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Learning first-year mathematics fully online: Were students prepared, how did they respond?

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Abstract

This paper reports on empirical results from a study that investigated first-year mathematics students' preparedness for, and response to, online learning. With the appearance of COVID-19 in 2020, lecturers were forced to make sudden changes to the established face-to-face learning environments, and students were expected to adapt to these changes. The idea of a blended learning environment is not new, and students globally have demanded flexibility in mathematics learning environments for some time. However, the idea of a sudden change in environments, particularly to fully online, was new to most lecturers and students. Key aspects in an online environment are students' ability to self-regulate their learning, and the availability and accessibility of technological resources. Quantitative data from the self-developed questionnaire were collected early in 2021, at a public university in South Africa, from a large sample over several modules. Results indicate students are partially prepared for learning fully online, with significant effect on performance.

Keywords: COVID-19, first-year mathematics students, online learning, performance, self-regulated learning, technological resources, tertiary education

INTRODUCTION

The arrival of COVID-19 in 2020 caused sudden and unprecedented changes to the higher education context, and the tertiary mathematics classroom was no exception (see, for example, Borba, 2021; Engelbrecht et al., 2020a, 2023; Parekh, 2021; QA Report, 2020). Almost instantly, blended and online learning moved from *important* to *essential* and lecturers were forced to make sudden changes to the established face-to-face learning environments, and students were expected to adapt to these changes (e.g., Durandt et al., 2022). Also, for some developing countries, like South Africa, the pandemic added to the pre-existing education inequalities (see Chirinda et al., 2021; Reddy et al., 2020). With the announcement of the national lockdown, many teachers (lecturers) did not have the same prior experience of an online environment and did not have the privilege of time to first learn how an online approach should be employed. A tongue-in-cheek name, 'panic-gogy' (for panic + pedagogy), was used to explain how teachers responded to the sudden change in learning environments (Kamanetz, 2020). 'Panic-gogy' refers to how teachers adapt their teaching approaches in a new environment, as well as an understanding of students' practical resources and problems (Engelbrecht et al., 2020a).

The idea of a blended learning environment is also not new to students, and globally students have demanded flexibility in mathematics learning environments for some time (e.g., Quinn & Aarão, 2020), but the idea of a sudden change in environments, particularly to fully online, was also unexpected to students. The question arises if all students, particularly in developing countries and in countries with pre-existing inequalities in education, could participate actively and meaningfully in online learning activities? Also, what challenges did they experience and was there a connection between these challenges and performance? In a student-centered approach, teaching should be based on what knowledge students need (Han, 2020); and, during the time of the national lockdown, most institutions focused on saving the

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Contribution to the literature

- Tertiary mathematics students in developing countries might have unequal scenarios related to the availability and accessibility of technological resources, and less flexibility to self-regulate their learning.
- Students with access to a smartphone and at least one other device perform significantly better when learning tertiary mathematics online than students with access to only a smartphone.
- First-year students' approach to solving tertiary mathematics problems, while studying online, has a significant effect on their performance.

academic year with the idea of leaving no student behind. In most cases, practices from teaching and learning with the old medium were simply applied to move to the new medium, but could students simply move to the new medium? The online offering mainly included the uploading of learning materials by lecturers (e.g., class notes, tutorial work, e-books), virtual lectures, and online assessments. We know that just replacing lectures with online versions might not work for mathematics (e.g., Trenholm et al., 2012). For students the shift to online teaching and learning, essentially, required the availability of dependable devices with fast and reliable connectivity.

Another key aspect in learning mathematics online is students' ability to self-regulate their learning. In an Australian study (before the arrival of COVID-19) regarding blended learning in first-year engineering mathematics, Quinn and Aaräo (2020) mentioned the issue that students might not have the skills needed to effectively self-regulate their learning. More flexibility in the way mathematics is offered provides more flexibility on the students' side and some students might misuse this flexibility to avoid mathematical studies with effect on performance. With the arrival of the pandemic, all students were forced to self-regulate their learning and lecturers had very little control. So, what did students do and how did they perform? We know from studies that a connection exists between effective online components (e.g., quizzes, online supporting material, and feedback through the online environment), students' self-regulated learning (e.g., learning conversations between lecturer and student) and positive learning outcomes (compare Acosta-Gonzaga & Walet, 2017; Laurillard, 2013; Quinn & Aaräo, 2020, and others).

The aim of the study reported on in this article was to investigate if first-year mathematics students from a developing country were prepared to learn fully online during the time of the COVID-19 pandemic. Furthermore, this investigation aimed to include key aspects, such as students' self-regulated study habits, as well as the availability and accessibility of technological resources that are essential for learning effectively in online environments.

The research questions informing this study were:

1. *What technological resources and devices were available to first-year mathematics students when learning fully online in 2021? And how did these resources influence their performance?*
2. *What self-regulated study habits did first-year mathematics students reveal during the time of learning fully online? And how did these habits influence their performance?*

Awareness of how prepared first-year mathematics students is for learning fully online, and the connection that might exist between students' availability and accessibility of technological resources, or self-regulated study habits and performance, could provide valuable information for the transformation of the mathematics classroom in developing countries. One hypothesis for this study is that first-year mathematics students are only partly prepared for learning tertiary mathematics fully online. This hypothesis is based on the expectation of substantial differences in the availability and accessibility of technological resources to students during the national lockdown, in both the grade 12 year (2020) and the first year at university (2021). A second hypothesis for this study is most first-year mathematics students lack self-regulated study habits while learning online. This hypothesis is based on former research reports from learning mathematics in blended environments (e.g., Quinn & Aaräo, 2020). We expect a moderate to strong connection between the availability and accessibility of technological resources, or self-regulated study habits, and performance.

This paper will report on relevant theoretical aspects, the self-developed questionnaire (largely informed by challenges reported by both lecturers and students during the time of the pandemic in 2020, see next section), and the results and discussion; it will end with concluding remarks.

THEORETICAL PERSPECTIVES

Aligned with our pragmatic aim for this investigation (see Creswell, 2013 for a clarification of a pragmatic approach to research), the following two underlining theoretical perspectives are relevant:

1. understanding learning of tertiary mathematics in online environments and the importance of digital tools and online resources, and
2. key aspects of self-regulated learning and study practices that are expected from students at the tertiary level.

Learning Tertiary Mathematics Online and the Role of Digital Tools and Online Resources

Already more than a decade ago Laborde (2007) discussed the role and uses of technology in the teaching and learning of mathematics. The study focused on the secondary level within the topic area of dynamic geometry and results show a relationship between mathematical knowledge and the way technology is used, between students and technology, and between teachers and technology. One inference from the study is that the integration of technology should result from long-term work considering all dimensions and role players and should not merely be an inclusion of technology in all circumstances. During the time of the pandemic this was not possible.

Before the arrival of COVID-19, the work from Engelbrecht et al. (2020b) regarding the transformation of the mathematics classroom with the growing use of the internet in educational contexts already emphasized the importance of digital tools and online resources. In this pre-COVID-19 era, educators mostly tried to follow a student-centered approach by investigating blended learning approaches and incorporating technology in the mathematics classroom that can make a difference to students' presage factors (e.g., mathematical anxiety) and improving performance. One example is the study from Quinn and Aaräo (2020) focusing on learning first-year mathematics in blended learning environments. The initial idea with the introduction of blended learning environments at the tertiary level was to enrich and improve efficiency in traditional face-to-face teaching by making minor changes to pedagogy, and this was usually done by adding resources and supplementary materials. We also know that learning outcomes in mathematics courses can be improved by online learning tools that automate key learning conversations and effective learning activities (Quinn & Aaräo, 2020). However, the changes between environments are challenging, specifically if the intention is to create a rich and effective domain and both, educators and researchers, are still experimenting with the ideas. On the one side the pandemic made all role players (administrators, lecturers, tutors and students) more aware of the possibilities of digital tools and online resources, but on the other side pushed everyone towards implementation, even if that implied teaching and learning in an unfamiliar territory.

A body of literature exists on the theoretical aspects related to the integration of digital technologies and the challenges of constructing effective online learning environments for mathematics education (e.g., Borba & Villareal, 2005; Drijvers et al., 2009; Healy et al., 2010). One example from a Brazilian study (Healy et al., 2010) is associated with the complexity of introducing new artifacts into the mathematics classroom. It seems that teaching and learning mathematics online can result in new mathematical practices and hence can alter mathematics as a knowledge discipline. Also, by including new artifacts into the mathematics classroom students' learning processes should be investigated. The intention from lecturers might be to give equal opportunities to all learners, but some students might not be able to adapt easily to the new scenario.

In building a learning environment for distance or online education, three main strands are important (Borba et al., 2016; Engelbrecht et al., 2020b, p. 827):

(1) *principles of design*,

(2) *social interaction and construction of knowledge*, and

(3) *tools and resources*.

However, in this paper we do not report on design elements, nor an in-dept discussion on suitable theoretical frameworks, instead if students had the technological resources to easily access the material online and participate regularly in learning activities.

Characteristics of Self-Regulated Learning at University

Self-regulated learning can be defined as "an active, constructive process whereby learners set goals for their learning and then attempt to monitor, regulate, and control their cognition, motivation, and behaviour, guided and constrained by their goals and the contextual features in the environment" (Pintrich, 2000, p. 453). We know from other research that the teaching and learning approach for first-year mathematics students should encourage self-regulation of learning (e.g., Quinn & Aaräo, 2020). Student learning is described by three components, *presage* (referring to what happens before the learning starts), *process* (referring to how the student approaches his/her learning), and *product* (referring to the outcomes achieved) (compare Biggs, 1989; Trigwell & Prosser, 1997). Thus, the theory indicates a connection between the learning conditions (e.g., availability of reliable technology in an online learning environment), self-regulated habits of students (e.g., regular engagement with learning activities), and performance (e.g., positive learning outcomes).

Changing the mathematics classroom causes changes in students' habits, for example, how and when students engage with content. Some students might find it easier to adapt to changes and others might experience more difficulties, especially in unequal scenarios. Healy et al. (2010) mentioned the necessity for fundamental research into the similarities and differences of the mathematical cognition between students. The theme of mathematical cognition is not the primary focus of this paper, rather the active processes from students to control their cognition. In this paper, we focus on first-year students' learning strategies, and particularly their approach to solving tertiary mathematics problems, while studying online. The latter idea includes an investigation of the characteristics of the student, his/her perceptions of the learning context, and approaches to learning.

Table 1. Population per faculty, linked with a degree, & specialization field

Faculty	Degree & specialization field	Population
Science	BSc degree: Focus on physical or mathematical sciences or information technology	362
Science	BSc degree: Focus on life sciences	59 (pilot group)
Science	BSc degree in the extended curriculum program[a]: Focus on any of the sciences	574
Education	BEd degree: Focus on FET[b] mathematics teachers	58
Engineering	BEng degree: Focus on any of the engineering fields	510
Business	BCom degree: Focus on chartered accounting (CA)	517
Business	BCom degree: Focus on any of the business fields (except CA)	1,366

Note. [a]An extended curriculum program is offered to students who do not meet the normal entrance requirements of the faculty. These entrance requirements are largely determined by English & mathematics marks obtained in the final school year. Such a program refers to an extension of the usual time required to complete the degree (for example, a normal three-year BSc degree will be four years), & additional support to & monitoring of students; & [b]FET refers to further education & training, which is grade 10-12 phases of the South African public school system.

DESIGN AND METHODS

The sudden change from a face-to-face to an online learning environment, with the outbreak of the COVID-19 pandemic, required a pragmatic approach from all role players.

Research Design

The idea to conduct this study developed late in 2020 after six to seven months of exposure to teaching first-year mathematics fully online at a large public university in Johannesburg, South Africa. Several challenges were reported by lecturers and students after day-to-day interactions over a distance, and we decided to conduct a study to gather more information on these challenges. Some reported challenges included a lack of reliable devices, no internet connections, login issues, not sufficient data, difficulties to access material online, and difficulties to upload assessment tasks. The study was quantitatively oriented, and data were collected by a self-designed questionnaire (see later section for more details on the instrument) in the first semester of 2021, during the month of May, from the 2021 first-year cohort of mathematics students (see next section for an explanation of the population and sample). Most of the students in the population were also 'forced' to learn online during their final school year (grade 12) in 2020 and during the first year at university in 2021, thus the expectation was that they would provide useful information regarding the challenges they experienced.

The questionnaire was made available via the university's learning management system for a period of two weeks. Students were invited to participate by a formal announcement and after one week reminded by another announcement. They also received information on the purpose of the study and instructions how the questionnaire should be completed, and how answers should be saved in the online environment. Data were collected simultaneously online from students registered in six different first-year mathematics modules (**Table 1**), except for one group regarded as the pilot group (BSc students from a first-year mathematics module majoring in life sciences, n=59, see **Table 1**). Data from the pilot group were collected one week before the other groups to practice the implementation conditions and to control the conditions over several groups in the major study, which were included in the analysis.

Participants

The questionnaire was available to a population of 3,466 first-year mathematics students. The participants were from different faculties (science, education, engineering, and business) and were registered for only one mathematics module depending on their degree and specialization. For this study, the student populations from the respective seven mathematics modules were considered collectively as the 2021 first-year cohort in mathematics. **Table 1** shows the population per faculty linked with a particular degree and specialization field.

The questionnaire was made available to the population and completed voluntarily; thus the sample was self-selecting. Ideally a sample should not be determined by volunteers, but rather be selected through probability methods (compare Tanur, 1983). For practical reasons, the random selection of a representative sample per module, and at the same time guaranteeing that students would complete the questionnaire online, was not feasible in this investigation. The obvious potential shortcoming with this method of collection is that it can introduce a sample bias; those participants with the most challenges in terms of resources (devices and/or data) may, in fact, not have had the opportunity to complete the questionnaire. Such participants may, therefore, be underrepresented in the data. On the other hand, participants that differ from non-participants, in their attitudes, study habits, and behaviour, and those participants with a lack in self-regulated habits, might not have completed the questionnaire. This limitation has previously been mentioned in literature sources, for example, Watkins and Hattie (1985).

In total, 1,270 participants across all seven mathematics modules completed the questionnaire, which gives a response rate of 36.6%. In the contexts of teaching evaluations, Dillman (2000) provides a formula, which may be used to calculate the response rate required for a specified level of confidence in the results, with the population size and number of respondents as variables. A response rate of 36.6% from a population of over 3,000 students is adequate for the data analysis and observations to be meaningful.

The sample consisted of approximately 47% male students. About 12% of students indicated English as their home language, with roughly 85% of students selecting one of the remaining 10 official languages of South Africa as their home language (e.g., Xhosa). The majority of the sample, approximately 66%, completed their final school year in 2020–a year heavily affected by the COVID-19 pandemic and national lockdown. Almost 21% of the sample matriculated in 2019, while the others completed their final school year before 2019. Approximately 43% of the sample indicated they attended online classes during the national lockdown in 2020, while 39% indicated they relied on self-study during this period. Roughly 60% of the sample obtained between 50% and 69% for mathematics in grade 12 and about 78% of the sample obtained between 60% and 79% for English in the same year.

Data collection Instrument

After the idea for this study was born late in 2020 (see previous section), a questionnaire used as data collection instrument was developed by the authors of this paper early in 2021. They themselves experienced several obstructions in their role as lecturers of a first-year mathematics module during the phase of online teaching in 2020 and 2021. Examples of these obstructions are unequal technology shortages and connectivity problems on the student side, computer literacy of students (some more advanced than others), hard to hear and see students, difficulties presenting online lectures, and so on. The first author also has experience in a management role during this time. The questionnaire, specifically developed for this study, consists of 37 items, organized into four sections that collected information on several aspects:

- ❖ Section A: Characteristics of sample (seven items).
- ❖ Section B: Participants' grade 12 experiences (in 2020) related to learning mathematics online during national lockdown period (eight items).
- ❖ Section C: Digital tools and technological resources that participants had at their disposal to participate in the online environment in 2021 (11 items).
- ❖ Section D: Participants' self-regulated study habits when they were expected to learn tertiary mathematics fully online in 2021 (11 items).

Necessary measures were taken to reduce the threats to validity. During the developmental process the expert opinion of another experienced mathematical subject specialist and statistical expert were taken into consideration to confirm the instrument measures the concepts that it's intended to measure (construct validity), it is representative of what it aims to measure (content validity) and appears to be suitable to its aims (face validity). One might argue that not all questions relate to the challenges students faced in 2021 (the availability of digital tools and technological resources and their self-regulated study habits, like sections A and B) and this aspect can reduce content validity, but for a comprehensive understanding of the results we argued questions on the characteristics and former experiences of the sample are relevant. This viewpoint was also supported by the specialists. Class tutors, who were exposed to fully online learning but more familiar with the tertiary environment than first-year students, were asked to complete the questionnaire during the pilot phase. Their feedback was used to make slight changes to the phrasing of some questions to enhance content validity. Finally, a subject specialist checked the items for a second time. The same instrument was used for the entire population and the authors realize the results cannot be generalized beyond the sample data. These actions enhances both internal and external validity.

One example item from *section C* from the questionnaire related to the availability of technological resources to participants is:

Question ID 17

I have the following devices available to use for my studies in 2021 (please select all applicable options):

Multiple answer question, options given were:

- *A smartphone*
- *A tablet*
- *A laptop computer*
- *A desktop computer*
- *None of the above*

One example item from *section D* from the questionnaire related to participants' self-regulated study habits is:

Question ID 27

Thus far, while studying at ... in 2021, on average I have spent the following number of hours per week (reading through the slides and textbook, watching pre-recorded videos, attending live classes, practicing tutorial problems and assessments) studying mathematics:

Multiple choice question, options given were:

- *Less than an hour per week*
- *1 hour per week*
- *2 hours per week*
- *3 hours per week*
- *4 hours per week*
- *5 hours per week*
- *6 or more hours per week*

Limitations

One limitation is the authors' dual role as researchers and lecturers in two of the seven mathematics modules. This limitation was purposefully addressed by balancing the roles; additionally, the collection of data was online and carefully controlled without any interference of the module lecturer. Another limitation is the external validity and generalizability of findings due to the sampling technique. A further limitation, with research related to this rapid change in environments, is the decreasing value of papers. One might argue COVID-19 is something of the past, or more controlled by vaccines, so the results from the study might not be that valuable to the research community. In our view, COVID-19 has influenced and emphasized the link between mathematics education and digital technology. Thus, the results from this paper have value for the future, particularly for developing countries and countries with existing education inequalities. The results contribute to the body of knowledge that might be useful in future 'similar' crisis situations and for incorporating technology in the tertiary mathematics classroom.

Data Analysis

Data were analyzed using Stata version 17.0 (StataCorp, 2021). Categorical data were described using frequency tables and proportions and continuous data were described using summary statistics, including means and standard deviations. Groups of participants were compared using the independent samples *t*-test or ANOVA, or, where the assumption of normality was more seriously violated, using the Wilcoxon Rank Sum test (Mann-Whitney U test) or the Kruskal-Wallis test. The assumption of normality was assessed by inspection of histograms throughout. The assumption of equality of variances was assessed using Levene's test throughout.

RESULTS AND DISCUSSION

First, we report on results obtained from data collected from sections C and D from the questionnaire (results from sections A and B were used to describe the participants, see former section of this paper, and not to find an answer to the research questions):

(1) the availability and accessibility of technological resources to participants in the online learning environment, and

(2) the reported self-regulated study habits of participants when learning mathematics fully online.

Second, we report on the results after comparing participants' responses for specific questions. We were seeking for connections between key aspects (1 & 2) and the performance of participants.

Although 1,270 participants responded in total, many of these included responses with missing data, that is, item non-responses. Since both, list-wise deletion and available cases analysis (pairwise deletion), may potentially result in biased estimates of means, regression coefficients, etc. from a statistical perspective, we opted to make use of an available-case analysis (pairwise deletion) as it offers an attempt to remedy the data loss problem that comes with list-wise deletion. Thus, the total number of responses varies from question to question.

Participants' Availability and Accessibility to Technological Resources

11 questions from *section C* in the questionnaire (see previous section on the data collection instrument) collected data on what digital tools and technological resources participants had at their disposal to participate in the online learning environment in 2021. The first question asked participants to indicate whether they were located in Gauteng[1] province with access to a university campus[2]. Access to one of the campuses also implied access to the resources offered by the university (e.g., reliable internet access, computer laboratories, and a library). During this time, there were no regular teaching activities on campus that would have prompted first-year students to access one of the campuses (even for the first time). Moreover, the majority of first-year students might have been unfamiliar with the campus environment and many students might have been unaware of the infrastructure and resources offered by the institution. The majority of participants (1,118, roughly 91%) indicated they were in Gauteng and able to access one of the university campuses during the first semester of 2021; although 109 (roughly 9%) of respondents were not in Gauteng (**Figure 1**).

Responses to other questions in the questionnaire (e.g., questions related to the hours of the Internet connectivity and sufficiency of data) suggested participants did not necessarily make use of the institution's resources, despite having the opportunity to access these. Other factors, besides those mentioned above, that might explain this behaviour from students are high transport costs that prevented students travelling to and from a campus at least weekly, even if they were relatively close to a campus, and health concerns because public transport could often be crowded.

[1] Gauteng is one of South Africa's nine provinces and contains the country's largest city, Johannesburg. The province is highly urbanized and is the most densely inhabited.

[2] The public university in Johannesburg has four campuses spread throughout the city.

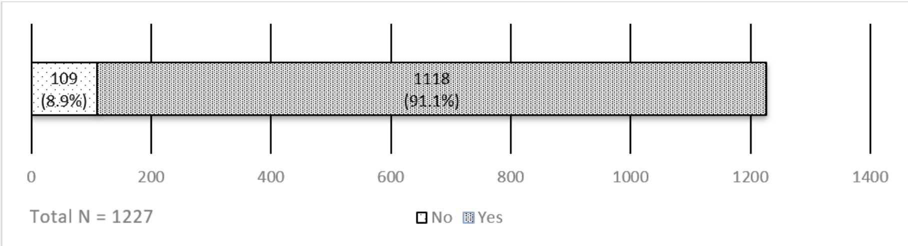

Figure 1. Number of participants located in Gauteng Province (Source: Authors' own elaboration)

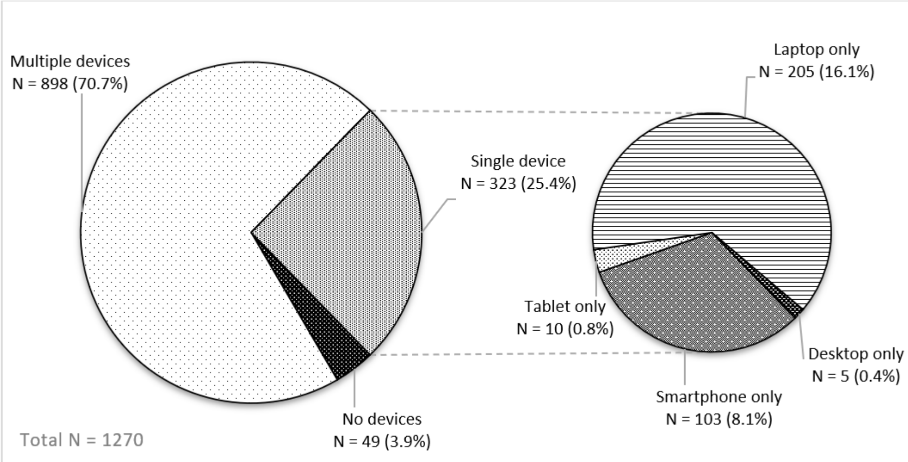

Figure 2. Devices available to participants (Source: Authors' own elaboration)

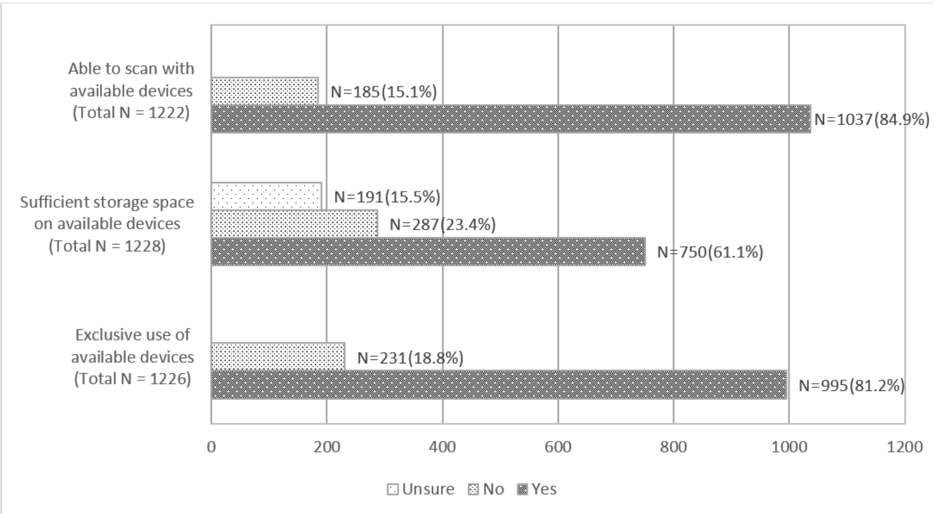

Figure 3. Concerns mentioned by participants explaining the effectiveness of available devices (Source: Authors' own elaboration)

A further six questions aimed to gather information on the devices participants had at their disposal for online teaching and learning. While 898 (70.7%) participants indicated that they had some combination of a smartphone, a tablet, a laptop, or a desktop available to use for their studies, 323 (25.4%) participants indicated that they only had one device to use, and a further 49 (3.9%) participants did not have any of the mentioned devices. The distribution is indicated in **Figure 2**.

Theoretically, all participants should have had access to the devices through the resources provided by the university; but, in practice, that was not the case as explained in the previous paragraph. Noteworthy, and rather concerning, 103 (8.8%) participants only had a smart phone available to study first-year mathematics online.

A further two questions gathered more information on the capabilities of the available devices, and one question asked if participants had exclusive use of these devices. While most participants indicated they were able to view the learning material online, some issues were mentioned.

Figure 3 shows results about three issues related to the availability of devices that can give an indication of the effectiveness of the devices.

Table 2. Device sharing

Number of people the devices(s) were shared with	Frequency (n)	Percentage (%)
0 (participant had exclusive use of available devices)	995	81.1
1 (participant had to share devices with 1 other person)	165	13.5
2 (participant had to share devices with 2 other people)	40	3.3
3 or more (participant shared with 3 or more people)	26	2.1

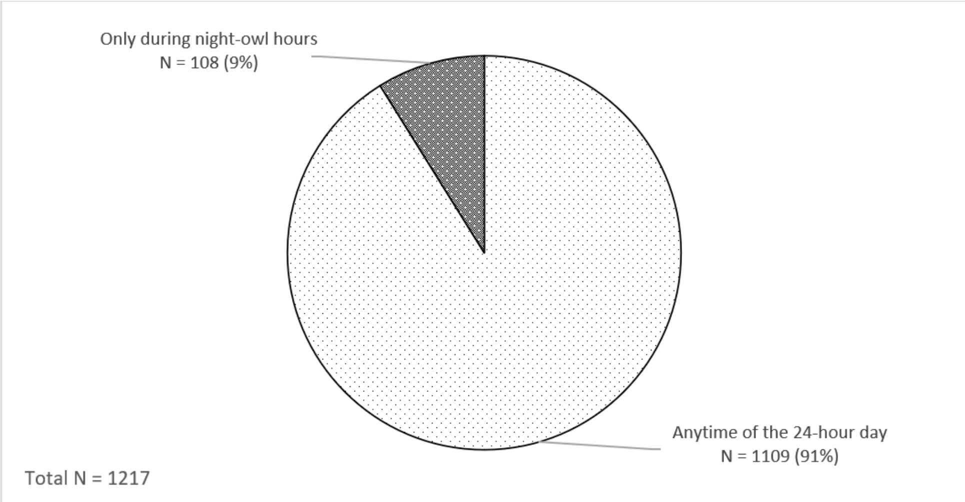

Figure 4. Times of the day participants could access the Internet (Source: Authors' own elaboration)

Results show that 185 of 1,222 (15.1%) participants indicated they were unable to use their devices for scanning. The scanning function was particularly important for submitting assessment tasks online. Then, 287 of 1,228 (23.4%) participants indicated their devices had insufficient storage space for all learning material made available to students during the semester. Further, 231 of 1,226 (18.8%) participants indicated they did not have exclusive use of the devices available to them for studying online.

Table 2 indicates the number of users with whom participants had to share devices. Moreover, some participants had to share their devices with as many as three or more other users (possibly siblings or parents expected to study or work online). These participants, who shared devices, also had to study other modules at the university apart from the mathematics module.

The last three questions in this section of the questionnaire focused on the frequency of power cuts (mostly caused by the ongoing energy problems experienced in South Africa) and the participants' ability to connect to the internet. Results show that 9% of participants, see **Figure 4**, indicated they were only able to access the internet during so-called night-owl hours (typically from 00:01 until 05:00/06:00/07:00, depending on the service provider). Indeed, most of the data provided to students by the university were reserved for the night-owl periods. The results suggest that these participants were fully dependent on the data provided by the institution. Only 729 of 1,218 (59.9%) participants indicated they had sufficient data to download all learning material and to participate in online learning activities.

Figure 5 shows 40.1% of participants indicated they did not have enough data for all material and activities. As mentioned previously, it seems that several participants indicated they had access to campus and, hence, unlimited data through the university's infrastructure, but strangely they did not view 'going to campus' as a source of data.

Participants' Self-Directed Study Habits

11 questions from *section D* in the questionnaire collected information on the participants' approach to online learning, specifically their study methods and habits. We expected that responses from participants (indicating *how* they studied, *how often* they studied, and *how purposefully* they engaged with the online learning material) would provide information on their self-regulated study habits. A total of 1,212 participants indicated the number of hours per week studying mathematics, with the responses summarized in **Table 3**.

Studying mathematics suggested the following activities:

(1) reading through the slides and e-textbook,

(2) watching pre-recorded videos,

(3) attending live online lectures,

(4) practicing tutorial exercises, and

(5) completing assessments.

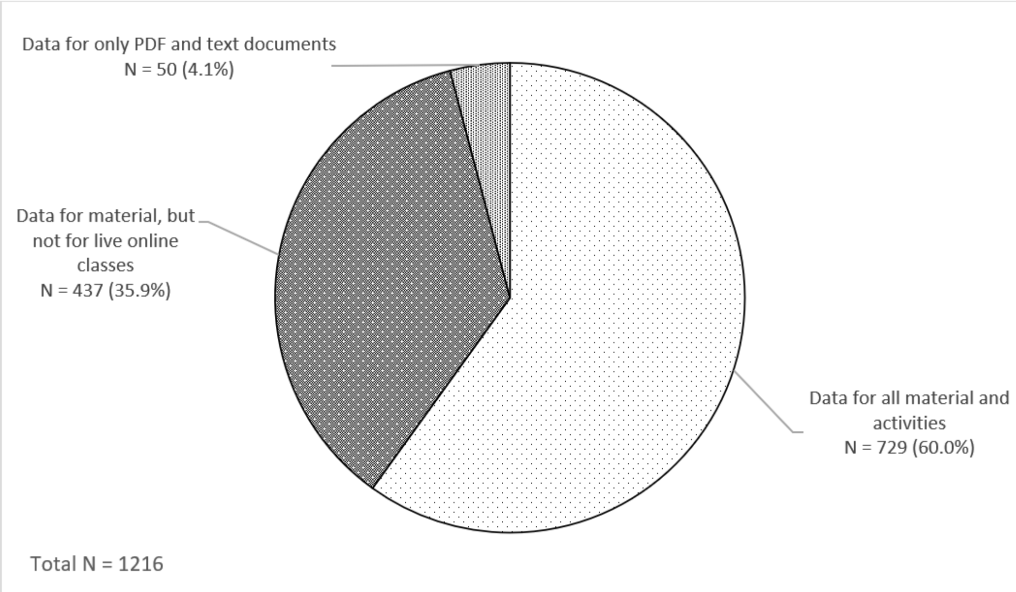

Figure 5. Sufficiency of data for participants' needs while learning online (Source: Authors' own elaboration)

Table 3. Time spent on studying mathematics per week

Hours per week	n	Percentage (%)
Less than an hour per week	21	1.7
1 hour per week	33	2.7
2 hours per week	60	5.0
3 hours per week	135	11.1
4 hours per week	204	16.8
5 hours per week	211	17.4
6 or more hours per week	548	45.2

Note. n: Number of participants

To understand the results in context, it should be noted that within a 'normal' semester with usual face-to-face teaching, a first-year mathematics student will have between three and four and a half hours of tuition depending on the particular mathematics module (that is, four to six 45-minute periods, including both lecture and tutorial periods) and, added to this total, more hours for practicing exercises and completing assessments. Results from this investigation revealed 114 (9.4%) participants indicated they were spending less time on studying mathematics weekly than what they would have if they attended all the weekly lectures and tutorials under normal conditions. Also, 548 (45.2%) participants indicated they spent six or more hours per week studying mathematics. In interpreting this result, we acknowledge the self-selecting nature of the sample might have contributed to a higher number of diligent participants who completed the questionnaire (see Watkins & Hattie, 1985). Notwithstanding, the 548 participants engaged in self-directed learning behaviour for at least the minimum time expected to engage with the content.

Figure 6 shows how participants used their weekly time to study mathematics. To collect this data, participants were given a list of activities from which they could have selected one or more activity they engaged with on a weekly basis. Each activity could only be selected once.

Figure 6 shows the frequency an activity was selected by participants, with a total of 1,211 valid responses. Participants rarely chose to reach out to the lecturers or tutors for consultation and more often chose to reach out to other students for support. A clear preference for slides and notes prepared by the lecturers can be noticed opposed to the prescribed textbook (1028 (84.9%) participants selected "reading the slides and notes" as a weekly activity over only 757 (62.5%) selecting "reading the textbook" as a weekly activity). One reason might be that students understood the notes from the lecturer more easily than the explanation in the textbook.

During online teaching and learning in 2021, lecturers often made use of assessment opportunities to support and monitor students. The first-year mathematics modules adopted a hybrid continuous assessment model[3] during the pandemic to accommodate the adjusted academic calendar from the university. The multiple assessment opportunities explain the large number of participants (975, or 80.5%) who selected "complete assessments" as a weekly activity. The result that only 899 (74.3%) participants selected "watching videos" as a weekly activity is surprising. One reason might be the availability and accessibility of technological resources.

As mentioned before, 437 (36.1%) participants indicated that they only had enough data for study

[3] At the end of the semester a continuous assessment mark was compiled according to a specific formula, considering the marks from all the assessments throughout the semester. Students with a final continuous assessment mark of 40-49% were granted a supplementary examination. Students with a final continuous assessment mark of 50% or more passed the module.

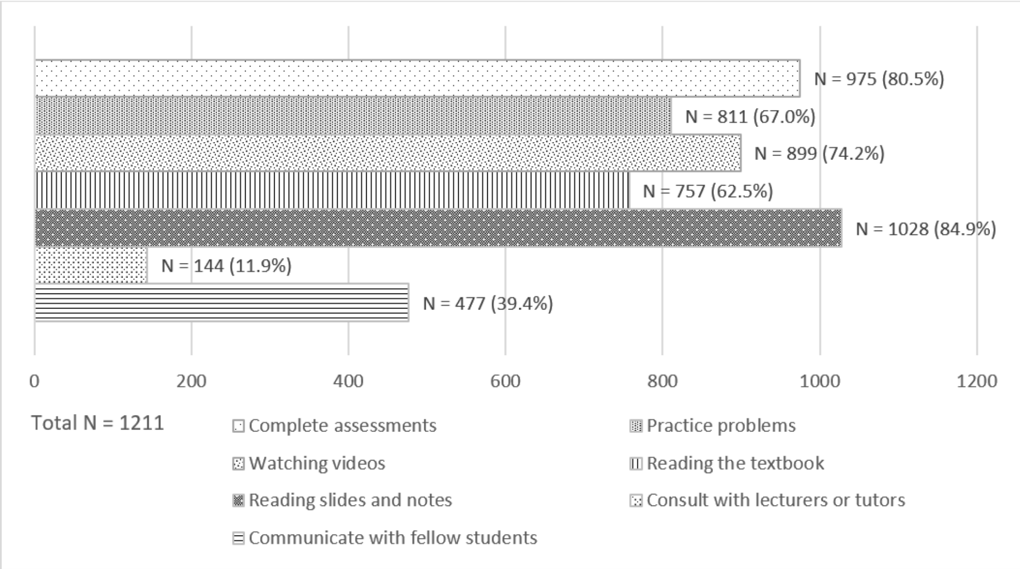

Figure 6. Number of participants engaging with different learning activities studying mathematics per week (Source: Authors' own elaboration)

Table 4. Frequency of participants' communication with the module lecturer

Contacted lecturers	Frequency (n)	Percentage (%)
Never	586	48.8
Once	340	27.1
More than once	284	23.5

material, but not online classes. Video content consumes a comparable amount of data to the online classes and might not have been a viable option for these students. Unexpectedly, only 811 (67%) participants selected "practice problems" as a weekly activity. This suggests that remaining 400 (33%) participants were often passive in their engagement with the content, which is a concern.

The tendency to rarely consult with lecturers or tutors was confirmed by participants' responses in a follow-up question in the questionnaire (**Table 4**). Close to 50% of the 1,210 participants indicated that they never contacted the module lecturer. This phenomenon is also present in face-to-face tuition and the understanding is that students find it easier to engage with peers than with lecturers. However, when students receive face-to-face tuition, they have a natural opportunity to engage with lecturers during contact time, while with online teaching this engagement opportunity seems more challenging. Students might feel insecure to contact or consult lecturers.

Two more questions focused on how participants prepared for major assessments (two semester tests per semester that contributed between 60% and 70% towards the final continuous assessment mark, or the final summative supplementary assessment).

Figure 7 shows a summary of activities participants engaged with while preparing for a major assessment. The frequency an activity was selected by the 1211 participants is indicated on the horizontal axis.

Figure 6 and **Figure 7** show that participants' behaviour in preparing for a major assessment bears a resemblance to their weekly study habits. Of the participants, 1,028 (84.9%) read slides and notes weekly while 1018 (84.1%) participants read materials only in preparation for a major assessment; 899 (74.2%) participants watched videos weekly while 952 (78.6%) participants watched videos only in preparation for a major assessment; 757 (62.5%) participants read the textbook weekly while 868 (71.7%) participants read the textbook only in preparation for a major assessment. The major difference seems to be with the number of participants practicing problems; 811 (67%) participants indicated that they practiced problems weekly, while 1,187 (98%) participants indicated practicing at least some problems only in preparation for an assessment. The data show a positive trend in students' self-directed learning behaviour. However, the number of, and which kind of, problems should also be considered. Results show 554 (45.7%) participants reported that they practiced only a few problems on each topic in preparation for an assessment, as opposed to 633 (52.3%) participants who reported practicing several problems per topic. We note that 24 (2%) participants selected neither option. Moreover, only 522 (43.1%) participants reported practicing problems from revision exercises that include a combination of several topics.

In addition to the quantity of problems a student attempted in preparation for major assessments is the way in which students approached these practice sessions. The chart in **Figure 8** depicts the responses we received from participants when asked to indicate how they would approach a mathematics problem that they did not know how to solve. A majority of 696 (57.6%) participants indicated that they would attempt to solve the problem for several minutes before consulting a model solution, while 328 (27,2%) participants indicated

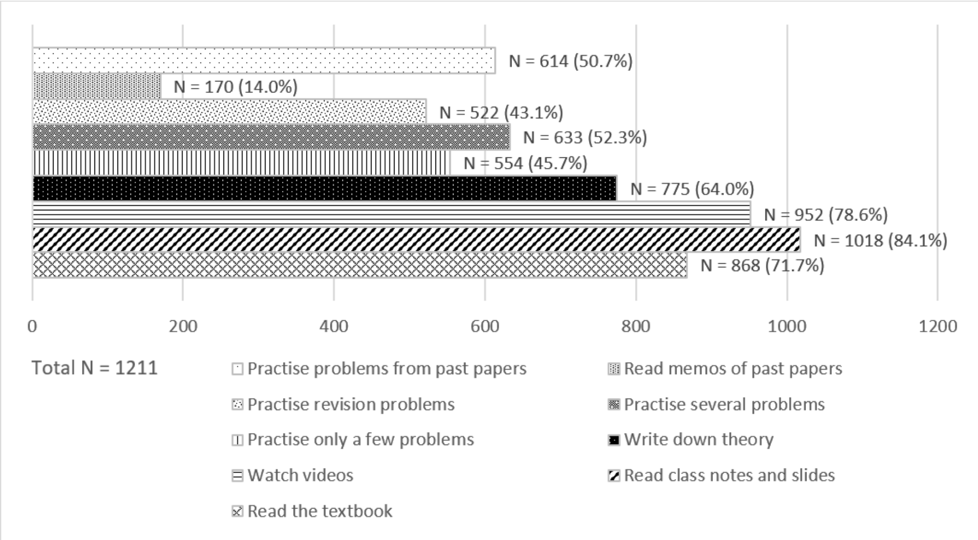

Figure 7. The frequency of learning activities selected by participants in preparation for major assessments (Source: Authors' own elaboration)

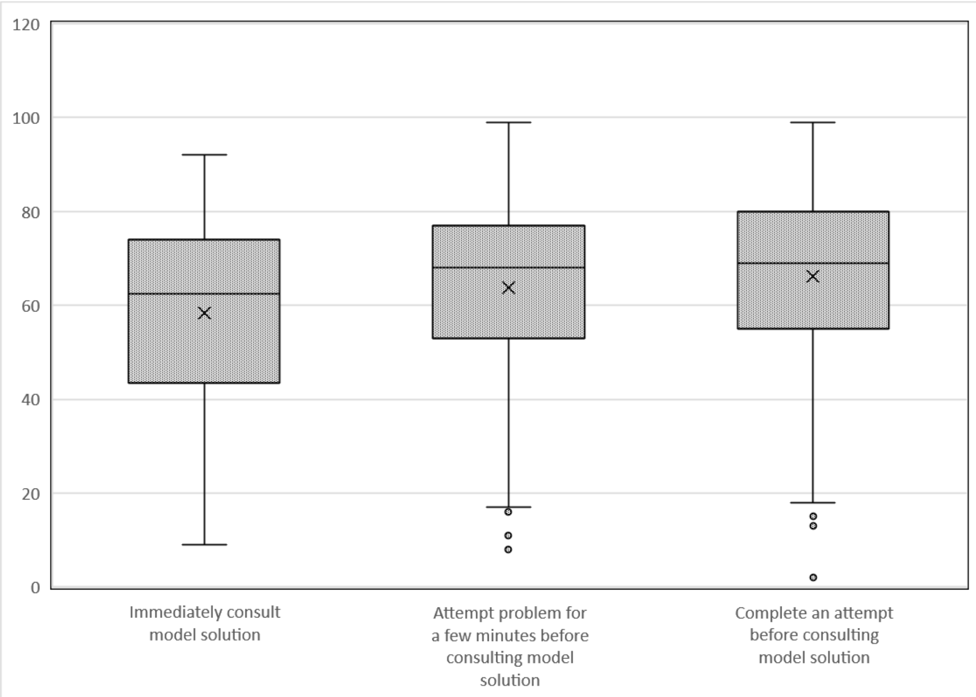

Figure 8. Different approaches from participants when attempting mathematical problems that they do not immediately know how to solve (Source: Authors' own elaboration)

they will continue the attempt to solve the problem until arriving at a solution before consulting the model solution. Thus, 84.8% participants showed active engagement with the content. On the other hand, the remaining 15.2% participants immediately consult a model solution if they encounter a mathematical problem that they do not know how to solve. This latter behaviour indicates a more passive way to engage with the content.

Connections Between Key Aspects and Performance

One measure to determine how prepared a student was for studying mathematics at the tertiary level, or his/her ability to overcome obstructions, is the final mark obtained for the module. During the phase of 'forced' online teaching and learning, continuous and major assessments were online.

Lecturers were not used to the required conditions and had no time to do research on this aspect before implementation, thus using the final mark as a measure during this phase might not be ideal. This, coupled with the possibility of misconduct on the student side during online assessments, might skew the analysis by showing that a factor does not seem statistically significant while it should have been the case. Thus, if a factor appears statistically significant through analysis, its real impact may be far more significant than the data suggested.

Table 5. Wilcoxon rank sum for respondents in Gauteng vs. not in Gauteng

	Frequency	Rank sum	Mean rank
In Gauteng	1,029	576,316	587.3
Not in Gauteng	97	58,185	554.1

Connection between available technological resources and performance

As stated earlier, our first hypothesis was that first-year mathematics students are only partly prepared for learning tertiary mathematics fully online. In terms of the availability and accessibility of technological resources, we conjectured that students who were in the Gauteng province of South Africa with access to the campuses (and hence the resources offered on campus) would have performed better. A Levene's test (Levene, 1960) of equal variance was performed that indicated unequal variance (F[1, 1,124]=4.142, p=0.042). Consequently, an adjusted t-test, using Satterthwaite's degrees of freedom (Satterthwaite, 1946), was performed. However, its results did not indicate a difference in the final continuous assessment mark between participants in Gauteng (mean [M]=64.6, standard deviation [SD]=18.3) and participants outside Gauteng (M=69.3, SD=16.3); t(120.064)=-1.45, p=0.92 (one sided). This seems to contradict our hypothesis but correlates to our observations regarding students' attitude towards using campus resources as discussed in the prequel. Due to the lack of normality on the final continuous assessment mark in both groups, the Levene's test was followed up with a two-sample Wilcoxon rank sum test (Wilcoxon, 1945), also called the Mann-Whitney U-test (Mann & Whitney, 1947). The summary statistics of the Wilcoxon test are reflected in **Table 5**. While the result of the Wilcoxon test is also not statistically significant (z=-1.152, p=0.25), we do see a trend that participants not in Gauteng have a lower rank sum and mean rank. One reason why the location of a participant could have been less significant than expected is the underuse of campus resources as mentioned in the previous section.

Next, we determined to what extent the lack of an appropriate device(s) influenced a participant's performance. Still related to our first hypothesis that first-year mathematics students are only partly prepared for learning tertiary mathematics fully online due to substantial differences in the availability and accessibility of technological resources, we conjectured that a participant with access to not just a smartphone (that is, at least one of the following devices: laptop, desktop, or tablet) performed better (obtained a higher mark) than a student with access to only a smartphone. This was tested using a one-sided t-test as the assumption of equal variances was evaluated using the Levene's test, which showed no serious deviations from the assumption of equal variances (F[1, 1,118]=0.057, p=0.811). There was a significant difference in the final continuous assessment mark for users with access to more than just a cell phone (M=64.39, SD=17.89) and smartphone only users (M=57.91, SD=18.12; t[1,118]=3.34, p=0.0004). Indeed, the difference of means between the two groups was 6.43%. While not unexpected, this result emphasizes the importance of the type of device available to a first-year mathematics student when engaging in online learning.

Further, to test how the differences in availability and accessibility of technological resources influenced preparedness, we investigated the availability of devices to participants. One might have had access to a laptop but might be obliged to share the use of that laptop with several others. The third conjecture was that a participant, with exclusive use of the device(s) available to him/her, performed better overall than participants who were obliged to share the device(s) with one or more others. This conjecture was tested using a one-sided t-test. The Levene's test shows no serious deviation from the assumption of equal variances (F[1, 1,123]=0.133, p=0.715). The result of the t-test shows a significant difference in the final continuous assessment mark for students with exclusive use of their available devices (M=64.26, SD=18.087) and those that shared devices (M=61.38, SD=18.184); t(1,123)=2.082, p=0.019. The difference in means between the two groups was 2.88%. The exclusive use of available devices to a first-year student learning mathematics online seems important.

Connection between self-regulated study indicators and performance

The second hypothesis is that most first-year mathematics students lack self-regulated study habits. To test this hypothesis, we conjectured that the performance of a participant directly relates to the amount of time spent studying mathematics per week. The Levene's test shows variances appear to be similar (F[6, 1,108]=1.639, p=0.133). The p-value is greater than a threshold of 0.05 and we conclude that the variances do not differ greatly. We do not have sufficient evidence to reject the second hypothesis. A Kruskal-Wallis equality-of-populations rank test (Kruskal & Wallis, 1952) was performed as the assumption of normality was not met. The results of the Kruskal-Wallis test show no significant difference in students' final continuous assessment marks across the different categories (χ^2[6]=10.285, p=0.113). This seems to support a claim that the quantity of time spent studying mathematics does not necessarily improve the performance of a student.

Furthermore, we were interested in the connection between a participant's approach to solving mathematics problems and his/her performance. A one-way analysis of variance (ANOVA), see Fisher (1918), was used to test a participant, who first tries to solve a mathematics problem by him-/herself and delays looking at the model solution when preparing for major assessments, will have a better final continuous assessment mark compared to one who looks at the model solution without really trying to first solve the problem. The Levene's test showed no serious deviation from the assumption of equal variances ($F[2, 1,109]=2.035$, $p=0.131$). There was a statistically significant difference ($F[2, 1,109]=9.83$, $p=0.0001$) in final continuous assessment marks for the three categories (participants immediately consulting the model solution, participants attempting to solve the problems for a couple of minutes before consulting the model solution, and participants finding a suggested solution before consulting the model solution), see **Figure 8**. Post-hoc comparisons using the Šidàk test (Šidàk, 1967) show that the mean final mark for those that looked at the solution immediately (M=58.43, SD=19.31) differed significantly from both those that spend a few minutes trying first (M=63.84, SD=17.73; mean diff=5.41, $p=0.002$) and those that completed an attempt and have a suggested solution before looking at the solution or a hint (M=66.13, SD=17.92; mean diff=7.7, $p<.001$). The latter two groups did not differ from each other significantly. This result indicates that a participant's active engagement with the content (i.e., spending time to try to obtain a solution to a mathematical problem oneself) as opposed to a participant's passive engagement with the content (i.e., just immediately looking at the model solution of a mathematical problem) has a significant impact on the final continuous assessment mark. It seems that some participants lack self-regulated study habits. The combination of the last two conjectures relate to the second hypothesis on participants' self-regulated study habits; it seems important how a student spends his/her time while studying mathematics, and if the student is actively engaged with the content.

CONCLUSION AND PERSPECTIVES

In this study, a large sample of first-year mathematics students' preparedness for, and response to, online learning during the time of the COVID-19 pandemic were investigated. The sample was from a public university in South Africa. Quantitative data were collected via a self-designed questionnaire that was largely informed by difficulties both lecturers and students reported during the time of "forced" online teaching and learning in 2020. Data were analyzed using Strata, and various statistical tests were performed to report on the availability and accessibility of technological resources to first-year students while learning online, their self-regulated study habits, and the connection between these aspects and their performance.

It seems that the availability of devices, and the exclusive use of these devices, have a significant effect on student performance. Several students had to share devices with others and experienced difficulties with connectivity and data shortages. Similar difficulties were reported in other studies during the time of the pandemic (compare Chirinda et al., 2021). Although students had the opportunity to use institutional resources they mostly decided not to do so. The reason for this behaviour is unclear and require further inspection. Also, results show students with access to a smartphone and at least one other device performs significantly better when learning tertiary mathematics online than students with access to only a smartphone. One might argue that in a context with pre-existing educational inequalities students are less compliant to learn online.

A connection between self-regulated study habits and performance could also be confirmed, similar to other studies (compare Quinn & Aarão, 2020). In this study, first-year students' approach to solving tertiary mathematics problems, while studying online, has significant effect on their performance. Students that showed activate engagement with the content (e.g., attempting to solve the problems for a couple of minutes or finding a suggested solution before consulting the model solution) performed significantly better than students with a more passive approach (e.g., immediately consulting the model solution). One suggestion for lecturers is to enhance active learning approaches in online environments. Also, the strategies to design online activities and incorporate tools to advance students' self-regulated study habits. One example with a positive outcome is the use of quizzes (compare Quinn & Aarão, 2020).

We also know from other studies that learning conversations are key (compare Laurillard, 2013). In this study students preferred to study from the slides and notes provided by the lecturer, although they rarely interacted in conversations with the lecturer. It might be necessary to create more deliberate opportunities for learning conversations between lecturers and students in an online classroom.

We realize that the questionnaire used in this study collected important and valuable data, but for a more comprehensive study of the challenges students faced (e.g., related to prior learning and attitudinal aspects) a qualitative component could have been informative. Due to practical reasons this was not possible.

Further ideas following from this study is an investigation into the challenges posed to the lecturer when incorporating technology (for either online or hybrid teaching) in tertiary mathematics classrooms in countries with educational inequalities. Some might argue the pandemic is something of the past, and others might argue the tertiary teaching and learning environment has changed forever due to the pandemic. Most likely, the exposure to technology will have a lasting impact on teaching practice and learning activities (see Callaghan et al., 2022). Either way, research on the students' experiences should be investigated (Trenholm et al., 2016) and knowledge about technological resources available to, and self-directed study habits of, first-year mathematics students in developing countries can contribute to the body of knowledge to support students' online learning in future.

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Data sharing statement: Data supporting the findings and conclusions are available upon request from the corresponding author.

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