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Abstract: Higher Education Institutions have adopted technology-based teaching methods to prevent the spreading of the contagious coronavirus (COVID-19). In the Fourth Industrial Revolution (4IR) era, technology-based teaching methods are indispensable for scaffolding teaching, learning and assessment. Mathematics is an important discipline in education, and provides a basis for problem solving, critical thinking and analytical skills, which is important to consider when focusing on sustainability. Thus, to add knowledge to the field about integrating technology-based teaching methods in mathematics, Higher Education environments during and post-COVID-19 need to be interrogated. This added knowledge is be valuable in the 4IR era post-COVID-19 for sustaining mathematics in Higher Education. This study explored participants’ experiences, views, implications and suggestions for technology-based teaching methods for mathematics. These participants (N = 45) were postgraduate students and mathematics school teachers at the research site in KwaZulu-Natal, South Africa. The research location for this qualitative study was a South African Higher Education Institution, and the study was conducted during the COVID-19 pandemic. The Community of Inquiry theoretical framework and the Substitution, Augmentation, Modification and Redefinition (SAMR) theoretical model guided this study. Participants were invited to two interactive online workshops. At these workshops, participants were introduced to different technology-based teaching methods. Then, they were invited to individual online interviews. The findings of this study suggest important experiences, views and suggestions for using technology-based teaching methods in Higher Education mathematics contexts in the 4IR era. These findings provide important implications and further research possibilities for embedding sustainable mathematics in Higher Education in the 4IR era, post-COVID-19.

Keywords: community of inquiry; fourth industrial revolution; learning; mathematics higher education; SAMR; sustainability; teaching methods; technology

1. Introduction

The COVID-19 pandemic forced Education Institutions worldwide to swiftly transition to using technology-based teaching methods. These teaching methods involve using technology-based devices, tools and platforms for teaching, assessing and learning. As such, they are excellent teaching methods for controlling the fast-spreading COVID-19 disease [1]. Technology-based teaching methods refers to using technology-based devices, platforms and tools for teaching, assessing and learning. In this study, these teaching methods incorporated cell phones, the Hovercam, PowerPoint presentations, videos, computers, Microsoft Teams, Zoom, WhatsApp and Moodle/Learn 2021. The Hovercam is a portable device linked to a computer. The lecturer can use the Hovercam to display...
and project information and material in real time as the lecture progresses. The Hovercam can also be used to enlarge pictures, resources and images as the lecture progresses, and it may be used to record lectures. The participating university changed the name of its official online learning platform from Moodle to Learn 2021 during the COVID-19 pandemic. These teaching methods and platforms allowed lecturers and students to use multiple innovative strategies to communicate, discuss and share ideas, information and knowledge.

In the era of the 4IR, lecturers and students must adapt to integrating technology-based devices, platforms and tools for teaching, assessing and learning [2]. Technology is transforming rapidly, and research [3,4] shows that technology-based teaching methods can support the face-to-face contact-based teaching methods typically used at educational institutions. Educational environments that embrace the 4IR encourage teaching, assessing and learning that supports collaboration, group work, peer teaching, critical thinking and interactive problem-solving techniques while using technology-based devices, platforms and tools [5–8].

Thus, the COVID-19 pandemic has revolutionised teaching and learning globally, making it necessary to explore different forms of pedagogy to ensure the endurance and quality of education. Additionally, in the era of the 4IR, technology-based pedagogy has advanced, leading to transformed teaching and learning. Mathematics is an important discipline in education, and using technology to teach mathematics can considerably impact learning outcomes [9]. Mathematics also provides a basis for problem solving, critical thinking and analytical skills, which is important to consider when focusing on sustainability [10]. Within this context, this study aims to explore how sustainable mathematics higher education may be embedded in the 4IR era post-COVID-19. For this study, technology-based devices, platforms and tools included audio, pictures, presentations, videos and texts to scaffold teaching, assessments and learning [11]. This study showed that technology-based teaching methods advanced the successful teaching, assessment and learning of mathematical content and essential mathematical skills. However, challenges were apparent due to electricity cuts, unstable internet connections and load shedding. Load shedding is a planned interruption in the electricity supply in South Africa to avoid an excessive overload in the electricity grid. South Africans have been provided with a schedule of load shedding times in each area. Nevertheless, the lecturers used technology-based devices to add teaching, assessing and learning resources onto technology-based platforms to support and encourage sustainable learning [12–14].

Teaching and learning are the foundation of education [15]. In the context of sustainable mathematics education, it is important to explore pedagogy that encourages students’ critical thinking. Moreover, in the era of the 4IR, it is important to explore how technology can be integrated within pedagogy to support decision making and critical problem solving [16]. For embedding sustainable mathematics higher education in the 4IR era post-COVID-19, applying mathematics knowledge and skills to solving real world problems is important. Furthermore, within the era of the 4IR, online collaboration enables the sharing and exchanging of ideas to promote sustainable mathematics education [17]. Thus, this study focuses on how technology-based teaching methods support critical thinking, problem solving and decision making. Participants in this study collaborated within a technology-based online environment to solve real world problems. Consequently, the study aimed to answer the central research question: In the era of the 4IR, what are postgraduate students’ experiences of and implications for technology-based teaching methods for embedding sustainable mathematics in higher education post-COVID-19?

The article is organised as follows: Section 1 introduces the study, and Section 2 provides an overview of the literature reviewed. This section includes discussions on sustainable mathematics education, higher education, technology-based teaching methods for mathematics, the community of inquiry (CoI) theoretical framework and the substitution,
augmentation, modification and redefinition (SAMR) theoretical model. Section 3 provides an overview of the study’s materials and methods. This section includes discussions on the background of the study, participants, pilot study, main study, online workshops, semi-structured online interviews, data analysis and ethical considerations. In Section 4, the results of the study are presented. This section presents results based on the participants’ experiences of social, teacher and cognitive presence within a technology-based online environment. In addition, the manner in which the lecturers enhanced and transformed teaching and learning using technology-based teaching methods is discussed. After that, the findings of this study concerning the implications of technology-based teaching methods for embedding sustainable mathematics education post-COVID-19 are presented. Section 5 presents the discussion based on the analysis of the findings. The last section, Section 6, presents the conclusions. This section summarises the major findings, limitations, implications and future research possibilities.

2. Literature Review

2.1. Sustainable Mathematics Education

Sustainable Development Goals (SDGs) refer to global goals developed by the United Nations aligned with the 2030 Agenda for Sustainable Development [18]. These goals deal with social, environmental and economic problems that occur globally. The goals include addressing issues of education, hunger, poverty, clean energy, gender equality and climate change [19]. For countries to achieve and address these goals, there is a need for collaboration between various stakeholders, including government, communities, different organisations, businesses and society members. Following and achieving these goals will help countries attain sustainable development.

Although sustainability is generally linked to economics or ecology, it also applies to education [20]. Sustainable development in education is being encouraged in many countries to align with the SDGs, and for mathematics, activities and materials are being developed to affirm that they are relevant and useful to the teacher and student [21]. Sustainability for mathematics education refers to approaches to teaching, learning and assessing mathematics that results in relevance, effectiveness and environmental responsibility. Moreover, mathematics teaching aims to encourage and support students’ understanding and development of critical mathematical thinking, which involves solving challenges and problems related to the real world [10]. This approach to teaching and learning mathematics includes integrating beliefs about sustainability into mathematics pedagogy and curriculum development. Considering real-world-relevant issues involves the need for students to understand the impact of resource management, environmental pollution, climate change and their link to mathematics education.

Thus, mathematics education is being transformed towards encouraging sustainable thinking and practices and being mindful of the environment to ensure that students and teachers are cognisant of the global situation [21]. Thus, for sustainable mathematics education, key concepts include teaching and learning relevant real world issues, critical thinking, problem solving, recognising key relationships, making connections with decisions, integrating mathematics pedagogy with other disciplines, integrating technology within pedagogy, being aware of one’s responsibility to the environment, considering the long-term effects of mathematics decisions and being aware of ethical considerations of mathematics decisions being made [10].

Furthermore, considering the practical applications of mathematics to real world issues encourages critical thinking and knowledge development, improves values, advances empathy, and promotes the sharing of ideas [22,23]. In this way, students can recognise the relevance of mathematics decisions. In addition, students need to understand mathematical concepts and the relationships between these concepts so that they can make meaningful and informed mathematical decisions for future sustainable develop-
ment [20]. Thus, there is a need for cooperation and collaboration between key stakeholders to encourage sustainable mathematics education. Within the education domain, these key stakeholders include policymakers, curriculum designers and implementers of the curriculum. Hence, government departments, education departments, politicians, higher education institutions and lecturers must develop and design curriculum material and activities to empower students to learn relevant and real world mathematics and actively participate in creating a more sustainable future.

Therefore, to sustain mathematics education in the future, teachers of mathematics need to use novel sustainable pedagogy and structure problems and activities differently [10]. It is also important for designers of curriculum material and activities to think carefully about how the material is presented to make it more accessible and understandable for all users [20]. We are in the early phases of choosing and classifying principles of sustainable mathematics for Higher Education [24]. Hence, it is important to research to add knowledge to the field so that more information is available to make these important decisions about mathematics curriculum design and delivery. Therefore, there is a need for the current study.

2.2. Higher Education in the Fourth Industrial Revolution Era

Traditional Higher Education institutions face many challenges, including the rapid shift to online or blended technology-based teaching and learning [25, 26]. This results from teaching and learning within the Fourth Industrial Revolution, requiring a transformation in traditional educational environments [5]. The Fourth Industrial Revolution (4IR) is best explained as the integration of technology, computers and the physical world to create a comprehensive united society that has transformed our existence [27]. Research [3, 28–30] proposes that the 4IR depends on technology, the Internet of Things (IoT), technology-based platforms, robotics, technology-based tools, artificial intelligence (AI), technology-based devices and virtual reality (VR). Technology is essential to education and has transformed all levels globally [31, 32].

Consequently, within Higher Education, educational institutions must adapt so that lecturers and students can grasp critical thinking skills and flexibility for future success in the 4IR [32–34]. Adapting teaching and learning is an important development in Higher Education [11]. Moreover, when adapting learning, it is important to encourage communication and collaboration skills [35, 36]. Hand in hand with these transformations in Higher Education is a need to link formal content knowledge with real world knowledge [37, 38]. Teaching, assessment and learning should be authentic and applicable for students, so that the link between what they learn in the formal educational context and how this knowledge is connected to the physical world around them is distinct [39–41].

Moreover, students and lecturers must be familiar with teaching, assessing and learning by using technology-based teaching methods, tools and devices. Lecturer expertise in using technology-based teaching methods is important. Transforming to technology-based teaching methods supports the teaching, assessing and learning processes. This allows complex lecturer and student interaction levels to scaffold meaningful and sustainable learning [12, 42]. Using technology-based tools, devices and platforms may enrich traditional teaching methods since activities that integrate technology encourage students to succeed as they collaborate, interact and participate on a universally linked platform [43, 44].

2.3. Technology-Based Teaching Methods for Mathematics Higher Education Post-COVID-19

Using technology-based teaching methods, resources and devices is more affordable and widespread in the 4IR and has transformed how we work, think and live [45, 46]. Education institutions throughout the world are shifting towards using technology-based devices for blended teaching, assessing and learning modes [31, 32]. Although technology has improved society, not everyone is a competent technology user [47]. Moreover, not all
students can access technology-based tools, resources, platforms or devices in South Africa. Access is necessary to participate equally in a technology-based education environment. In this study, technology-based tools, platforms and resources are technology-based devices used to scaffold teaching, assessment and learning in mathematics Higher Education lecture rooms. These include, among others, the computer, the Hovercam, the interactive whiteboard, the overhead projector, Zoom, Microsoft Teams, WhatsApp and the document camera.

Technology-based resources, tools, platforms, devices and websites may scaffold technology-based teaching and learning [48]. However, to integrate technology-based teaching methods effectively in Higher Education institutions, lecturers must have sufficient knowledge and skills to use technology-based teaching methods successfully [49]. Thus, lecturers must select the most appropriate and easily accessible tool, device, resource or platform to promote effective teaching, assessment and learning. Therefore, when designing technology-based lectures, these lecturers must be accustomed to the technology-based devices, tools, platforms and resources selected to provide adequate support to promote students’ understanding [50].

For mathematics education, using graphical calculators, computers and mathematics software programmes (e.g., Sketchpad and GeoGebra) for communication, representing information and problem solving has increased [51,52]. Before COVID-19, much research [49,53–58] was done on using technology, online courses, online resources and online platforms for teaching, learning and assessing mathematics. In the COVID-19 pandemic era, more research [4,8,59–61] has been conducted and has revealed that lecturers and students are concerned about the strengths, challenges and limitations of using technology for teaching mathematics education. Moreover, research has been carried out on the feasibility and effectiveness of online platforms, resources and devices for technology-based teaching, assessment and learning [62–64].

In the COVID-19 pandemic era, Higher Education Institutions (HEIs) experienced challenges and strengths when using technology to teach, learn, and assess mathematics education [1,8,25]. Moreover, to support students’ learning in Science, Technology, Engineering and Mathematics (STEM), one must understand how best to engage students’ interests by personalising their learning [26]. Consequently, technology-based teaching methods are the foundation for embedding sustainable mathematics education post-COVID-19. Thus, this study focuses on adding knowledge about integrating technology-based teaching methods in mathematics in Higher Education environments during and post-COVID-19. This added knowledge would be valuable in the 4IR post-COVID-19 for sustaining mathematics in Higher Education. Accordingly, this study will add to current research to advance notions of sustainable mathematics in higher education post-COVID-19.

2.4. Community of Inquiry Model

In the era of the 4IR, students are expected to use technology-based devices, platforms and tools when learning within online or blended environments [65,66]. However, when using technology-based teaching methods, lecturers must carefully consider integrating technology to enhance students’ learning [44,67]. The first theoretical framework used to frame this study was the community of inquiry’s (CoI) theoretical framework model. Garrison [68] established this model for online learning contexts. The model is based on ideas around cognitive, social and teaching presence, as depicted in Figure 1.
As evident in Figure 1, the CoI model’s overlapping components reinforce the development of blended, hybrid and online courses with active education settings or communities [68]. These active education settings depend on students and lecturers sharing and collaborating on knowledge, ideas and views. Thus, social presence (SP) is how students and lecturers communicate and interact within an online learning environment [70]. For this study, social presence (SP) was evident during both interactive workshops. The teaching presence (TP) was evident during the facilitation of both workshops. The cognitive presence (CP) was evident when completing and uploading tasks using technology-based platforms such as Moodle/Learn 2021.

Within the domains of the CoI model, aspects of TP indicate the quality of instruction [71], and ideas around CP refer to significant learning via online knowledge building and collaboration [72]. In this study, the participants’ educational experience was supported by lecturers selecting the relevant material and supporting discussions using technology-based platforms. In this way, students could access different learning resources independently [73]. In addition, the participants’ educational experience was enhanced by lecturers preparing participants for active online interactions by setting a suitable climate for engagement and interaction via technology-based platforms. Students interacted risk-free in a safe online teaching and learning environment [74]. These interactions between students and the lecturer were evident in WhatsApp, Zoom chats and the Moodle/Learn 2021 discussion forums.

Within the ambit of this study, the CoI model was relevant and provided a scaffold for technology-based teaching methods since high interaction and communication were evident via technology-based platforms and discussion forums. Thus, the overlap between the SP, TP and CP components led to the educational experiences that the participants discussed during the semi-structured online individual interviews. Moreover, the community of inquiry model was used to interrogate and analyse the data collected to explore the consequences of technology-based teaching methods for embedding sustainable mathematics in 4IR Higher Education contexts post-COVID-19.

Figure 1. The concepts of the community of inquiry model were adapted from [69] (p. 6).
2.5. The Substitution, Augmentation, Modification and Redefinition Theoretical Model

The second theoretical framing used in this study was the Substitution, Augmentation, Modification, and Redefinition (SAMR) model [75]. This theoretical model guided the data analysis process in this study. The SAMR model offers four techniques for incorporating technology-based tools into teaching and learning. With substitution, technology-based teaching tools may substitute traditional teaching tools with no apparent purposeful modification. Augmentation refers to when technology-based teaching tools are used to improve teaching and learning activities. Modification refers to when using technology-based teaching methods suggests the need for extensive restructuring of teaching and redefinition; using technology-based teaching methods completely transforms traditional teaching [76]. The SAMR theoretical model can be quickly adapted to the educational environment [77].

For this study, the SAMR model assisted in exploring how technology-based teaching methods supported teaching and learning. Thus, when using this theoretical model, the enhancement tools for teaching and learning are substitution and augmentation [78]. The transformation tools for teaching and learning are modification and redefinition [79,80]. As a lesson preparation tool, it empowers academics to design, advance and incorporate technology-based tools and pedagogy within the educational environment. For this study, the two interactive online workshops and the online semi-structured interviews assisted in exploring the technology-based teaching methods as possible strategies for substitution, augmentation, modification or redefinition.

3. Materials and Methods

3.1. General Background

This article reports on a study focusing on the views and suggestions for technology-based teaching methods for embedding sustainable mathematics in Higher Education in the 4IR era, post-COVID-19. This qualitative study uses an interpretive approach to analyse the data generated. Data were generated from participants at one Higher Education institution (HEI) in South Africa. This HEI usually offers contact-based teaching, learning and assessment. However, during the COVID-pandemic era, this institution’s teaching, learning and assessment were conducted online. The HEI provided essential devices and resources for staff and students to assist students and staff during the rapid shift to online teaching and learning. Thus, the participants in this study had access to a laptop and data packages. In addition, students and lecturers had access to zero-rated websites at the participating HEI. These zero-rated websites included the online platforms and websites used in this study.

This HEI was purposively selected due to convenience and access. Both researchers lecture at this institution. The participants in this study were postgraduate mathematics Higher Education students and practising mathematics teachers at schools in KwaZulu-Natal, South Africa. Participants were purposively selected for convenience since these participants were taught or supervised by the researchers. Data generation for this study included two interactive online workshops and a semi-structured individual interview with selected participants. Data for this study was generated over one semester (14 weeks).

3.2. Participants

Before the study commenced, participants were sent a comprehensive informed consent form that details the research process. The choice to withdraw from the study without prejudice was discussed with the participants. Participant coding was used to ensure participants’ anonymity, confidentiality and privacy. The sample population was postgraduate mathematics Higher Education students. These students were also teachers of mathematics at schools in KwaZulu-Natal, South Africa. Forty-five participants were invited to participate in the study. Thirty-eight (84%) participants agreed to participate in the
study (17 male and 21 female). Eight participants (four female and four male) were selected at random to participate in the pilot study. The remaining thirty participants (13 male and 17 female) were participants in the main study.

3.3. Pilot Study

The pilot study improved the trustworthiness, validity and dependability of the interactive workshops and interviews. Access to the internet, data and electricity was limited because of load shedding in the locations of the participants. Consequently, the workshops lasted longer and had many interruptions due to these challenges. To limit challenges in the main study, the times and dates of the online workshops were negotiated with the participants to eliminate the challenges during the pilot study. Also, the workshop and interview questions were revised collaboratively with pilot study participants and colleagues in the mathematics Higher Education field. This was done to enhance the reliability of the research instruments and research process.

3.4. Main Study

Thirty participants (13 male and 17 female) participated in the main study. The data generation phase included a semi-structured individual interview and two interactive online workshops. The workshops and interviews were planned collaboratively with the participants to eliminate the challenge of scheduling the workshops and interviews during load shedding times. Twenty participants were purposively selected to be interviewed (9 male and 11 female). Participant coding protected each participant’s identity, confidentiality and privacy. The participant coding used in this study was as follows. Participants were coded in the order that they were interviewed. For example, the first postgraduate mathematics education student (PMES) interviewed was coded as PMES 1, and the sixth postgraduate mathematics education student (PMES) interviewed was coded as PMES 6.

3.5. Online Workshops

Two online workshops via Zoom and Microsoft Teams (digital platforms used at the participating university) were conducted with the PMESs for this study. The researchers facilitated these workshops. Before each workshop, the participants were emailed content material, sample questions, group work assessment tasks, individual assessment tasks, PowerPoint presentations and examples of online resources and websites focusing on the content under study. The participants were also provided with information and resources about using technology-based teaching methods in online mathematics education environments. The researchers shared information and resources with PMESs about using technology-based platforms, for example, WhatsApp, Microsoft Teams, Moodle/Learn2021 and Zoom.

For this study, the first workshop focused on Information and Communications Technology (ICT) and ICT pedagogical practices in mathematics education. The second workshop focused on misconceptions in mathematics education. Subsequently, after the second interactive workshop, all participants were invited to participate in the semi-structured online interviews (Microsoft Teams, Zoom and WhatsApp). The PMESs could select which technology-based platform they wished to be interviewed on.

3.6. Semi-Structured Online Individual Interviews

The semi-structured individual online interviews focused on exploring PMESs’ experiences of technology-based teaching methods for mathematics. Online interviews were conducted via Zoom, Microsoft Teams and WhatsApp chats. The researchers asked participants questions; if a further explanation were required, the researchers would explain further or probe participants’ interview responses. Each semi-structured interview began with general questions to allow each PMES to feel comfortable during the interview. Each interview was approximately 45 min long. PMESs were allowed to keep their videos on
or off, depending on their internet connectivity and preference. The online interviews then advanced to specific questions focusing on the PMEs’s experiences of technology-based teaching methods for mathematics education. The interview process took five weeks since the interviews were scheduled based on the participants’ availability and the load shedding schedules.

During the individual semi-structured interviews, participants were asked questions based on their experiences with technology-based teaching methods for mathematics education. The semi-structured interviews focused on the following key questions:

- What are your experiences of social presence within a technology-based online environment?
- What are your experiences of teacher presence within a technology-based online environment?
- What are your experiences of cognitive presence within a technology-based online environment?
- What do you think are the implications of technology-based teaching methods for sustainable mathematics education post-COVID-19?

At the end of each semi-structured individual online interview, participants were asked to peruse their responses and revise or add further information where necessary.

3.7. Data Analysis

Qualitative data analysis started by first interrogating participant responses to the semi-structured interview questions. Secondly, similar responses were collated and grouped. Thirdly, major themes were constructed. Finally, the study’s theoretical frameworks, i.e., the Community of Inquiry model (CoI) and the Substitution, Augmentation, Modification and Redefinition (SAMR) theoretical model, were used during data analysis. The relationship between the data generated and these theoretical frameworks was explored. To ensure the accuracy of the captured responses, member checking was conducted.

3.8. Ethical Considerations

Ethical clearance for this study was applied for and granted by the Research Ethics Unit at the participating university. Participants were provided with a comprehensive informed consent letter which the participants completed before the study started. Participant coding was used to ensure the confidentiality, privacy and anonymity of participants.

4. Results

4.1. Social Presence, Substitution and Augmentation

Participants indicated that technology-based teaching methods allowed them to interact, engage and collaborate with their peers and lecturers. For example, they had more time to discuss tasks and collaborate on problem-solving strategies for their online module. This was not what they experienced during face-to-face teaching and learning. Time and location were not a problem since participants could discuss and communicate online using WhatsApp and other technology-based platforms. These notions are expressed in the selected interview transcript excerpts in Table 1.
Table 1. Participants’ feedback about their experiences of social presence.

<table>
<thead>
<tr>
<th>Question</th>
<th>Feedback</th>
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<tbody>
<tr>
<td>What are your experiences of social presence within a technology-based online environment?</td>
<td>PMES 2: ...more time to work with the group online...we could share strategies of using technology in our classes...we could discuss and share tips about misconceptions we found...</td>
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<td></td>
<td>PMES 5: ...we could discuss at any time using technology and our phones...we did not have to wait for a specific time to follow the timetable...we had more interaction on WhatsApp...</td>
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<td>PMES 8: ...when we were discussing the different types of teaching we could do with technology...helpful that we could send pictures of ...resources...lecturer could provide instant information on what would work and what would be difficult to do with technology...this way made more sense to us, and we could understand the work better...</td>
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<td></td>
<td>PMES 12: ...we all had different ways to help the class with the mistakes and misconceptions section...easy to share online...feedback from the lecturer was quick...no need to wait for the next lecture time...using the technology supported us with our learning...this made understanding the work easier.</td>
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<td></td>
<td>PMES 15: ...had lots of fun talking and working with the class and the lecturer...technology made a difference...more discussion and communication by using WhatsApp...better than when we attended lectures at university...</td>
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<td>PMES 19: ...class participated ...sent a message or asked a question at least once...built a small online community using technology...chatted all the time...when we needed help, we shared information online...technology helped us with learning the work for this class...</td>
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</tbody>
</table>

Based on the selected excerpts, it is important to note that students and lecturers constantly communicated and interacted with each other within the online environment under study. The use of online devices augmented the teaching and learning process. Technology-based tools improved the traditional teaching and learning material. In addition, students and the lecturer substituted the printed material for online material and resources. Although there was no purposeful modification by providing online resources and material, teaching and learning were enhanced. These materials were used as enhancement tools and shared via WhatsApp and other online platforms. Thus, it was evident from the interview transcripts that technology-based platforms promoted social presence, substitution and augmentation for the current study.

4.2. Teacher Presence, Modification and Redefinition

Participants indicated that technology-based teaching methods allowed them more opportunities to engage with their lecturers. For example, they had more time to discuss the different ICT pedagogical tools and the misconceptions in mathematics education. The lecturer also created a safe online learning environment where students could interact risk-free. There was no fear of their ideas being dismissed or ridiculed. They generally had allocated time slots for consultation with their lecturers during face-to-face teaching and learning. Set consultation times were not scheduled when using technology-based teaching methods. Students could discuss challenges and misconceptions with their lecturers anytime using technology-based platforms. These views are evident in the following excerpts from the interview transcripts in Table 2.
Table 2. Participants’ feedback about their experiences of teacher presence.

<table>
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<th>Question</th>
<th>Feedback</th>
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<tbody>
<tr>
<td>What are your experiences of teacher presence within a technol-</td>
<td>PMES 4: ...more time with our lecturers...we could talk to them online at any time...they were always available for us...</td>
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<tr>
<td>ogy-based online environment?</td>
<td>PMES 7: ...even though we did not see our lecturers like when we went to campus...they were always there helping us with all the online systems...Moodle, Zoom, WhatsApp...</td>
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<td>PMES 9: ...we were not afraid to talk to each other or discuss ideas online...everyone listened and gave comments...no one made fun of us or laughed at us...we could share what we knew freely...</td>
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<td></td>
<td>PMES 14: ...when studying the content, I had problems understanding certain sections...I asked for help on WhatsApp...different students gave comments to help me...the lecturer provided advice and other online resources that assisted me...the Hovercam was very useful for explaining key concepts...I could ask for more help as I read the information...the lecturers provided advice at all times...even after lecture times...</td>
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<td></td>
<td>PMES 17: ...the workshop ...using ICT and the different strategies with ICT in mathematics was interesting...I learned new ideas to help me when I am teaching...the support from the lecturers was amazing...patient...helped me with my many questions...they were by my side all the time, even after the workshops...</td>
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<td>PMES 19: ...the other students and my lecturer helped me all the way with this module...I asked questions after hours since I am teaching during the day and have family responsibilities...no one complained when I asked for help late at night...the lecturers were always available to assist me...</td>
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</table>

The interview transcripts showed that the lecturers were present to support their students at all hours. Technology-based online environments provided students with a platform to continuously engage and collaborate with their lecturer for additional support and when they needed additional help. The lecturers modified and redefined current teaching methods to provide extra support. Traditional teaching was restructured, and extra teaching support was provided during teaching time using the Hovercam and other technology-based tools. In addition, extra teaching support was provided outside of traditional consultation times using WhatsApp and the Learn online platform, which increased teaching presence. Thus, in the current study, technology-based teaching methods transformed traditional pedagogy, allowing lecturers to increase their teacher presence and restructure and redefine their traditional teaching methods.

4.3. Cognitive Presence, Substitution, Modification and Redefinition

Participants indicated that technology-based teaching methods encouraged meaningful engagement, resulting in profound and critical thinking about mathematics education in general and problem solving in particular. For example, they had more time to reflect on their problem-solving strategies. They could debate different strategies and enhance their thoughts about misconceptions about mathematics education. During face-to-face teaching and learning, students had limited time to reflect in class, and often the debates and discussions did not result in meaningful learning. Encouraging meaningful learning and knowledge production was not limited by technology-based teaching methods but enhanced through technology-based platforms. These opinions are reflected in the following selected interview transcript excerpts in Table 3.
What are your experiences of cognitive presence within a technology-based online environment?

<table>
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<th>Question</th>
<th>Feedback</th>
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<tbody>
<tr>
<td>PMES 1: …the maths work was uploaded at the start of the semester…I had more time to look at what was expected…I had time to think carefully about each task…</td>
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<td>PMES 3: …I had the chance to discuss my thinking with the class and the lecturer…I discussed my steps for solving the tasks…as a group, we discussed online other problem-solving strategies…this helped me with my understanding, and I could see where the gaps were in my problem-solving…my thinking became clearer…</td>
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<td>PMES 6: …learning online is very different…I have more time to think carefully on my own…I then can talk to my class on WhatsApp…this helps to clear my thoughts…more serious about our work…before we would chat in class and not always about maths…now we can still chat, but we are not wasting anyone’s time…people can respond when and if they want to and if they are free…we share ideas freely…</td>
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<td>PMES 11: …I found it better when we are working online…I can use my time wisely…I can think more carefully about what we are studying when I am on my own…then when we discuss as a group…we learn from each other…we debate with each other…maths makes more sense when we discuss openly…</td>
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<tr>
<td>PMES 18: …sometimes when we attended usual lectures…discussions were not focused …we were always distracted by someone…online discussions are more focused and helpful…we think more clearly…we gain more knowledge from discussing using Zoom or WhatsApp…</td>
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</tr>
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</table>

The interview data showed that technology-based teaching methods encouraged participants to think, reflect and debate their ideas and problem-solving strategies. Thus, cognitive presence was visible via online knowledge building and collaboration. The interview excerpts show that the participants engaged with each other and their lecturers freely within the technology-based environment. In addition, lecturers substituted traditional handouts for uploaded material and resources. This allowed students more time to think about the resources and activities. In this way, the lecturers modified and redefined their traditional pedagogy. Also, when students engaged and collaborated on problem-solving activities outside of teaching time, this showed a restructuring of traditional teaching and learning. Thus, technology-based online environments provide students and lecturers with a flexible teaching and learning platform. This flexibility encouraged cognitive presence and revealed evidence of a transformation of traditional pedagogy.

4.4. Implications of Technology-Based Teaching Methods for Embedding Sustainable Mathematics Education Post-COVID-19

Participants indicated that technology-based teaching methods encouraged sustainable mathematics education. They believed that technology-based teaching methods would be popular post-COVID-19. The important lessons learned when using technology-based teaching methods during COVID-19 would support students and lecturers to improve on technology-based teaching methods post-COVID-19. This would support the notion of embedding sustainable mathematics education for the future. These ideas are evident in the selected interview transcript excerpts in Table 4.
Table 4. Participants’ feedback about the implications for sustainable mathematics education post-COVID-19.

<table>
<thead>
<tr>
<th>Question</th>
<th>Feedback</th>
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<tbody>
<tr>
<td>What do you think are the implications of technology-based teaching</td>
<td>PMES 3: ...using technology to teach even after COVID-19 would benefit...already familiar with this...know what the problems are, and we can solve them as we go along...</td>
</tr>
<tr>
<td>methods for sustainable mathematics education post-COVID-19?</td>
<td>PMES 7: ...I think it would be easy to work with online lectures...we can use a blended approach...we need to move with what is current...the Hovercam would be very helpful to students...everyone is working with technology and working online...</td>
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<td></td>
<td>PMES 10: ...we learnt many valuable lessons during COVID...need to use what we learnt to improve online or blended teaching...</td>
</tr>
<tr>
<td></td>
<td>PMES 13: ...we cannot lose what we gained when using technology for teaching and learning...technology is important in society...we need to change how we think about teaching for the future...</td>
</tr>
<tr>
<td></td>
<td>PMES 16: ...we learnt a lot from how our lecturers used technology...we were discussing and debating freely using technology...it was the first time I worked with the Hovercam...this will be good for future lectures...even when we go to face-to-face...technology must also be used for lectures...hybrid teaching will be good...</td>
</tr>
<tr>
<td></td>
<td>PMES 20: ...good experiences and bad experiences with online learning...mostly good...learning and discussing online helped me with mathematics...the lecturers were always there to help...I could share with my class at any time...only because of the online method...not the same if we only use contact classes...we cannot lose this important method...we must continue working online for lectures...</td>
</tr>
</tbody>
</table>

As is evident from the preceding interview transcripts, participants indicated that technology-based teaching methods had challenges and strengths. However, based on the participant interview transcripts, the strengths outweighed the challenges. Thus, technology-based teaching methods would support and encourage sustainable mathematics education post-COVID-19. These views are explored further in the discussion section that follows.

5. Discussion

5.1. Converging Notions of the Community of Inquiry and the SAMR Model

Technology-based teaching methods were important in the current study and provided access to material, resources and support when students faced challenges [16]. In addition, technology-based teaching methods scaffolded teaching, assessment and learning in this study [32]. Within the ambit of the community of inquiry model, participants in this study worked in a risk-free and safe online environment [58]. Based on the participant responses, social presence was founded on online communication and interaction between students and lecturers [54]. As was evident from the selected interview transcripts, technology-based teaching methods provided opportunities for lecturer and student interaction. In addition, student-lecturer interactions encouraged meaningful and sustainable learning [12]. These findings are supported by research in the field [13,14]. The interactions showed a high level of social presence in this study. The lecturer and students engaged in clarifying misconceptions as well as scaffolding teaching and learning. These interactions indicate teaching quality and show evidence of teacher presence [55]. In addition, the lecturers enhanced teaching and learning by providing online resources and handouts. Students had more time to engage with the material and activities. Thus, technology-based tools in this study augmented teaching and learning activities [78]. These findings are supported by research in the field [25,34].
Moreover, teaching activities were restructured and modified to create more online collaboration and problem solving opportunities. Technology-based teaching tools and platforms, for example, the Hovercam and the online Learn platform, supported both the students and the lecturers to modify and redefine traditional pedagogy. In this way, technology-based teaching methods transformed traditional pedagogy [79,80]. Thus, using technology-based teaching methods improved access to information, and lecturer-led support was quick and easy. Consequently, technology-based teaching methods have transformed traditional teaching and learning [25,32,79].

Furthermore, the lecturers created a safe technology-based environment where students could interact freely with each other and with the lecturers [58]. Providing additional online resources for students who needed extra support created the opportunity for students to access resources at any time, which encouraged independent learning and enhanced teaching and learning [73,78]. For this study, it was also evident that the lecturers used technology-based devices to upload resources onto online platforms to encourage independent and sustainable learning [10,12]. Students were encouraged to work at their own pace to self-regulate their learning. Thus, the participants used technology-based devices and platforms for independent and collaborative learning within the technology-based environment [49,65]. These online engagements stimulated thinking and the sharing of problem-solving strategies. This showed cognitive presence, since significant learning, knowledge building, and collaboration occurred using technology-based teaching methods [72]. The evidence of cognitive presence for the current study showed that students used technology-based teaching methods to scaffold their learning, promoting knowledge building and independent learning.

5.2. Implications of Technology-Based Teaching Methods for Embedding Sustainable Mathematics Education Post-COVID-19

Participants believed that many important lessons were learned through technology-based teaching methods, and that using technology in education is essential [31,32]. The lessons gained regarding embedding sustainability for mathematics in Higher Education must not be lost. Adapting innovative pedagogic strategies is vital within Higher Education [26]. Using technology-based teaching methods enriches and enhances traditional teaching methods since activities that integrate technology encourage students to collaborate, interact and participate on technology-based platforms [43,44,78].

In the current study, participants implied that a blended or hybrid approach would benefit them post-COVID-19. These views support the view that sustainable mathematics education encourages sustainable learning [10]. These findings are supported by research in the field [10,17,23]. In addition, participants valued social and teacher presence and implied that this supported aspects of cognitive presence. Similarly, research [70–72] indicates that within the ambit of the Community of Inquiry model, social presence exhibited by interaction and communication within an online learning environment is supported by aspects of teaching presence and pedagogy that stimulate cognitive presence. Moreover, in the current study, it was evident that technology-based teaching methods provided the opportunity to enhance and transform traditional pedagogy [76]. Thus, technology-based teaching methods encourage learning via online collaboration and knowledge building.

6. Conclusions

6.1. Summary of Major Findings

Firstly, in this study, it was evident that lecturers provided various opportunities for students to interact, collaborate and discuss freely within the online environment. The social presence of both the students and lecturers was evident. This significant interaction and communication enhanced and transformed mathematics teaching, assessment and
learning. Thus, technology-based teaching methods in this study encouraged social interaction and the social presence of the community while enhancing and transforming teaching and learning in the online learning environment. This view conforms to the CoI and SAMR theoretical frameworks.

Secondly, this study’s findings suggest that the lecturer created a safe learning environment for the participants through technology. If clarification and further explanation were required, the lecturer was present virtually. Teaching presence scaffolded technology-based teaching and learning and transformed traditional pedagogy. The CoI and SAMR theoretical frameworks maintain that teacher presence is important for enhancing, modifying and redefining the quality of online teaching and learning.

Thirdly, this study shows that technology-based teaching methods supported meaningful engagement and enhanced critical mathematics thinking. Participants debated and discussed mathematical problem-solving strategies which stimulated meaningful learning and knowledge production. Strategies that encourage and develop cognitive presence are important for transforming teaching and learning. The philosophies of the CoI and the SAMR theoretical frameworks support this notion.

Lastly, it was evident in this study that the participants’ educational experiences inspired their acceptance of technology-based teaching methods. Participants valued technology-based teaching methods within the ambit of the COVID-19 pandemic. They believed that using technology for teaching and learning post-COVID-19 in the era of the 4IR would benefit students. This study revealed that technology-based teaching methods allowed for sustainable mathematics education. The lessons learned when using technology-based teaching methods during COVID-19 would support students and lecturers to improve and transform technology-based teaching methods post-COVID-19 in the 4IR era.

Thus, the findings of this study reveal the benefits of using technology-based teaching methods that advance social, teacher and cognitive presence for mathematics education. In addition, the findings of this study reveal strategies that the lecturers used to enhance and transform traditional pedagogy. These findings show how lecturers may use technology-based teaching methods for substitution, augmentation, modification and redefining their pedagogy. In addition, this study discussed the findings concerning teaching methods for embedding sustainable mathematics education post-COVID-19. However, limitations do exist.

6.2. Limitations

This study was a small study involving postgraduate mathematics education students at one Higher Education Institution. The findings may be specific to this selected HEI and the conditions experienced by its lecturers and students. It is important to consider that the choice of the institution and discipline being researched (mathematics education) was purposeful and based on convenience for both researchers. We also recognise that the participating HEI students were provided with laptops as part of an external funding initiative. In addition, all lecturers and students at this HEI had access to zero-rated websites. Access to zero-rated websites allowed lecturers and students access to information from these websites without using their data. These zero-rated websites included the online platforms that were used in this study. Moreover, every student and lecturer was provided monthly data packages during the COVID-19 pandemic.

Thus, the findings cannot be generalised for other HEIs with less favourable conditions. Therefore, we are not claiming that our findings are generalisable; rather, we argue that comparisons with research conducted at other HEIs with similar and different conditions can help lecturers and students to make more informed decisions about integrating technology for teaching and learning mathematics education. Thus, the findings of this study have implications for researchers, lecturers, students and HEIs involved in mathematics education.
6.3. Implications

Our findings highlight important lessons that should be considered to ensure the success of technology-based teaching methods in mathematics education nationally and internationally. The findings indicate that technology-based teaching methods are valuable for mathematics Higher Education post-COVID-19. These findings have implications for promoting the sustainability of Higher Education in general and mathematics in Higher Education in particular. Therefore, this study adds to the emerging knowledge concerning the implications of technology-based teaching methods for embedding sustainable mathematics in Higher Education in the 4IR era, post-COVID-19. Thus, the findings of this study have implications for HEIs, lecturers, students, curriculum designers and researchers in mathematics education.

There is a need to provide access and the necessary infrastructure for students to enable them to participate equally in blended and online education environments. Students from underprivileged backgrounds may not have access to reliable technology-based devices, tools, resources, internet connectivity or infrastructure. This intensifies existing inequalities in education and promotes the digital divide.

In addition, technology may be unreliable at times. Therefore HEIs need to provide technical support to lecturers and students to address technical issues. Technology cannot be integrated within educational environments without ensuring that lecturers are effectively trained to develop technology-based materials and activities that encourage active engagement and critical thinking. Thus, lecturers and students must have access to ongoing training opportunities to acquire the skills necessary to engage effectively in a technology-based educational environment.

The implications discussed here can be time-consuming, costly and resource-intensive for HEIs. Hence, HEIs need to consider partnerships with government departments, non-governmental organisations and businesses to secure funding to support their plans to alleviate the digital divide and provide ongoing development and training for lecturers and students. Moreover, the implications discussed signpost recommendations for future research possibilities.

6.4. Future Research Possibilities

Although this study was a small-scale study carried out at one HEI, the findings of this study are significant. The findings reveal the importance and relevance of this study for improving knowledge and responding to practical issues related to technology-based teaching of mathematics education post-COVID-19. The findings offer ideas for future research possibilities that address theoretical and practical considerations.

For example, comparative research can be conducted at different HEIs. This type of research will add to existing knowledge by offering new ideas or alternative perceptions based on evidence-based mathematics education research. Moreover, given the increasing demand and use of technology in educational environments globally, it is important to address issues of equity and inclusion. It is important to consider the consequences for students with limited access to technology-based tools, devices and the necessary infrastructure to participate equally in a technology-based educational environment. Research focusing on equity and inclusion of students to enable them to participate equally in an online educational environment needs to be conducted.

In addition, similar studies can be conducted using different methodologies or research designs, for example, using quantitative research instruments to generate quantitative data from a larger sample population. Thus, future research possibilities include qualitative and quantitative mathematics education research with other HEIs.

Furthermore, conducting a study to research the impact of technology-based teaching methods on student learning outcomes would be useful. For example, students’ performance can be analysed before and after using technology-based teaching methods. This
type of research will assist with measuring the effectiveness of technology-based approaches.

Also, future research opportunities may provide practical implications for policy development and decision making concerning technology integration within the mathematics education curriculum. Moreover, the findings of this study provide mathematics education lecturers with practical technology-based strategies that may improve student performance. Future research opportunities could include conducting research using other innovative technology-based pedagogy to improve active student engagement, learning outcomes and student performance in mathematics education.

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