed to examine mathematics education students' experiences and perceptions of technology-based pedagogy during the pandemic. Each interview lasted about 30- 40 minutes. The interviews were conducted using online platforms, for example, Zoom and WhatsApp. The interviews were conducted at a time that each participant chose. To place the participants at ease, every online interview began with a few common questions. It then advanced with precise items focusing on the participants' perceptions and experiences of using technology-based pedagogy during the COVID-19 pandemic. The online interviews concentrated on the critical question that follows:

- What are mathematics education students' perceptions and experiences of using technology-based pedagogy during the COVID-19 pandemic?

The online interviews included the following sub-questions:

- What are your perceptions and experiences of using technology-based tools, devices and pedagogy during the COVID-19 pandemic?
- What are your perceptions and experiences of using the WhatsApp platform during the COVID-19 pandemic?
- What are your perceptions and experiences of using the online Zoom platform during the COVID-19 pandemic?
- What are your perceptions and experiences of using the Learning Management System (Moodle) during the COVID-19 pandemic?
- What are your perceptions and experiences of the virtual communities of practice created during the COVID-19 pandemic?
- What are your perceptions and experiences of studying remotely/online during the COVID-19 pandemic?

Each interview was recorded and transcribed. Thereafter each participant was emailed a copy of the transcript. Participants were asked to peruse the transcripts to ensure that their responses to the interview questions were captured correctly.

3.7. Data Analysis

Data analysis was based on the theoretical framing for this study, i.e., Virtual Communities of Practice (VoP). The coding and categorising of themes were founded on this framework. Data analysis started with open coding to examine and organise the data into codes; secondly, codes were classified and clustered into themes. Then, the participants' responses were compared to see if there were any similarities or differences. Moreover, to ensure the accuracy of the results, all transcripts were sent to the relevant participants to ensure that their responses were accurately captured and transcribed. Participants could also clarify their responses if responses were not clear.

4. Results

The results reveal that participants had various perceptions and experiences concerning using technology-based pedagogy during the COVID-19 pandemic. These perceptions and experiences were categorised into two sub-themes strengths and challenges of using technology-based pedagogy during the COVID-19 pandemic. The results for these sub-themes are presented as follows.

4.1. Strengths of using technology-based pedagogy

The participants explained that using technology-based pedagogy within the context of the pandemic revealed strengths. The participants commented on the strengths of WhatsApp as an online platform, useful technology-based tools, such as the Hovercam for online teaching and learning and the use of different online platforms that fostered a supportive online community of practice. Figure 1 represents the percentage of participants who indicated that there were strengths to using technology-based pedagogy.

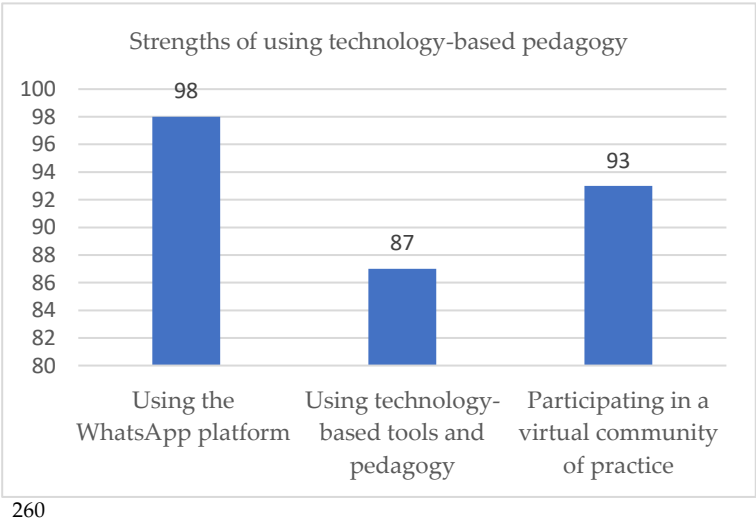


Figure 1. Percentage of Participants Who Indicated the Strengths of Using Technology-Based Pedagogy

The participants' views that best convey these strengths are presented in Table 2. 266

Table 2. Transcript Excerpts of Participants Focusing on the Strengths of Using Technology-Based Pedagogy 267 268

Question	Feedback
What are your perceptions and experiences of using the WhatsApp platform during the COVID-19 pandemic?	Anand: "…WhatsApp was convenient and easy to use…" Cameron: "…we used WhatsApp and created a group…we could share ideas and resources on WhatsApp…the whole class formed our own online community WhatsApp group…" Glenda: "… I first try the work on my own, and then I ask for help on WhatsApp if I need it or check if my attempt is correct…I take a picture of my work and send it to the group…it is easy and quick…" Lungi: "…I am used to using WhatsApp…it was easy to respond to questions…with WhatsApp, we get responses from others quickly…this help supported me…" Pretty: "…WhatsApp was quick, and I could send messages easily about my work …sometimes if I had family problems, I could also ask for help on the group…" Rakesh: "…WhatsApp was easier to use than the university Learn platform…I could get the lecture links for the Zoom lectures from my WhatsApp group…we could share the assignment questions on the group…I did not need to learn how to use WhatsApp since I normally use it with my friends and family…" Sam: "…we could share our teaching problems with each other… we could share teaching resources and examples for different math sections…the WhatsApp group was a very supportive group…"
What are your perceptions and experiences of using technology-based tools, devices and pedagogy during the COVID-19 pandemic?	Anand: "…it was the first time we saw the Hovercam…it was great to do the math problems step by step online…" Bongani: "…Hovercam made the math problem solving easy…it was like being in the class with the lecturer…even though we used videos and PowerPoints before so they were also interesting especially since we were working online from home…" Jane: "…the advanced technology tools we used in the lectures were great…learnt a lot about even using my cell phone to teach and learn…the lecturer showed us how to use the Hovercam, how to use teaching videos and how to make sure our PowerPoint presentations to benefit our learners… it was like being in the class and following all the steps…" Linda: "…I never used the Hovercam before…it was good to learn about the different devices like the sharing button on Zoom and the question banks on different websites…the lecturer even showed us how to use Moodle to set up tests and have the computer mark them for us…the Hovercam made math problem solving easy…we could easily follow the problem-solving process step by step…" Nancy: " I found this exciting…these new gadgets we were learning about…we could stop the lecturer at any time if we need more explanations…the Hovercam and online videos even allowed for us to go back and forth…"

	Sam: "…I never knew about this device, the Hovercam…it looks like something that will benefit my learners when I teach online…something good to know for future teaching…the explanations and step by step process was useful…"
What are your perceptions and experiences of the virtual communities of practice created during the COVID-19 pandemic?	Bongani: "…the online class group helped me a lot…even when my family had COVID, I could talk to the class online…they supported me…they even told me about the COVID testing site near me…the drive-through place..." Ned: "…we worked well together as an online group…we supported each other with the math problems online…the lecturer was also part of this online group and assisted us immediately if we needed help or any further explanations or examples…we could also check up on each other at any time…" Rakesh: "…with the online group, we could use WhatsApp or Zoom since we also had an online discussion group on Zoom and Moodle…if someone was behind with their work, we could support them and encourage them…some people had a problem working from home, so we provided constant online support……the online WhatsApp group also helped me understand and complete some math tasks…." Susan: "…the online group supported me throughout the semester…it was good to know that the class was with me every step of the way…" Thuli: "…I had good help from the online group. The help was not only about the academic work but also with personal family issues… I knew I could count on the group at any time…" Tom: "…some of us had the same challenges with the tasks…we could work together with the problem-solving steps online…we helped each other…"

From the interview transcripts, it was evident that the participants maintained that when using the different online platforms, technology-based tools and supportive online community of practice, there were strengths to using technology-based pedagogy during the COVID-19 pandemic.

4.2. Challenges of using technology-based pedagogy

The participants also explained that when using technology-based pedagogy, they experienced particular challenges. Participants expressed their unease with specific online platforms, the challenges of studying online during the COVID-19 pandemic, and the challenges they experienced with specific Learning Management Systems (LMS). Figure 2 represents the percentage of participants who indicated that there were challenges when using technology-based pedagogy.

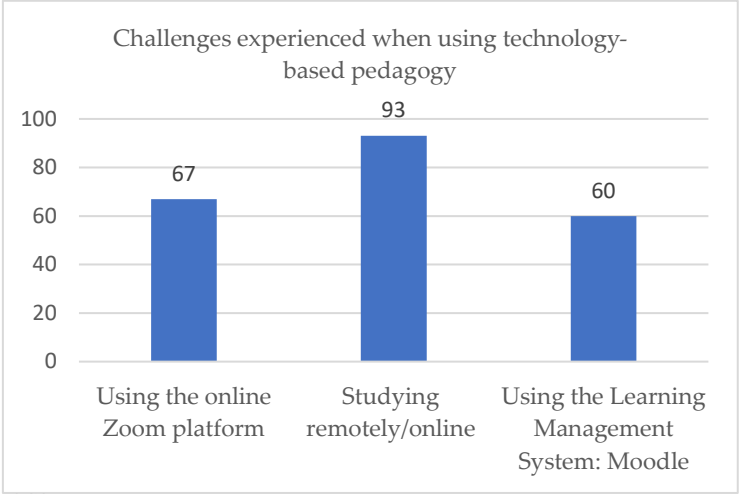


Figure 2. Percentage of Participants Who Indicated They Experienced Challenges When Using Technology-Based Pedagogy

The participants' views that best convey these challenges are presented in Table 3.

Table 3. Transcript Excerpts of Participants Focusing on the Challenges Experienced When Using Technology-Based Pedagogy

Question	Feedback
What are your perceptions and experiences of using the online Zoom platform during the COVID-19 pandemic?	Bongani: "…didn't know anything about Zoom…first time experience…eish…I had to ask for help…had to learn about this…" Cameron: "…the workshops took too much data…Zoom is expensive…the resources were hard and took too long to download…very expensive too…takes a lot of data…" Jane: "…was challenging at first…I had to use trial and error with Zoom…had problems with my video …I think the university should teach us to use Zoom first…" Lungi: "…very expensive to buy a computer…didn't think I would need this when I registered…I struggled also with the expense for data and Internet…" Ned: "…Zoom is new to me…I needed to learn everything about how to use Zoom…I think it was unfair for the university to ask us to use Zoom without providing any training to us students…just when I learnt how to use Zoom…the Zoom buttons for the system were changed…I had to learn this again…" Thuli: "…online lectures…expensive…lots of money…I didn't know that I would be studying online when I registered in February…this was frustrating for my family and me…" Tom: "…the workshops were challenging to follow…my Internet was not stable…I had issues with connectivity…"

What are your perceptions and experiences of studying remotely/online during the COVID-19 pandemic?	Anand: "…working from home is distracting… need…space to work…attend...Zoom lectures…my car…" Lungi: "…my small children are with me at home… it is difficult to attend Zoom lectures with them around me…I found it a problem to focus on my studies while at home…" Nancy: "…my family is big…live together…because of COVID-19 everyone is at home…my house is not big…I often attend lectures in my kitchen…it is embarrassing…I cannot put my video on because of where I am sitting for lectures… my parents don't understand that I need to attend lectures …I also have other work at home …this was very stressful for me…I couldn't balance my home life while studying online…my husband also fought about this…I could not cope…but lucky I had my friends from class who understood what I was going through, and they supported me…" Pretty: "…as a mother and wife, I have lots of other responsibilities…because of COVID-19…housework and cook…it was difficult to concentrate on my studies…I prefer studying campus…" Sam: …at my place, there is no privacy…I can't participate in my lectures because everyone at home is listening or talking during the lecture… I found it hard to ask questions during the lectures. I used the WhatsApp group to ask my questions…the online group supported me during the semester…" Tom: "…I am angry with the university…I paid for face to face lectures because I can't study on my own online…if I wanted to study online, I would have paid for online classes…I normally work in the university library because the network and connectivity where I live are not good …I don't even have a laptop…I thought I would use the university computers at the campus for my assignments…it is expensive working online from home…I do not have the money for this…"
What are your perceptions and experiences of using the Learning Management System (Moodle) during the COVID-19 pandemic?	Cameron: "…Moodle was a big problem for me…I came back to studying after a few years…I forgot my password…it took the university a long time to help me with my password problems… I started attending lectures late in the semester…I had a lot of work to catch up on…if it were not for the class's online support, I would have been in big trouble completing my work…it was very stressful for me…" Glenda: "…Moodle gave me trouble from the start…I always took a long time to get onto Moodle…the university also had something called Global Protect, which I needed to be on before logging onto Moodle…this was difficult since the connectivity in my area was slow and unreliable…the university must use a more user-friendly system for us students…" Linda: "…I used Moodle a long time ago for my first degree…I know how to use it, but the university made changes, and we had to migrate to a new platform…this was difficult, and then we could not see our modules…I had to catch up

	because I started attending my lectures late…I even did not know when we had the lectures…lucky for me, we had the online group, which helped me a lot..." Lungi: "…sometimes because most of the class were having problems with Moodle, if I used the discussion group, it took a long time for others to respond…I then used WhatsApp to ask for help…Moodle is only good for submitting our assessments…it is not good for online discussions…." Thuli: "…Moodle was ok…I knew how to use it, but the class hardly looked at the questions on the discussion group, so I could not get help there…it was a challenge for me to use Moodle to discuss the math questions that I had problems with…" Rakesh: "…hard…took me time…found I was replying to old discussion questions…I felt like the Moodle discussion group wasted my time and effort…the university must relook at this system…it does not work for all of us…"

From the interview transcripts, it was evident that when using the different online platforms, the use of the university's official Learning Management System (Moodle) and while studying remotely/online during the COVID-19 pandemic, participants experienced many challenges. The results of this study are discussed in more detail in the following section.

5. Discussion

5.1. Strengths of using technology-based pedagogy during the COVID-19 pandemic

Figure 1 represents the percentage of participants who explained the strengths of using technology-based pedagogy during the COVID-19 pandemic. From Table 2, it was evident that the participants' responses indicated that the WhatsApp platform, when used as a technology-based pedagogy, was efficient for obtaining instantaneous responses and provided a means of quick communication between peers and the lecturer. This view is supported by research [23; 24], which indicates that students value WhatsApp for quick collaboration and communicating thoughts and ideas. In this study, WhatsApp communication included both social and academic messages. Based on the excerpts as reflected in Table 2, creating a supportive and collaborative online community was beneficial for the participants.

Moreover, the increase in the use of cell phones allows lecturers to engage and interact with their students on a personal level [24]. This allows students to interact with their lectures from any location, thus providing them with dynamic learning [25]. The participants in this study appreciated the online mathematics support they received when the mathematics concepts and topics were discussed. Additionally, the participants mentioned the value of the social support they received online from their community of peers and the lecturer. During the COVID-19 pandemic, an online community was initiated to provide a social support structure for the participants. The participants' perceptions and experiences of this support structure are presented in Table 2. This view is supported by research [24; 26] which indicates that online social support is helpful and promotes the psychosocial quality of life.

Furthermore, the participants valued using the different technology-based tools and devices during the COVID-19 pandemic. The participants mentioned the Hovercam, an innovative technology-based device used during online teaching and learning. Research indicates that using innovative and dynamic digital devices is advantageous to online

teaching and learning groups [25]. This study shows that online technology-based pedagogy encouraged and founded cooperative interactions within the VCoP that was created [24; 27]. Based on the analysis of the interview data, it was evident that the participants received encouragement and motivation from members of the VCoP. Through shared interests and collaboration [24; 28], the participants worked together virtually. The participants incorporated the notions of a VCoP by participating online, sharing ideas and resources, and supporting other VCoP members virtually.

Also, during the interviews, the participants indicated that the VCoP promoted effective collaboration and engagement [24; 29]. In addition, the participants indicated in their interviews that when using the different online platforms, for example, WhatsApp and Zoom, the VCoP sustained and encouraged participants to acquire new knowledge. When the participants had challenges, they discussed these virtually with other community members. These interactions were apparent from the interview data. Thus, the virtual community of practice created for these participants provided an additional layer of academic, job-related, social and mental support for the members of the VCoP.

5.2. Challenges experienced when using technology-based pedagogy during the COVID-19 pandemic

Figure 2 represents the percentage of participants who indicated that they experienced challenges when using technology-based pedagogy during the COVID-19 pandemic. Based on the interview excerpts in Table 3, it was evident that the participants were first exposed to Zoom during COVID-19. They had not used this online platform previously. The participants indicated that they required time to prepare and practice using Zoom. Attending lectures and workshops via Zoom was a new experience for the participants. They required practice and initiated collaborative online engagement to navigate this platform successfully. Also, certain Zoom functions were reviewed during the workshops, requiring the participants to learn new skills during the second workshop. Thus, valuable teaching time was used during the second workshop due to reskilling participants and addressing procedural queries. To use online platforms successfully, participants required access to tools, devices and data. Some participants experienced some challenges, as shown in Figure 2. Participants were affected by unstable connectivity, issues with electricity shortages and limited access to the Internet. These challenges limited participants from participating equally with online technology-based pedagogy. Similarly, research [24; 30] suggests that students must have access to stable Internet connections to participate equally in online teaching and learning. However, many developing countries have facilities and infrastructure that are inadequate, which creates hurdles around access to the Internet and issues with unstable connectivity [24; 31].

Participants experienced many unforeseen expenses in the 2020 academic year due to the purchase of laptops, computers and data. Under normal circumstances, the research site offers the contact mode of teaching and learning, but like many HEI worldwide, this university initiated online teaching and learning due to COVID-19. Hence both students and lecturers needed to adapt quickly to this new way of teaching and learning.

Due to COVID-19, many people were forced to work from home. As a result, this created challenges for the participants since they constantly attended lectures with their families around them. As a result of studying at home, family duties were undertaken before the participants could start with academic work. It is evident from Table 3 that the participants had challenges when using Moodle. Previously, the participants did use the university's Learning Management System (Moodle). However, they did experience challenges with quick feedback and responses from their online community [24]. This online platform was also awkward and time-consuming to use. Based on the analysis of the online interviews, it was evident that the participants' challenges with access to data and devices affected their equal participation in online teaching and learning. The participants indicated that they needed access to technology-based tools, devices and the Internet to

engage equally and actively with online teaching and learning [30]. Similarly, research [24; 32] maintains that to promote and develop notions of independent learning, it is important for students to access the necessary and essential resources for teaching and learning.

6. Conclusions

This study aimed to explore postgraduate mathematics students' perceptions and experiences of using technology-based pedagogy during the COVID-19 pandemic. From the perceptions and experiences of the participants, it was evident that they had both strengths and challenges when using technology-based pedagogy during the COVID-19 pandemic. From the results and the discussion section, it was apparent that if the Virtual Communities of Practice's (VCoP) philosophies are incorporated within online teaching and learning environments, technology-based pedagogy may increase the advantages of meaningful online teaching and learning. The higher education environment for 21st-century pedagogy has changed, and higher education environments enriched with technology are encouraged. Notions founded on the VCoP framework endorse interactive, supportive and shared strategies. These strategies effectively reduce mathematics anxiety, support problem-solving in mathematics and promote student achievement. This was apparent for this study because traditional pedagogy was transformed to include technology-based pedagogy, and a collaborative and engaging technology-enriched VCoP was created. The VCoP that was created supported online teaching and learning. For this study, the participating students incorporated the notions of the VCoP. They interacted online, discussed, shared, and acquired new knowledge and resources.

This study concludes with recommendations for lecturers wanting to use technology-based tools, devices and pedagogy post-COVID-19. Firstly, the difficulties of using technology-based pedagogy during COVID-19 are essential for lecturers to be aware of. To avoid these challenges, the lecturer must check with their students if they have the essential technology-based tools, devices and Internet data. To further improve on the challenges mentioned in this study, lecturers should test the online resources to see if they are indeed accessible, economical to use, and user-friendly. One way to establish this is for lecturers to practice using online resources to understand better the amount of data used and the time required to download this information. This will assist the lecturer in informing the students about the data and time requirements for downloading these resources.

Secondly, when planning online lectures and workshops, lecturers must remember that their students have personal responsibilities. Thus, online lectures and workshops should be held at suitable times, and these lectures should be recorded and uploaded so that students can view these when they are available. Lecturers should make time available to allow for flexible online consultation if students require additional support.

Thirdly, the advantages of the VCoP created to support students when studying remotely/online during the COVID-19 pandemic were important. The participants in this study engaged with members of the VCoP and expressed the value of their interactive and supportive online discussions. Through this support and interactions, the participants were helped during online teaching and learning. Lecturers ought to recognise that students are sociable, and they need to communicate and socialise with other community members and provide and receive feedback and support. As was evident from the results of this study, the members of VCoP discussed academic work, family issues, and issues related to COVID-19, and the community members also supported each other with the job-related issues. It is important to understand that students need to communicate, collaborate, discuss and interact with others during the pandemic to support them socially and emotionally. This supportive VCoP, as discussed in this study, provided an important resource that may also be implemented when using technology-based pedagogy post-COVID-19.

Finally, the results of this study reveal that for the successful use of technology-based pedagogy post-COVID-19, professional development workshops for lecturers are needed.

~~These workshops are needed~~ to support lecturers in effectively using technology-based pedagogy to support and enhance their pedagogy in online environments. These professional development sessions would be advantageous to lecturers on a global level as we focus on sustaining education post-COVID-19. Due to the global importance of this study, more research on a larger scale involving other national and international higher education institutions could provide different perceptions and experiences of using technology-based pedagogy. These further research studies may also reveal additional perceptions and experiences of students in general and perceptions and experiences of mathematics students specifically on using technology-based pedagogy. The results, discussions and implications for this study will enhance knowledge in the field. This enhanced knowledge will be advantageous to the global field as we integrate technology-based pedagogy to promote sustainable education post-COVID-19.

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