Article

Challenges and Opportunities: Experiences of Mathematics Lecturers Engaged in Emergency Remote Teaching during the COVID-19 Pandemic

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Abstract: In this paper, we consider the experiences of mathematics lecturers in higher education and how they moved to emergency remote teaching during the initial university closures due to the COVID-19 pandemic. An online survey was conducted in May–June 2020 which received 257 replies from respondents based in 29 countries. We report on the particular challenges mathematics lecturers perceive there to be around teaching mathematics remotely, as well as any advantages or disadvantages of teaching mathematics online that they report. Over 90% of respondents had little or no prior experience teaching mathematics online, and, initially, 72% found it stressful and 88% thought it time-consuming. 88% felt there was a difference between teaching mathematics in this way compared with other disciplines. Four main types of challenges were associated with emergency remote teaching of mathematics: technical challenges; student challenges; teaching challenges; and the nature of mathematics. Respondents identified flexibility as the main advantage of online teaching, with lack of interaction featuring strongly as a disadvantage. We also consider respondents' personal circumstances during this time, in terms of working conditions and caring responsibilities and conclude by summarizing the impact they perceive this experience may have upon their future teaching. Forty-six percent% of respondents self-identified as having caring responsibilities, and 61% felt the experience would affect their future teaching.

Keywords: COVID-19; emergency remote teaching; higher education mathematics; teaching mathematics online

1. Introduction

With the advent of the COVID-19 pandemic, universities around the globe were forced to adapt to emergency remote teaching [1] at short notice and with limited preparation time. Teaching mathematics online presents specific challenges due to the symbol-heavy nature of the subject and the need for discipline-specific software [2].

It is early days in terms of publications emerging about the teaching of mathematics in higher education during the pandemic, but to the best of our knowledge none of them has addressed these issues. In the existing literature, there are a number of common themes. Assessment approaches appropriate for remote teaching have dominated a number of articles [3–5]. Reports on mathematics support during the initial university closures detail the greatly reduced numbers of students availing of services of this kind [6,7], which is an issue of concern. Others have focused on preservice mathematics teachers, looking at how they made the transition to using digital resources for mathematics [8,9], while more considered the teaching of specific subject areas [10,11] or age-groups [12,13]. More generally, some have researched specifically what mathematics educators in institutes of higher education can learn from their experience of these times [14]. One resource, tailored specifically for mathematics lecturers in the UK (www.talmo.uk, accessed on 17 September 2021), provides a series of community-led online workshops and resources to support lecturers in teaching remotely.

The aim of this research was to investigate how large numbers of mathematics lecturers in higher education moved to emergency remote teaching during the initial university closures that took place due to the COVID-19 pandemic, approximately around March–May 2020. Specifically, this paper addresses the following research questions:

1. How do mathematics lecturers describe their experience of emergency remote teaching?
2. Do mathematics lecturers perceive that there are particular challenges associated with teaching mathematics remotely?
3. Following this experience, what do they perceive the advantages and disadvantages to be of teaching mathematics online?
4. Were there personal circumstances that affected their ability to engage with emergency remote teaching as they might have wished?
5. Do mathematics lecturers think that their experience of emergency remote teaching will impact their future style of teaching?

2. Materials and Methods

2.1. Survey Instrument

The survey (see Appendix A) used in this study had to be purpose-designed, as it related directly to emergency remote teaching, and given that it was undertaken in May 2020, there were no similar surveys available at the time. It was piloted with a group of experienced mathematics lecturers, and changes were made to the questions as a result of their feedback. The survey led with profiling questions on the age, profile, gender, and country in which respondents currently worked, the years of experience teaching mathematics in higher education, and current employment status. Questions relating to class size, contact teaching hours, and modules taught were also included. There were a further six sections in the survey: types of technology; purpose of technology; assessment; student experience; remote teaching experience; and personal circumstances. It is beyond the scope of this paper to deal with all six sections at once, and so we will focus upon the last two of these: remote teaching experience and personal circumstances. Within these two sections, there were 18 questions, of which eight were open-ended.

2.2. Data Collection

The survey was conducted exclusively online using Google Forms, and was distributed via mailing lists and advertised via various online conferences in mathematics education.

2.3. Data Analyses

The quantitative data was analysed using Excel. General inductive analysis [15] was the method deemed most apt for the coding of the qualitative data. This involves both researchers independently reading and re-reading the raw data before identifying any themes and/or subthemes that seemed to emerge. Both researchers then came together to discuss and agree upon the appropriate themes, which were adjusted accordingly to ensure reliability. There was 82% agreement between the two researchers, which is classified as "nearly perfect agreement" [16]. Throughout this paper, N is used to report the total number of respondents to a given question, while n is used for the number who answered a certain way for a given question.

2.4. Sample

The responses to the profiling questions can be seen in Table 1. There were 257 respondents in the sample. There was a relatively even breakdown of gender among the respondents, which would not be typical for surveys of mathematicians given that there are more male academic mathematicians than female [17]. However, a mailing list for female mathematicians was targeted directly, which may account for the higher proportion of female respondents. The age profile showed a wide spread, with lower proportions under 30 years of age, and their years of experience teaching mathematics in higher education reflected this. The majority of respondents were permanently employed.

Table 1. Profile statistics of survey respondents (*n* = 257), showing their gender, age, years of experience teaching mathematics in higher education, and current employment status.

	Number	**%**
Gender		
Male	135	52.5%
Female	118	45.9%
Non-binary	1	0.4%
(Blank)	3	0.8%
Age		
20–29 years	16	6.2%
30–39 years	61	23.7%
40–49 years	69	26.8%
50–59 years	71	27.6%
60+ years	38	14.8%
(Blank)	2	0.8%
Experience teaching math in higher education		
0–1 year	8	3.1%
2–3 years	13	5.1%
3–5 years	20	7.8%
5–10 years	34	13.2%
10–15 years	31	12.1%
15–20 years	34	13.2%
20+ years	117	45.5%
Employment status		
PhD/Postdoc	3	1.2%
Short-term contract ($\leq$1 year)	16	6.2%
Long-term contract (>1 year)	28	10.9%
Permanent	205	79.8%
Retired but teaching	4	1.6%
(Blank)	1	0.4%

The highest proportion of respondents were based in Ireland (30.4%), which is where both researchers are also based, with the majority of respondents based in Europe at the time the survey was distributed (93%). In total, respondents from 29 different countries took part in the survey [18].

Both the subjects taught by respondents in the semester under review, as well as the class sizes, could influence their approach to online teaching or their experience of such. Almost three-fifths were teaching students majoring in mathematics, with just over half of respondents teaching service-mathematics students (students who are required to study one or more mathematics modules as part of their degree programme, but do not specialise in mathematics). Respondents also indicated their class sizes, with small being up to 30, medium being 30 to 100, and large over 100. Of the 256 responses, 59.4% had small classes, 50.4% had medium classes and 22.7% had large classes. The number of scheduled contact teaching hours that respondents had planned to do per week, pre-pandemic, was of interest as it would give a rough indication of the teaching workload involved. Sixty-five percent of respondents taught 8 h a week or less.

2.5. Limitations of the Study

1. 93% of respondents are employed in Europe, with 30% of respondents in Ireland, meaning that the results may not be generalizable to other continents.
2. The survey was only distributed in English, and was conducted online, advertised via mailing lists and online conferences. We do not know how representative a sample it is of mathematics lecturers as a result.

3. Results

The results of the surevy are detailed in this section.

3.1. Mathematics Lecturers' Experience of Emergency Remote Teaching

To explore how mathematics lecturers would describe their experience of emergency remote teaching, it was first of interest to establish a baseline for their prior experience in online teaching. This proved to be very low, with the vast majority (90%) of respondents reporting little or no experience prior to the COVID-19 pandemic.

3.1.1. Initial Experience of Online Teaching

Respondents were asked to rate their experience of online teaching when they first began under a series of headings: three positive (flexible, interactive, useful) and three negative (stressful, time-consuming, difficult). The results are shown in Figure 1 below.
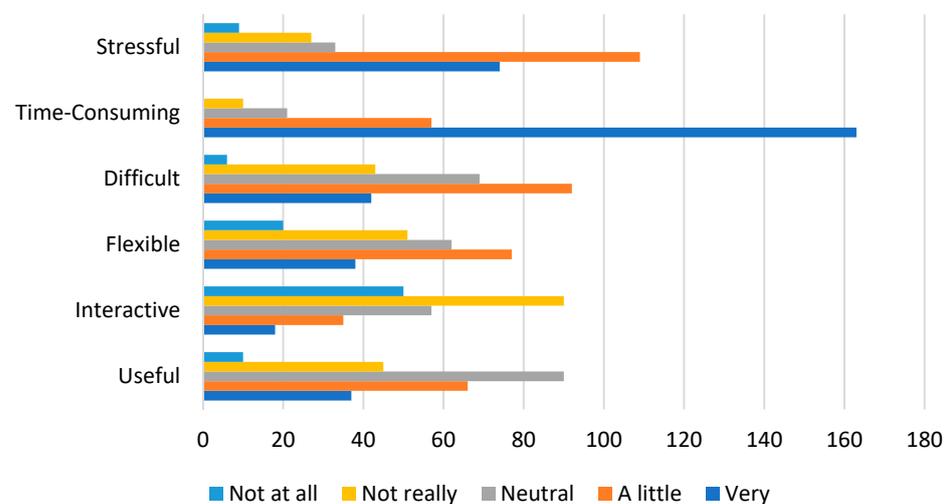

Figure 1. Responses to the survey question: "How did you find online teaching when you first began?" (*n* = 248–252).

Respondents overwhelmingly found online teaching to be stressful and time-consuming initially, with 72% of respondents rating it as a little or very stressful, and 88% rating it as a little or very time-consuming. By contrast, just over half (53%) rated it as a little or very difficult. On the positive headings, just under half (46%) found it to be a little or very flexible, with this dropping to 37% who found it a little or very useful, and only 18% found it a little or very interactive.

3.1.2. Later Experience of Online Teaching

Respondents were then asked the same series of questions, but in relation to their experience by the end of semester, the results for which are shown in Figure 2.

At this point, it can be seen that the numbers finding online teaching to be stressful have dropped substantially, with 47% now describing it as a little or very stressful. The same decrease is not evident in relation to the amount of time online teaching is taking by the end of semester, however, with 79% still now finding it a little or very time-consuming. Thirty-nine percent rated online teaching as a little or very difficult by the end of the semester. There was a small increase to 50% now reporting it to be a little or very flexible; a more substantial one to 48% finding it a little or very useful; and a similar increase to 31% stating that online teaching was a little or very interactive.
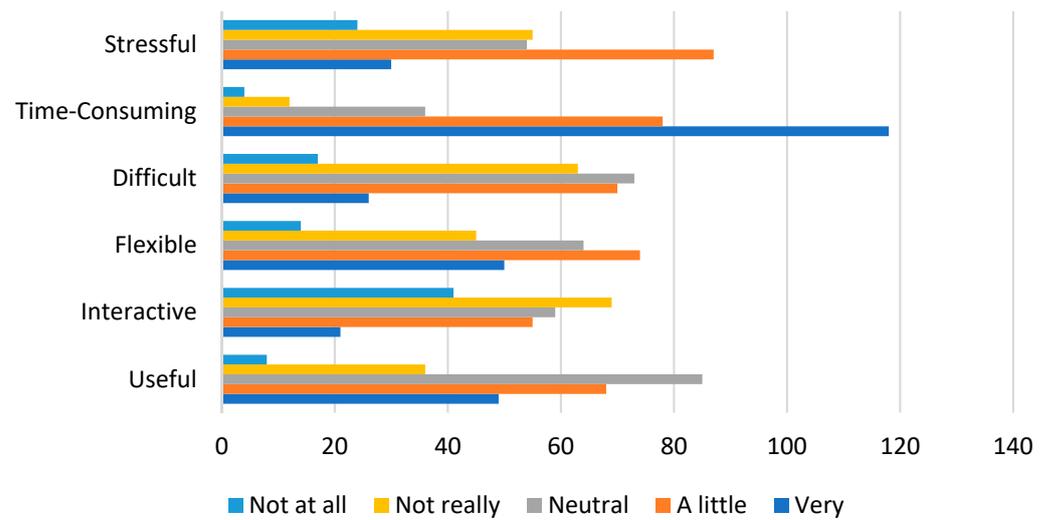
Figure 2. Responses to the survey question: "How did you find online teaching by the end of the semester?" (*n* = 245–250).

3.1.3. Comparison between Initial and Later Experiences of Online Teaching

If we directly compare the responses from each individual, we can observe what changes occurred in their own experience of online teaching from when they first began to the end of the semester. Figure 3 below shows the change in individuals' reported experiences, obtained by assigning a number between 1–5 to each opinion expressed (where 1 = "not at all" and 5 = "very"), and calculating the difference between the initial opinion and final opinion of each individual. In this way, a score of zero represented no change, and is shown as "About the same" in Figure 3, whereas a difference of ±5 either represented "Much less" or "Much more".
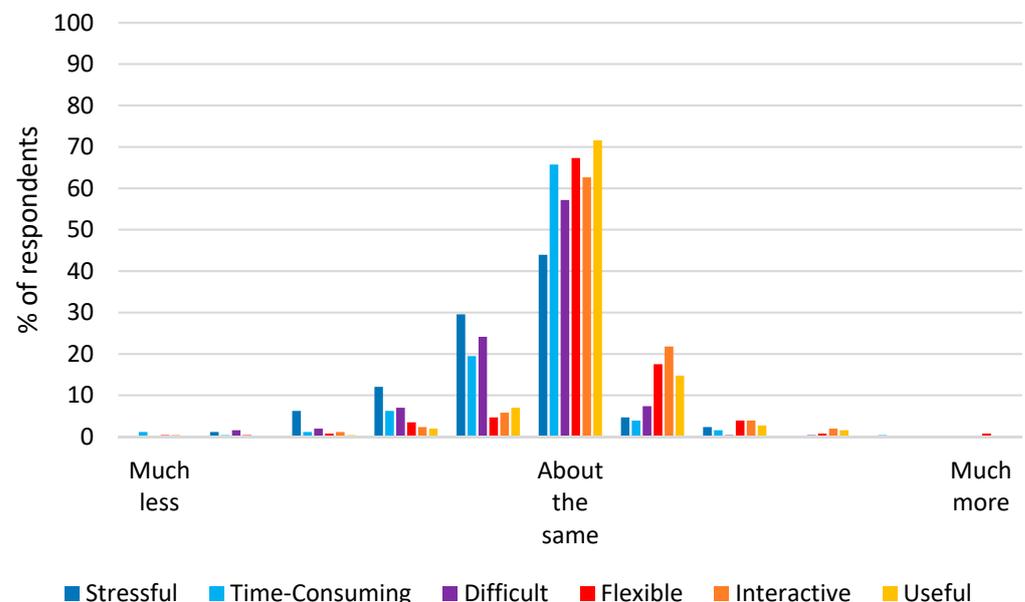
Figure 3. Differences between individual respondents' initial experiences of online teaching versus their experiences by the end of semester (*n* = 245–250).

The vast majority of respondents did not change their opinion under these headings from the start of their online teaching experience to the end of semester. Those that did change generally only moved one or two points to the right or left of where they had been, with very few individuals reporting a dramatic change in their experience. The

biggest change to be seen was in individuals' experiences of how stressful online teaching was; as might be expected, this became less stressful for lecturers as their experience with online teaching increased. Similarly, perceived difficulty levels decreased somewhat as their experience increased.

3.1.4. Comparison between Online Teaching and In-Person Teaching

Finally, respondents were asked to compare their experience of online teaching with their regular teaching, under these same headings. The results are shown in Figure 4.
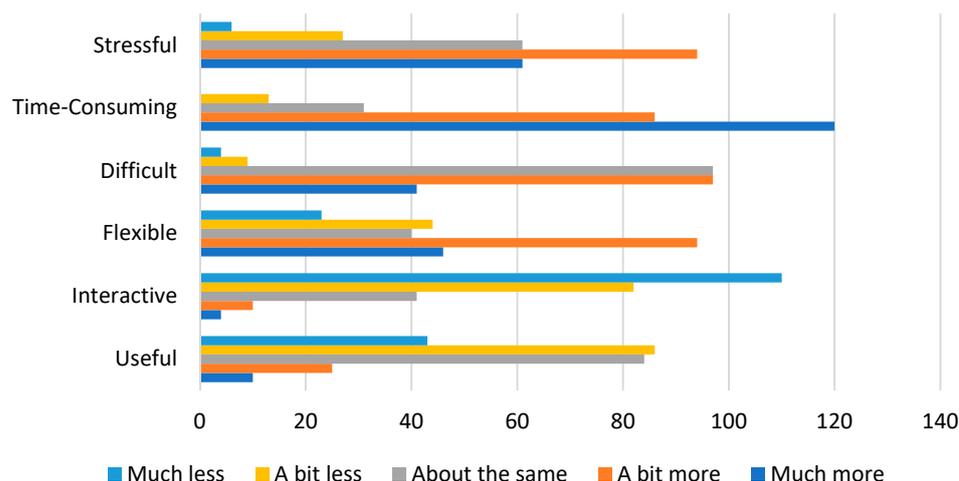
Figure 4. Responses to the survey question: "Comparing your experience of online teaching with your regular teaching, online teaching is..." (*n* = 247–250).

Overall, online teaching was deemed to be considerably less useful, with only 14% deeming online to be a bit more or much more useful than their regular teaching. Interactivity scored even lower, with only 6% of respondents deeming online teaching to be a bit more or much more interactive than their regular teaching. In terms of flexibility, however, mathematics lecturers were of the opinion that online teaching offered more, with 57% finding it a bit more or much more flexible than their regular teaching. Although lecturers were still finding online teaching to be more difficult than their regular teaching, almost 40% found it "about the same" with a further 40% finding it "a bit more difficult". The time-consuming nature of online teaching was evident in the fact that 82% of respondents rated it a bit more or much more time-consuming, with the majority finding it much more time-consuming. Lecturers were still finding online teaching to be more stressful also, with 62% stating it was a bit more or much more stressful than regular teaching.

Respondents were also asked about their engagement with work colleagues in terms of whether they were more likely to share teaching tips and support with colleagues at this time compared to normal, and 65% (*n* = 253) stated that they did so more than usual or a lot more than usual. Almost 64% of respondents (*n* = 255) felt that their administrative workload increased during the university closure. In terms of hours worked, two-thirds of respondents stated that they worked more hours or a lot more hours during this time than their typical working day on campus, with a further 26% saying there was no change.

3.2. Particular Challenges of Teaching Mathematics Remotely

The symbolic nature of mathematics means that different techniques may be required for online teaching of the subject; therefore, we wanted to explore whether the lecturers in this study perceived that there were differences between the teaching of mathematics remotely and teaching other disciplines online. There were 190 respondents to this open-ended question, and only 5% felt that there was no difference; ("*I work at a small college and collaborate with colleagues in all fields, and found that we all mostly have the same issues*"), with a further 7% unsure ("*I don't know as I don't teach other disciplines online*"). Among the

88% who felt there was a difference, there was some small level of dissent as to whether it was easier or harder to teach mathematics remotely, with 89% of the 144 respondents who commented further feeling mathematics was harder to teach, 8% feeling it was easier, and 3% thinking there were aspects which were easier and others which were harder. The reason that respondents felt it was easier to teach mathematics remotely was that there are no practical experiments, unlike in science subjects.

There were four main themes that emerged from an analysis of the 144 further comments: technical challenges (mentioned in 49% of comments); student challenges (38% of comments); teaching challenges (35% of comments); and the nature of mathematics (31% of comments). Four further sub-themes were subsequently identified under each theme, as shown in Figure 5.
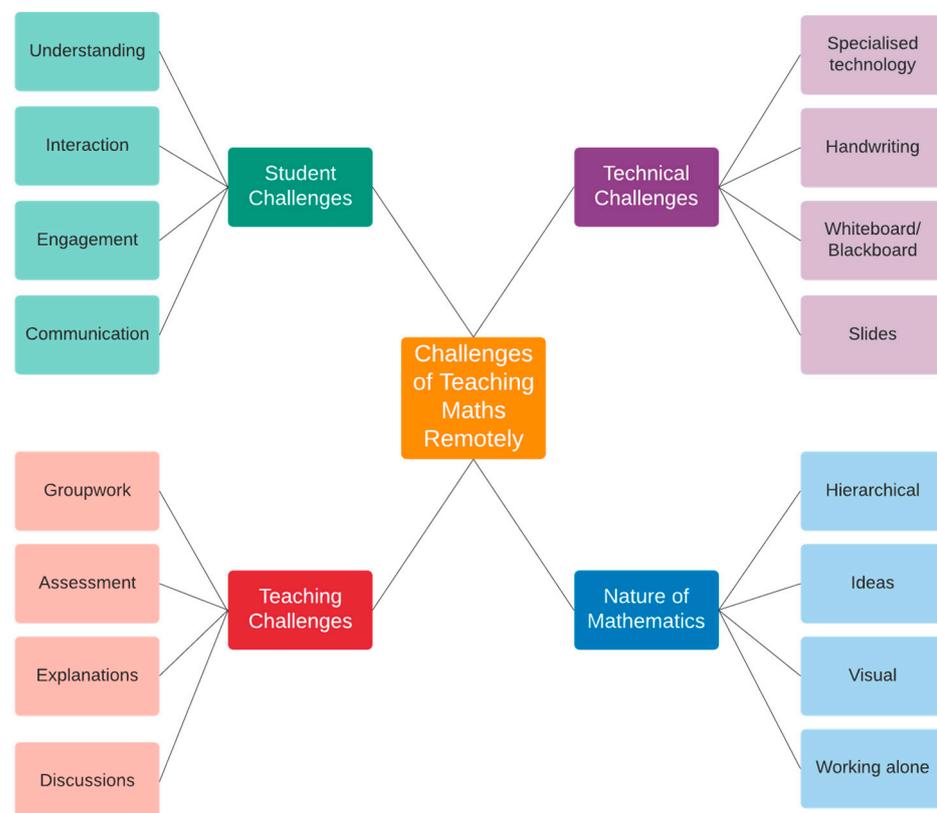
Figure 5. Themes and sub-themes in response to the question "Do you think that teaching mathematics online differs in any way from teaching other disciplines online? Please comment".

3.2.1. Technical Challenges

The most common sub-theme to emerge from the "technical challenges" theme was the need for specialised technology for the teaching of mathematics, with 28% of comments referencing this. Many respondents highlighted the "*technical issues specific to maths to do with sharing written work while discussing maths*", with a common observation being that "*(m)ost software assumes written English (or some other spoken language). It is hard to communicate mathematics online.*" Respondents reported finding tablets particularly useful in this regard. Closely related to this sub-theme was that of lecturers' desire to handwrite mathematics in real time during their lectures, which emerged in 19% of comments ("*The need of writing down while speaking is typical of maths*"). Many spoke of how difficult they found it to teach without being able to handwrite the material in their usual way ("*Writing mathematics is a core part of how I explain mathematical arguments in my teaching, I found it very constraining not to be able to do this live*"). Even with appropriate technology, many reported struggling to adjust ("*Not being able to scribble on paper/whiteboard feels really*

challenging"). There were numerous specific references to blackboards or whiteboards in 15% of comments, with most mentioning the constraints imposed on teaching without access to physical blackboards/whiteboards (*"I missed having a large blackboard space to lay things out in, so that I didn't have to flick between material"*). In addition, 10% of comments referenced the fact that, although commonly used in other disciplines, slides were simply not enough in mathematics (*"math is not easily and reasonably taught by using slides, so much harder to go online than many social sciences"*).

3.2.2. Student Challenges

The next most common theme related to the challenges that lecturers perceived relative to students. By far the most prominent of these, with 16% of comments overall, was the difficulty of gauging students' understanding of material when teaching remotely (*"During mathematical derivation or tutorial, you needed to see faces of students to gauge whether they are with you"*). Lecturers spoke of having lost the ability to *"read the room"* and of how they struggled to judge when students were stuck on material (*"How do you know which concepts they are struggling to grasp? They rarely tell you"*). This linked closely with the sub-theme of communication (13% of comments) - specifically students' difficulties in communicating mathematics, either by typing or expressing it orally. Lecturers identified that many students possessed neither the technology required nor the technical know-how to communicate mathematics effectively online (*"two-way communication of equations and diagrams is essential. It's relatively easy for us to produce these but students, especially those without good latex skills or access to a tablet computer or graphics tablet, struggle"*). Although lecturers themselves may have possessed this technology, it was not enough to facilitate communication (*"Our university quickly enabled us staff, but students did not have access to that technology and it was therefore extremely difficult for them to show us their work"*). This naturally led to challenges around interaction within the class (11% e.g., *"Lectures lose a lot when moved online because interaction with the class is harder/impossible"*), as well as student engagement (9%, e.g., *"engagement levels in mathematics actually tend to be even less online than in person"*). All of these challenges culminated in lecturers' concerns about students who did not properly understand material or engage sufficiently, and the "invisibility" of these struggles in a remote teaching environment: *"You cannot wander around the class and engage with students and talk to them and help them with their struggles. The students mostly do not attend the online classes we offer and then we cannot see what they are doing, we need to wait for them to ask for help. So students could be really struggling and that is invisible to us unless they choose to make it visible"*.

3.2.3. Teaching Challenges

In addition to their concerns about their students, lecturers also spoke about the challenges inherent in implementing some of their usual teaching techniques while teaching remotely. Principal among the sub-themes was that of the importance of face-to-face teaching for explanations in mathematics, with 15% of the comments referencing this (*"Very often it is easy to explain something in a face-to-face situation, but online it is much harder (even using video conferencing)"*). Many respondents did not elaborate greatly on the reasons for this, simply saying that it was "easier" in-person (e.g., *"Teaching mathematics involves explaining logic which I find much easier face to face"*). 1Ten percent of comments referenced classroom discussions, although these were split into two opposing camps: those who highlighted the difficulty of involving students in discussions around mathematics, both to explore material in more depth (*"if I want students to learn arguing I cannot use multiple choice tests"*), and to provide feedback to students in real-time (*"there is a need to correct or shape faulty opinions"*); and those who felt that mathematics was not a discursive subject (*"There is very little that is discursive"*). Assessment challenges featured in 7% of comments overall, with respondents commenting on the usual, closed-book assessment format used in mathematics (*"I think standard formal examinations (not open-book, with a time-limit and invigilated) are more important in mathematics than in other subjects such as the humanities"*), as

well as plagiarism issues ("*there are much more differences in assessing it, because of how easy it is to cheat*"). The difficulty of marking assessments in mathematics also featured ("*Marking hand-written maths online is very slow and inefficient*"), with lecturers observing again how students did not possess the technology to be able to provide anything other than *"lots of poor scans"* to be graded. Lecturers also identified a challenge in continuing with group-work in the manner in which they normally would have done (6% of comments), with some used to getting students to teach each other various aspects ("*the way I teach, I observe the students working through problems most of the time and have them come up and teach each other. All that is lost online*"), and others used to assigning group projects ("*For the mathematics that I teach, group engagement is important (for group modelling projects)*"). One lecturer noted that the absence of group-work meant an increase in workload for the lecturer as "*students lose motivation much quicker and little problems are all brought up to me and the big group instead of solving them directly in group work*".

3.2.4. Nature of Mathematics

Finally, respondents pointed to the specific nature of mathematics as a discipline, in terms of the differences of teaching it remotely compared to other subject areas. Respondents were somewhat divided about the benefits of working on mathematics alone (10% of comments), with some maintaining that "*math is much harder to work on alone but much easier in a group*", while others felt that "*On the end of the day, to learn something in mathematics you need to sit on your own*", with one lecturer describing it as an *"individual voyage"*. Several lecturers mentioned how they felt that students were not able for self-study in mathematics and that this posed problems for them. Another common sub-theme, with 9% of comments overall, related to the development of ideas in mathematics as a core aspect of teaching and learning within the discipline ("*the evolution of the idea is very important to be shown in mathematical courses*"). Again, lecturers struggled to create an environment suitable for this when teaching remotely ("*Mathematics involves building up knowledge together with the students, not just spelling out recipes. Bringing the students to building up knowledge with you when you are talking in front of a screen is difficult*"). In addition, 7% of comments highlighted the hierarchical nature of mathematics, in which one topic builds upon another ("*Since maths knowledge is very hierarchical it is very important that you see that your students understand before moving to the next step*"). Lecturers were concerned that they were unable to deal well with individual misconceptions in a remote teaching environment and that this would cause problems for students later on ("*Mathematics has so often each individual student having problems at different points, and if these points are not sorted, the following material is not really accessible*"). The visual nature of mathematics was also mentioned by respondents (6% of comments overall), with mathematics described as a *"visual art"* in which there is a *"need for students to see as well as hear—the visual nature of formatted mathematics"*. Again, lecturers mentioned the difficulty of ensuring this in an online setting.

3.3. Advantages and Disadvantages of Teaching Mathematics Online

At this point, we wanted to explore what mathematics lecturers perceive the advantages and disadvantages to be of teaching mathematics online, following their experience during emergency remote teaching.

3.3.1. Advantages of Teaching Mathematics Online

There were 174 comments made under this question, and by far the most common theme to emerge was that of flexibility, with 43% of comments specifically mentioning this. In most cases, respondents seemed to be referring to flexibility in terms of scheduling, either of their own time ("*I can choose the time of teaching and organize my day*") or that of their students' ("*Students can access at a time to suit them*"). Lecturers also saw the fact that they now had recorded material available as an advantage (20% of comments), with many of these mentioning that such recordings allowed students to work at their own pace (15% of comments) ("*Students can re-watch the material as often as they want and in a*

pace that suits them"), or specifically that such recordings would be reusable in future years (6% of comments) (*"Recorded lectures/labs are very useful to have for the future to facilitate flexible/distance learning"*).

Being able to work in any location was another advantage identified by the lecturers, mentioned in 19% of comments (*"You can teach from anywhere"*). The specific lack of a commute featured in 13% of comments (*"Students/teacher spend much less time spent in traffic"*), with a few respondents identifying cost savings for students as a result (*"students can work from home, which may be advantageous to those who have money issues"*). Others mentioned that this technology would mean that lecturers who were abroad for work would still be in a position to continue with their classes (presumably when such travel is commonplace again). Despite common concerns about disengagement among students during online learning, 3% of comments actually mentioned that attendance improved (*"I also think it allowed more students to attend the lecture easily"*) due to students not having to travel.

In 10% of comments, lecturers identified the self-study aspect of online learning as an advantage. Some favoured the flipped classroom approach made possible by the technology (*"As I am an advocate of flipped classroom, I could instead assume that students engaged with the notes before they view my videos or got in touch with me regarding a problem."*); others spoke of the benefit on online materials as supplementary learning resources (*"It can be best used to supplement what is being done in class"*). Several saw benefits from the increased responsibility placed on students for their own learning (*"In general, it forces students to be more independent, which is a good thing long term even if it is more difficult short term. Some students find that they are more capable of figuring things out for themselves than they realised, and learn to be more self-directed"*), although there were those that felt that this most likely only suited stronger students (*"It probably suits well-motivated students with a sufficiently strong background"*).

Ease of communication was another advantage cited in 9% of comments, with lecturers observing that *"(s)tudents were more willing to participate in discussions"* and *"(u)sing polls you can get very valuable student feedback on their level of understanding as you go along. This cannot be gauged as effectively face to face"*. The anonymity afforded by some communication tools appeared to encourage students to ask questions in a way that would not have usually happened in the classroom, with students availing themselves of the chat function in Zoom or whichever technology they were using.

Interestingly, given that two often-cited advantages of online teaching are accessibility [19] and ease of large-scale assessment [20], it is of note that only 4% of comments mentioned either of these. Accessibility tended to be mentioned without any further comment (*"(a)ccessible for students with disabilities"*), although comments on assessment often provided further details (*"I can see some advantages to computer-marked assessment, particularly for lower-level material and for judging threshold attainment"*).

3.3.2. Disadvantages of Teaching Mathematics Online

The disadvantages of teaching mathematics online was commented on by 207 respondents, with considerable overlap between this question and the responses to the particular challenges of teaching mathematics online, as might be expected, but with none falling under the theme of "Nature of Mathematics" that was seen in that section. The distribution of comments under the three main themes of Student Challenges, Teaching Challenges and Technical Challenges also differed substantially from the previous question, in which the last of these featured most prominently. By contrast, 81% of respondents mentioned Student Challenges as a disadvantage here, with 44% citing Teaching Challenges, and only 12% commenting on Technical Challenges in this section.

Most of the sub-themes under student challenges had been mentioned in relation to teaching online, with "interaction" the most prominent sub-theme of all, having 35% of respondents commenting under this heading (*"Very poor for interaction with students"*). A fifth of comments alluded to issues with engagement (*"Students do not engage nearly as*

much"), while a similar proportion mentioned again how hard it was to gauge student understanding and progress while teaching online (*"I can tell the 'mood' of my class a lot better in a classroom and what they seem to understand and what I need to do more work in"*). A new sub-theme that emerged strongly here, with 15% of respondents commenting about it, was that of "community" (*"widespread online learning makes it harder for a community of staff and students to develop"*). Respondents were particularly concerned about the impact of this lack of community spirit upon students, both in terms of learning and emotional support (*"For the student, the human element is missing or greatly reduced. It seems to be harder for them to ask 'small' questions. Sending an email is a bigger deal than asking me something as they walk out of the classroom. They probably also miss the (face-to-face) peer support"*). They also cited difficulties with lack of the kind of structure that comes from community engagement (*"I think students benefit from the structure and routine that comes with regular physical contact time through lectures and tutorials, both in seeing the lecturer/tutor and seeing other students"*). Communication difficulties was also mentioned, as before, by 13% of respondents.

The most cited teaching challenge, with a fifth of respondents mentioning this, was that of the time-consuming, labour-intensive nature of teaching online (*"dealing with people in person is a much faster and effective means of aiding their understanding"*), with many of them mentioning the personal impact of this (*"MUCH more work and stress"*). Thirteen percent commented upon assessment, citing the difficulty of examining online (*"I have not encountered a good solution for proctored exams"*), the increase in cheating (*"Standing over the legitimacy of the assessment. How do you stop cheating in remote exams/assignments"*) and the awkwardness of marking (*"marking (handwritten) exams on a tablet will be mind-numbingly slow compared to doing it with paper scripts"*). The difficulty of discussion and feedback again featured, this time in 10% of comments, with just 4% of them concerning group-work this time.

Respondents gave far less detailed responses in relation to technical challenges here, having done so in the previous question, and the only new sub-theme to emerge in the 12% of comments under this general theme was that of inequality in relation to disadvantaged students have less access to technology (*"It breeds inequality (of resources, access, class) between students"*).

3.4. Personal Circumstances

The next research question we wanted to explore was whether there were personal circumstances that affected mathematics lecturers' ability to engage with emergency remote teaching more than they might have wished. The first of the personal circumstances we asked about involved their working conditions at home, in terms of access to essential broadband/hardware/software to conduct their teaching. Almost all respondents answered these questions ($n = 252–255$), with 89% stating that they had sufficient access to broadband/wifi, 73% to hardware, and 86% to software. Among the 84 respondents who commented further, the most common themes were: purchasing enhanced wifi/hardware themselves (18% e.g., *"I did spend a fair amount of my own money on extra hardware"*); unresolved problems with their broadband/wifi (16% e.g., *"We live in a location that cannot get broadband"*); issues with their laptop (14% e.g., *"My laptop struggles with CPU requirements"*); and receiving nothing from their university (10% e.g., *"the university did not supply any of the hardware necessary for the remote teaching"*).

46% of respondents (119 individuals) self-identified as having caring responsibilities during the pandemic, amounting to 41.5% of male respondents and 50.9% of female respondents, as shown in Figure 6.
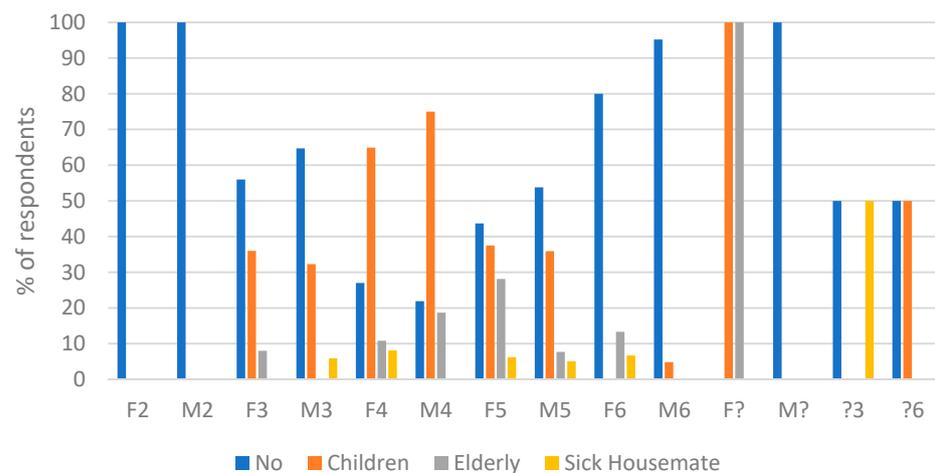
Figure 6. Percentage breakdown of responses to the question: "Did you have caring responsibilities (e.g., young children, elderly relatives, sick housemates)?" by gender and age, where F2 represents a female respondent aged 20–29, M3 represents a male respondent aged 30–39, and ? represents "prefer not to say" ($n = 257$).

The vast majority (82%) of these listed having children; 22% were caring for elderly relatives; 5% for household members who had fallen ill; 4% were caring for a spouse/partner; and 3% for a family member. Half of these respondents said that these caring responsibilities impacted upon their ability to engage with online teaching as fully as they would otherwise have done. This was especially prevalent among those who have children, where half (48% of males with children and 65% of females with children) felt that this had adversely impacted their online teaching, with comments such as: *"My working time was very limited, especially since I had to help my son with his schoolwork"* and *"It was hard to concentrate on teaching when I heard my children play or fight in the next room."* Many of those who stated that it had not impacted upon their online teaching felt that other aspects of their work had suffered, such as research (*"I sacrificed my research (rather than my teaching) in order to manage my caring responsibilities"*) or administrative duties (*"If anything suffered it was admin (e.g., making the kids' lunch while logged in (with mic muted and camera off) to some pointless meeting that I could not have avoided had I been physically present)"*). Alternatively, many referenced the ways in which the increased workload impacted upon themselves personally, such as the respondent who observed that *"the question whether having children impacted online teaching seems back to front. The surge in workload impacted my children by taking me away from them."* Others observed that *"Like many, I just worked VERY LONG days to get it all up and running"* or referenced their poorer work-life balance and the stress involved, or simply the physical constraints involved in working from home (*"Our flat is not big enough, I work from the windowsill in the bedroom, sometimes from the bed."*).

3.5. Impact upon Future Style of Teaching

Finally, respondents were asked if this experience of teaching online will impact how they teach in the future. There were 191 responses here, of which 61% said it would, 22% felt it would not, and the others were undecided. There were 115 further comments under this question. Of these commenters, 11% made it clear that they hoped to never again have to teach online (*"It will stay as a life experience that I never want in my career again"*), with a few respondents even stating that they would leave the profession if they had to teach online long-term (*"if this is the way we are going to have to teach going forward I will be considering retiring early"*). However, the remainder of the comments were considerably more positive about the impact, with 16% stating that they learned a lot through the experience; some felt this would impact upon their in-person teaching (*"I hope to be able to use what I learnt in the real classroom"*), while others thought that it would influence their future online teaching (*"I learned a lot about the technology and student experience of video lecturing which will shape*

how I do it in the future"). Fourteen percent mentioned intending to provide either online lectures, or recordings of their live lectures in the future, that students could view again afterwards. Many respondents stated that this decision was in relation to feedback from students ("*Students reported LOVING having recorded lectures*"). A tenth felt that while such online recordings were important, they would be less inclined to record entire lectures and instead use videos as a supplement "*to complement rather than replace lectures*", either by focusing on particularly challenging topics ("*I will still record some snippets about more difficult material*"), or else by providing basic material so as to free up class time for more difficult areas ("*I shall put more material online to deal with low-level, procedural skills. It would be good if this freed time to concentrate on more strategic issues in face-to-face teaching*").

In summary the key findings were:

- The vast majority of lecturers had no prior experience with online teaching of mathematics;
- Online teaching was very stressful initially but less so with experience, yet it was reported to be time consuming regardless of experience;
- The majority of respondents prefer to teach mathematics face to face, particularly for engagement and assessment of learning and understanding purposes;
- There is a distinct need for specialised technology to teach mathematics effectively online;
- Online teaching of mathematics offers a flexibility that is not present with face-to-face teaching;
- There are a number of external factors, such as caring responsibilities, which impact adversely on one's ability to teach effectively online when at home.

4. Discussion

This paper posed five research questions relating to the experience of mathematics lecturers in higher education adapting to emergency remote teaching. Initially, we set out to find out how mathematics lecturers in higher education would describe their experience of emergency remote teaching, both when they first began and by the end of their teaching semester. It is important to recall that over 90% of respondents reported little or no prior experience of teaching mathematics in an online environment and the move to online teaching requires the acquisition of "new skills and competencies" for a lecturer [21]. Northcote, Reynaud, Beamish, Martin, & Gosselin [22] identified "fear" as a common theme in reflective journals of lecturers moving to online teaching, and indeed, almost three-quarters of our respondents found it "a little" or "very" stressful initially; although this figure dropped substantially by the end of semester, just under half were still finding it stressful at that point. In comparison with their regular teaching, respondents were quite negative about the usefulness of online teaching, perhaps due to the numerous challenges they perceived to be associated with it. Howell, Saba, Lindsay, & Williams [23] recommend the cultivation of a "distance education faculty community", as they found that informal contacts and information from colleagues was of huge importance to educators moving to online teaching. This also appeared to be true of emergency remote teaching, with 65% of respondents to our survey finding themselves more likely or a lot more likely to share teaching tips and support with colleagues at this time. This move towards discussion of teaching practices and approaches among those who would not have traditionally done so is a positive one, with the potential to effect real change to lecturers' pedagogical practices if these conversations were to continue.

When asked about the particular challenges associated with the emergency remote teaching of mathematics, 88% of respondents felt there was a difference between teaching mathematics in this way compared with other disciplines, with 89% of these asserting it was more difficult, a finding that agrees with numerous studies regarding the online teaching of mathematics [24]. Indeed, as recently as 2005, Engelbracht & Harding [2] questioned whether it was even possible that all mathematics could be taught successfully online, and, more recently, it has been noted that advice specific to teaching mathematics online is still limited [25]. In our study, challenges identified fell under four separate headings: technical challenges, student challenges, teaching challenges, and the nature of mathemat-

ics. Notwithstanding the absence of the necessary equipment, many of the issues raised questions related to respondents attempting to mirror their in-person teaching approach online, and encountering difficulties in relation to no longer being able to handwrite their explanations onto large blackboards. Greiffenhagen [26] has written of the "almost iconic status" of the blackboard in mathematics education, and replication of this approach online is not straightforward, even in purpose-designed online modules, let alone in an emergency remote teaching situation. The importance of online interaction and communication with students in terms of student satisfaction and learning has long been established [27], but the concerns of our respondents lay more specifically with their difficulty in gauging students' understanding without in-person facial feedback as well as the added complication for students in attempting to communicate mathematics in an online setting. Indeed, the issue of providing feedback to students was raised as another challenge; in this respect, respondents may have also been experiencing the conflict between the form of feedback (or "feed out") traditionally associated with in-person teaching and the nature of feedback in an online environment, which is often more complex and expected to serve the dual purpose of both advancing and steering learning [24]. In his article about the nature of mathematics, Ernest [28] spoke of the importance of *"the active construction of understanding built on learners' own knowledge"*, and concerns about the creation of an online environment where this is possible abounded among our survey respondents. While there was disagreement about whether mathematics was a solo or group pursuit, the worry that students were not capable of self-study in the discipline emerged, one that has previously been cited by Tan & Hung [29]. The response to identifying specific challenges associated with teaching mathematics online makes a strong case for the importance of discipline-specific training to address such challenges, as found also by Sarfo & Yidana [30].

In terms of the advantages and disadvantages respondents now perceived to be associated with the online teaching of mathematics, almost half of all respondents cited flexibility as the main advantage they perceived, an advantage frequently reported for online learning [2]. Bennett & Lockyer [31] highlight the importance of balancing this flexibility with specific opportunities for student interaction to increase engagement, tying in with the disadvantages perceived by our respondents in relation to "interaction" and "engagement" while teaching online. The time-consuming nature of online teaching was the main teaching challenge cited here, an issue which has long been associated with a move to online teaching [32]. In fact, almost four-fifths of respondents reported still finding online teaching to be "a little" or "very" time-consuming by the end of semester, as well as citing increases in their administrative workloads during this time, with two-thirds estimating that they worked more or a lot more hours than their typical working day on campus, echoing a commonly-held concern about the additional time needed for a move to online teaching [23]. Difficulties in creating authentic, legitimate assessments online was another disadvantage raised, one which has been cited in a range of disciplines [33,34], but is of particular focus for mathematics, which relies so heavily on traditional, closed-book proctored examinations [3].

In relation to the question of what impact their personal circumstances had upon their engagement with emergency remote teaching, technical issues were cited by a minority of respondents, with issues in relation to access to broadband/wifi, hardware and software. In addition, almost half of respondents self-identified caring responsibilities. While the impact upon female academics in terms of publishing research has already been highlighted in other research [35], this work shows that female academics with children were more likely than their male counterparts to report that their caring responsibilities also impacted upon how they would have liked to engage with emergency remote teaching (65% versus 48%), a result that is significant with 90% confidence.

Although the vast majority of respondents had never taught online before in any form, within a couple of months of emergency remote teaching, three-fifths felt that their experience would impact upon their future teaching; having been given a "powerful new incentive" to engage with online teaching [36], many had developed skills that they

intended to continue to use in the future. Some specifically mentioned using what they had learned in the "real" classroom, echoing the work of Kearns [37], who found that the experience of teaching online had a positive impact upon the in-person teaching of some instructors. Others intend to move to a more blended approach in future, or at least provide recordings of lectures, which generally prove popular with students [38], although there are questions around whether videos that appear to have been watched actually have been [39]. Although a tenth of those who commented here volunteered unprompted that they never wanted to teach online again, this figure is largely in line with other findings on the experience of online teaching [40].

5. Conclusions

The results of this survey provide a snapshot of a unique period in time, where educators scrambled to adapt to emergency remote teaching in order to ensure the continuation of their students' education. The insights into the experiences of 257 mathematics lecturers, most of whom had little to no prior history of teaching in an online environment, provoke many more questions regarding the most appropriate manner to design online programmes in mathematics, the optimum balance in blended learning approaches, and how to adequately address the numerous challenges raised in relation to the effective provision of mathematics education online. The findings of this research indicate that for many of the respondents, the move to online teaching has been a beneficial experience that will impact positively on their teaching in the future. They have amassed experience, knowledge and resources that will complement their face-to-face teaching moving forward. A significant percentage of respondents, however, did state that it was not as positive an experience for them and as a result they are likely to revert to more traditional methods of lecturing when back in a face-to-face environment. Further research is required at a local level to ascertain the specific reasons for this hesitancy and how these lecturers can be supported by their institutions to utilise the aspects of online teaching and technology to enrich their face-to-face teaching in the way that it did for the other respondents. These insights emerged from responses given after the first few months of the pandemic; as such, further work is required to ascertain what the impact has been since, and we are undertaking a second survey to explore this in more detail. Finally, our work also highlights to some degree the differing impact of the COVID-19 pandemic on the work practices of individuals with caring responsibilities, and the increased workload reported by many during this time.

Author Contributions: Conceptualization, both authors; methodology, both authors; validation, both authors; formal analysis, both authors; investigation, both authors; writing—original draft preparation, E.N.F.; writing—review and editing, O.F.; visualization, E.N.F. Both authors have read and agreed to the published version of the manuscript.

Institutional Review Board Statement: This study was conducted according to the guidelines of the Declaration of Helsinki, and approved by the Institutional Review Board of Dublin City University (DCUREC/2020/079, 1 May 2020).

Informed Consent Statement: Informed consent was obtained from all subjects involved in the study.

Data Availability Statement: Not applicable.

Appendix A. Survey Questions

Appendix A.1. Remote Teaching Experience

This section will ask about your experience of remote teaching.

1. Had you ever done any online teaching before the pandemic? (1 = No, not at all, 5 = Yes, a lot)

2. How did you find online teaching when you first began?

	Not at All	Not Very	Neutral	A Little	Very
Stressful					
Time-consuming					
Difficult					
Flexible					
Interactive					
Useful					

3. How did you find online teaching by the end of semester?

	Not at All	Not Very	Neutral	A Little	Very
Stressful					
Time-consuming					
Difficult					
Flexible					
Interactive					
Useful					

4. Comparing your experience of online teaching with your regular teaching, online teaching is:

	Much Less	A Bit Less	About the Same	A Bit More	Much More
Stressful					
Time-consuming					
Difficult					
Flexible					
Interactive					
Useful					

5. Did you share teaching tips and support with work colleagues more than usual during this time? (1 = A lot less than usual, 5 = A lot more than usual)
6. How did your workday compare to a typical working day on campus, in terms of hours worked? (1 = A lot fewer hours, 5 = A lot more hours)
7. Do you think that teaching mathematics online differs in any way from teaching other disciplines online? Please comment.
8. Did your administrative workload increase during the university closure? Yes/No
9. What advantages do you see to online teaching? Please comment
10. What disadvantages do you see to online teaching? Please comment
11. Will this experience of teaching online impact upon how you teach in the future? Please comment.
12. Have you any advice about online teaching that you would like to pass on to fellow mathematics educators, based on your experience?

Appendix A.2. Personal Circumstances

This section considers a few of the personal circumstances that may have impacted upon your online teaching.

1. When working from home, for teaching purposes, did you have sufficient access to: Broadband or Wifi/Hardware/Software—Yes/No
2. If no, please comment further:
3. Did you have caring responsibilities during this time period (e.g., young children, elderly relatives, sick housemates)? (Please tick all that apply) Children/Elderly relatives/Household members who fell ill/Other

4. If yes, do you feel that this impacted upon your ability to engage with online teaching as fully as you would otherwise have done? Yes/No
5. If yes, what would you like to have done, had you more time?
6. Any other comments that you would like to make

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