MSOR Connections

Articles, case studies and opinion pieces relating to innovative learning, teaching, assessment and support in Mathematics, Statistics and Operational Research in higher education.

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EDITORIAL

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In this edition of MSOR Connections, we present Part 2 of a collection of ideas, issues, solutions and opinions on the teaching, support and assessment of mathematics and statistics, that were presented at CETL-MSOR 2022. Part 1 of this special edition was published on 7th March 2023.

CETL-MSOR 2022 took place in September 2022, when over one hundred delegates from across the globe gathered at Abertay University in Dundee, Scotland for the CETL-MSOR 2022 conference. We were delighted to welcome delegates in person and the conference themes reflected the advent of innovative technologies in teaching and learning, widening access and our recent emergence from the restrictions imposed by the covid 19 pandemic. In March 2020, the Higher Education sector was faced with the task of changing overnight, from traditional in-person teaching to delivering degree level programmes remotely without compromising access or quality. Online delivery of both teaching and assessment became the norm and while this initiated a rich period of innovation and creativity for the sector, issues such as digital poverty and mental health became more apparent. Since the end of the pandemic, we have had the pleasure of seeing our campuses full of students once more but whether our institutions have adopted ‘new normals’ such as Blended Learning or returned to in-person teaching, it cannot be denied that higher education teaching has changed.

In this edition we present five papers on the themes of implementing asynchronous learning, including both flipped classroom and online programmes, skills and assessment for employability and game-based learning. Mathias et al. explore the flipped classroom for teaching statistics to Widening Participation students and highlight several important considerations relating to cohort and content. Student reflections on asynchronous material, their preferences and how they interact with online lectures is discussed in Jones et al. and to complement this, Jack et al. present their reflections on the development and delivery of online distance learning postgraduate programmes and how to address the expectations of this rapidly expanding global market for higher education. In addition to online learning, Loddick and Mansfield reflect on how a game-based learning session was designed, delivered, and evaluated for teaching quantitative concepts. Finally, Masterson et al. discuss embedding problem solving and communication skills, in a bid to address the graduate attributes demanded by a rapidly developing employment market and how these skills can be assessed through ‘authentic assessment’.

MSOR Connections can only function if the community it serves continues to provide content, so we strongly encourage you to consider writing case studies about your practice, accounts of your research into teaching, learning, assessment and support, and your opinions on issues you face in your work. We welcome submissions to the journal at any time.

Another important way readers can help with the functioning of the journal is by volunteering as a peer-reviewer. When you register with the journal website, there is an option to tick to register as a reviewer. It is very helpful if you write something in the ‘reviewing interests’ box, so that when we are selecting reviewers for a paper, we can know what sorts of articles you feel comfortable reviewing. To submit an article or register as a reviewer, just go to http://journals.gre.ac.uk/ and look for *MSOR Connections*.

RESEARCH ARTICLE

Widening participation students' experience and perception of flipped learning statistics compared with traditional teaching in higher education

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Abstract

This paper presents data from a study comparing student experience and attainment when teaching statistics using Traditional Teaching (TT) and Flipped Learning (FL) approaches on a Foundation level module at a UK university. A survey of students' experience and perception of FL was conducted at the end of the year. The results showed that the students liked the flexibility of FL and believed that studying asynchronously encouraged them to improve their independent learning skill and motivated them to search for more information for the subject, a finding broadly supported by other studies (Price and Walker, 2021). However, what was surprising, is that students believed they learned 'better' with TT than with FL, a perception supported by student overall attainment data. The study concludes that careful considerations must be made to make FL effective. These include the student demographic and their mathematics competency, the module contents and difficulty level. Otherwise, the use of FL may reduce students' engagement and academic performance in mathematics at Foundation level.

Keywords: flipped learning, non-traditional students, widening participation, statistics.

1. Introduction and theoretical background of the study

The Covid-19 pandemic has dramatically changed how we work across all sectors of business, including university teaching. Teaching is evolving to further embrace flexible learning to meet the diverse needs of learners and enable them to take more personal responsibility for the learning process. These changes have been possible because of the vast potential of readily and easily accessible information and resources available online, as well as rapid advances in learning technologies that are making online teaching more accessible and engaging. Flexible learning continues growing from technological, pedagogical, and institutional perspectives, and for most universities, the question about flexible learning is not 'if' but about 'how' (Loon, 2022).

One mode of flexible learning is flipped learning (FL), which employs a pedagogical approach in which students learn knowledge asynchronously following instructions from tutor and then apply concepts and engage in the subject matter in a synchronous interactive environment (www.flippedlearning.org). The pedagogical benefits of FL to the learners, as evidenced in many studies, includes improvement in academic performance, cognitive and affective domains (better engagement in learning and higher motivation) and transferable skills (independent and self-regulated learning and time management) (Bond, 2020; Birgili et al., 2021). The current understanding of the effectiveness of this strategy is, however, mostly based on research conducted at secondary school or at undergraduate level on traditional students entering a university through a conventional route; many studies were conducted in Asia (Bond, 2020; Birgili, et al., 2021). Limited attention has been given to how FL impacts on widening participation and non-traditional students.

Widening Participation and non-traditional students, in this context, are comprised of students from under-represented groups in higher education (Laing and Robinson, 2003; OfS, 2020). Many of these students have not gained sufficient skills and subject knowledge required to access degree study, often due to disrupted educations and, therefore, choose a Foundation Year programme as an extra year of study to gain entry to their chosen undergraduate course. Foundation Year programmes are often established within a university specifically as a part of the university's commitment to improving access to higher education from under-represented groups (Laing and Robinson, 2003; Leech and Marshall, 2016).

The teaching on Foundation programmes in many universities has two objectives; the first is to fill the gap between a student's current subject knowledge and the assumed knowledge of their chosen degree programme (i.e., the UK A level content associated with pre-requisite qualifications for standard entry) and the other is to develop a student's cognitive, academic and transferable skills, epistemological maturity, self-regulation, and self-efficacy. In this respect, FL has been shown to positively contribute to developing transferable skills among students such as self-directness and self-management (Cakiroglu and Ozturk, 2017; Narendran et al., 2018). FL can also improve student behavioural and cognitive engagement (Jamaludin and Osman 2014, Huang, et al., 2019).

In this paper, we evaluate Foundation students' experience of being taught statistics using FL and TT approaches, within a research-intensive UK university Foundation Programme in academic year of 2021 - 2022. The aim of the study is to provide responses, evaluations, and recommendations to the following questions:

1. Do Widening Participation (Foundation level) students believe that a FL makes a positive contribution to learning mathematics? The hypothesis is that Widening Participation students would find FL beneficial in improving cognitive and transferable skills.

2. Does the use of FL have a positive impact on student attainment when used to teach mathematics to Widening Participation (Foundation level) students? The hypothesis is that FL would provide Widening Participation students better learning experience, hence improving their attainment in mathematics.

2. Context

The Foundation programme discussed in this paper provides access to a wide range of degree courses for learners from under-represented groups in higher education (OfS, 2020) who need a year 0 course to prepare them for undergraduate studies. These students are classed as Widening Participation students and most are from families with low household income or low socioeconomic status. Demographically, the Foundation group consists of two types of students: those who have had more than 3 years away from education and are returning to study as mature students aged over 21; and another group who completed advanced level (A-level) in school in recent years but did not achieve desired grades for direct entry to the university courses, often due to educational disadvantage.

This study focuses on two groups of students who studied Mathematics 1 (M1) for social sciences and Mathematics 2 (M2) for Business and Biology. The number of students in the M1 group is 30 and in the M2 group is 22. The averages of GCSE grades (graded from 1-9) achieved in both groups are similar, 5.7 for the M1 group and 5.6 for the M2 group.

The study modules contained two themes, algebra and statistics. Each theme was taught for 2 hours per week for 20 weeks. The statistics content, which is the focus of the study, was the same in both modules and was taught by the same tutor. Statistics was chosen as the topic for the study because the subject does not require very high level of algebra skills and the students can study the content with little support. Moreover, there are existing evidence claims that FL positively impacts on learning introductory statistics for undergraduates (Farmus, et al., 2020).

3. Traditional versus Flipped Learning

The research was designed to allow both groups to experience both FL and TT approaches (see table 1), thereby permitting students to reflect on the effectiveness of the FL approach in comparison to TT approach in supporting them to develop transferable skills, improve their emotional and cognitive engagement in learning as well as academic attainment. The M1 group studied descriptive statistics using FL for 10 weeks in the teaching block 1 (TB1) while the same content was taught to the M2 students using TT, then both groups were assessed on the content with an open-book test. The teaching methods were swapped for the following 10 weeks in the teaching block 2 (TB2), followed by an open book test, when teaching inferential statistics.

Table 1. Modes of teaching in M1 and M2 in the 2021-22 academic year.

Statistics content	M1	M2	Assessment
Term 1 (10 weeks): Descriptive analysis	FL	TT	Open book
Term 2 (10 weeks): Inferential analysis	TT	FL	Open book

The teaching cycle of a week for FL typically involved an instructed asynchronous learning activity followed by synchronous learning in a face-to-face classroom setting. The asynchronous activities included an introduction to the topics of the week, the aims, study tasks, and practice questions. The student's preparedness for the synchronous session was assessed at the beginning of each synchronous session using an online voting tool. This was followed by several high cognitive exercises. Optional, weekly online practice was also provided to allow the students to further consolidate their knowledge. The teaching cycle of a week for TT typically involved initial classroom teaching of the week's topics, followed by practice after the class. Students who demonstrated signs of struggle with learning tasks in both groups were provided with one-to-one support by a tutor and offered an additional one-hour optional workshop.

The asynchronous activities required staff to produce many online materials, which can be time consuming (Mason, et al., 2013). MyMaths, an interactive online teaching and homework subscription website, developed by Oxford University press, and tutor pre-recorded videos were used as the source of the learning material for asynchronous activities in the flipped learning teaching. MyMaths resources were also used as non-compulsory consolidation material for the traditionally taught classes. Using interactive lessons designed by MyMaths saved a significant amount of work for tutors who could focus on writing instructions for asynchronous activities and prepare synchronous activities and assessment materials.

4. Evaluation

Student experience was evaluated at the end of the academic year, after 20 weeks of teaching. The questionnaire, sent to all students in M1 and M2, included sections asking students about their transferable study skills (4 items), emotional and cognitive engagement (5 items), and overall experience (3 items). The statements in the questionnaire used a 5-point Likert scale from "strongly disagree" (1) to "strongly agree" (5). The Cronbach alpha, a measure of internal consistency, was 0.94, confirming excellent reliability for the questionnaire. Two free-text questions were included to allow the students to provide open explanations about their experiences. The combined response rate to the questionnaire was 35.2%.

5. Results and discussion

5.1 Transferable study skills

Figure 1 shows the responses to questions regarding attitudes toward FL in relation to opportunities for developing independent study skills, student satisfaction with the pace of learning, the degree to which the learning addressed individual student need, and for developing students' time management skills.

Results indicate that 68.4% of the students agreed or strongly agreed that FL encouraged them to develop independent study skills and that they were satisfied with the pace of learning. Only 5% and 15.8% disagreed or strongly disagreed with these statements, respectively. These results are consistent with Chivata and Oviedo (2018) who found that 87% of undergraduate students agreed and strongly agreed that they liked the flexibility of FL when studying an English subject at the Colombia University. Wilson (2013) suggests that FL strategy creates a feeling of greater accessibility, which is particularly important in the diverse ability cohorts and when teaching subjects, like mathematics and statistics, that often cause anxiety among the students (Wahid et al., 2014).

Only 57.9% and 47.4% of the students agreed or strongly agreed that the asynchronous activities helped them to tailor the learning to meet their needs and improved their time-management skills, respectively. These results are in line with Mason et al. (2013) findings among mechanical engineering students who recognised that the flipped learning strategy required self-discipline and some adjustment to their study habits.

Student's response in the free text also supported what has been found in the questionnaire. In the open-ended comments the students explained that they liked FL activities because

> *"It gives me more time to understand each mathematical concept. Or to speed up certain parts of the video if needed."*
>
> *"Allowed you to pick and choose which topics to learn more about before the lesson."*
>
> *"Flipped learning allows the brain to digest what you are going to further go over in the classroom"*

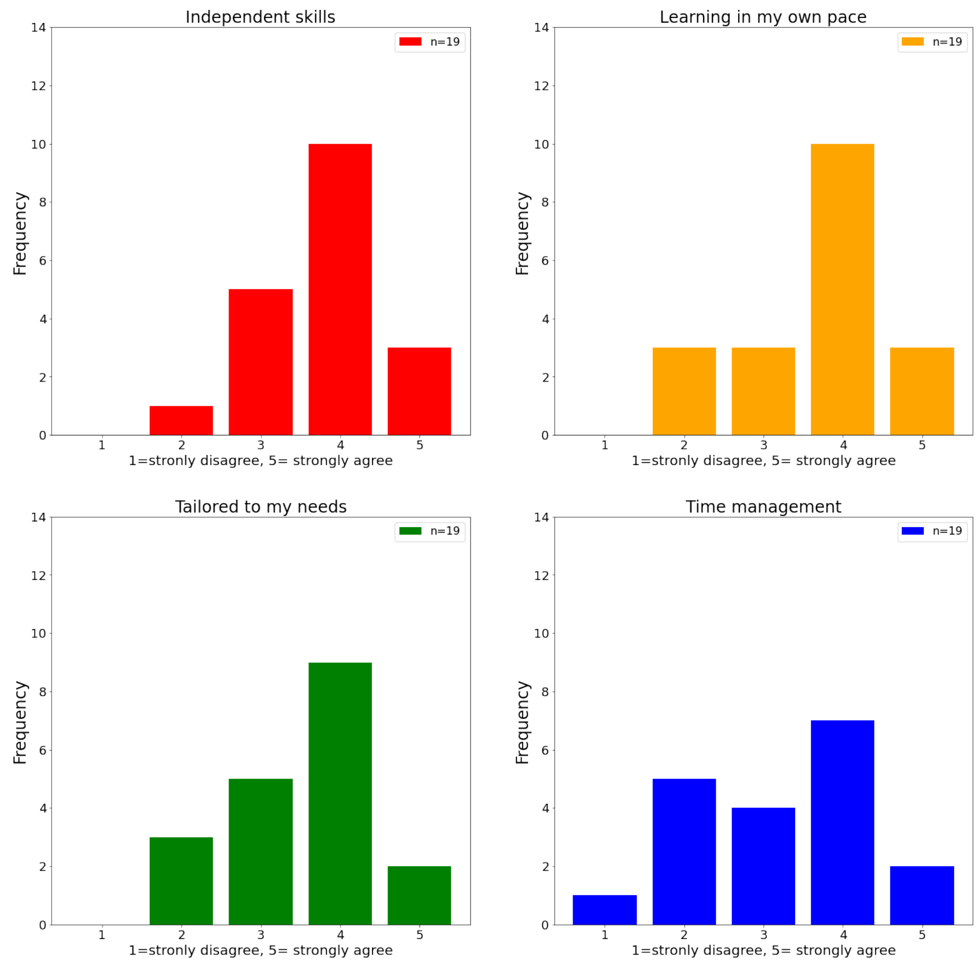

Figure 1. Students' response to the questionnaire regarding study skills

5.2 Emotional and cognitive engagement

Responses to questions about the impact of asynchronous sessions on emotional and cognitive engagement was also positive, as shown in figure 2. Results show that 68% of students agreed or strongly agreed that the asynchronous activities encouraged them to actively search for more information about the subject matter, compared to 26% who disagreed or strongly disagreed. In addition, 79% agreed or strongly agreed that the asynchronous activities were effective in helping them to prepare for the synchronous sessions compared to 21% who disagreed or strongly disagreed.

In relation to student understanding, 58% of students agreed or strongly agreed that studying asynchronous activities made synchronous sessions easier to understand compared to 26% who disagreed or strongly disagreed. Finally, 68% agreed or strongly agreed that studying asynchronous activities encouraged them to attend synchronous sessions compared to 21% who disagreed or strongly disagreed. In the open-ended comments the students explained that they liked FL's asynchronous activities because:

> *"It encouraged exploring the topics within different forms of media such as YouTube."*
>
> *"It gave me a chance to prepare before class, so I understood more"*
>
> *"They made me feel more confident"*

However, the data also shows that, in general, the students did not think that the FL approach to teaching mathematics improved their interests in mathematics; only 47% of the students agreed or strongly agreed that studying FL activities made synchronous sessions more interesting, whilst 26% were not sure and the remaining 26% disagreed. This contradicts other studies, which suggest that students who were taught using FL strategy found the module more interesting in comparison to cohorts taught using the traditional methods (Price and Walker, 2021). The reason for these inconsistencies could be that Foundation students in this paper have chosen to study degrees with lower mathematical demands and were less interested in mathematics to start with.

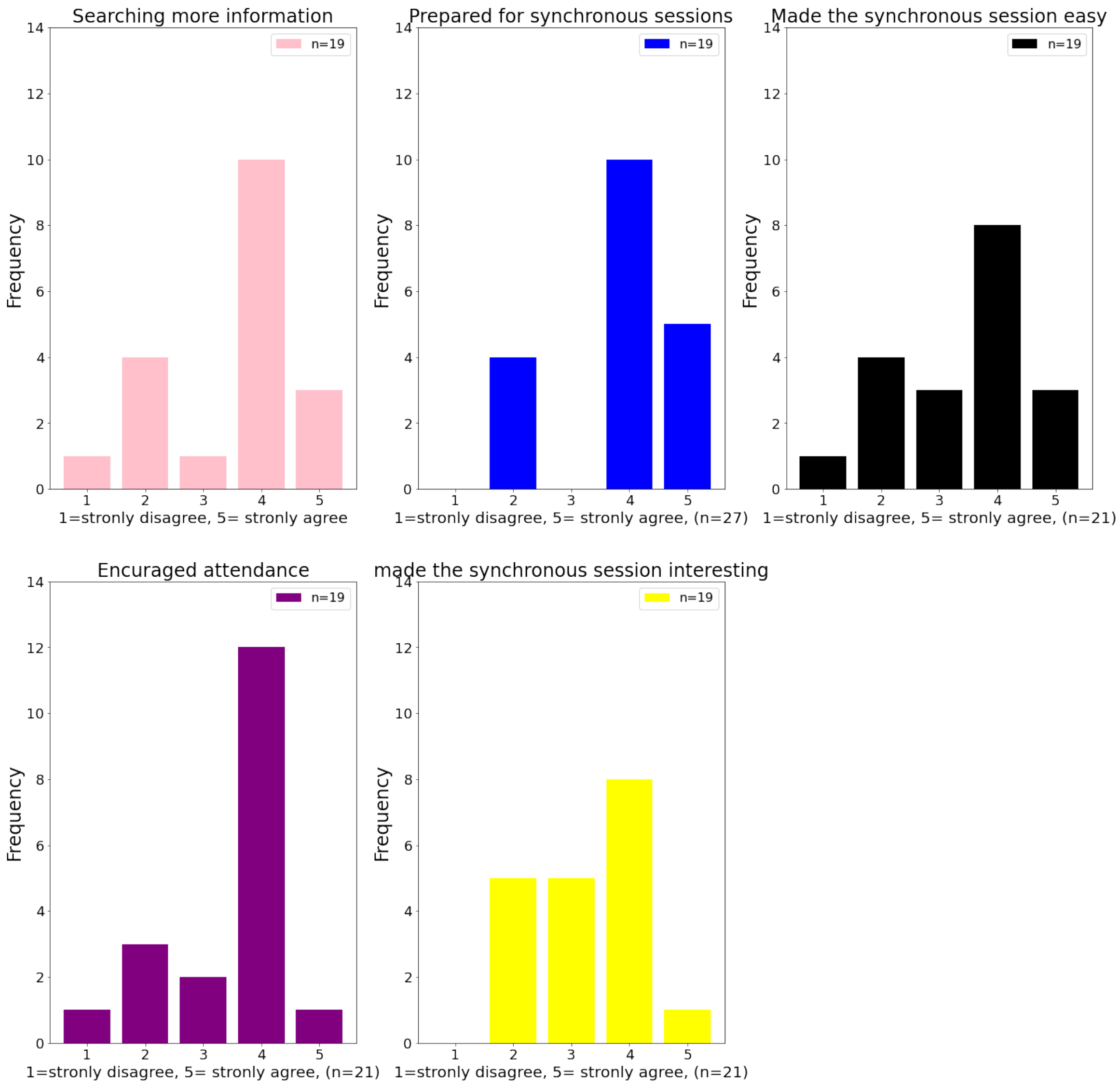

Figure 2. Students' response to the questionnaire regarding emotional and cognitive engagement

5.3 Overall student satisfaction and attainment

The students' responses to their overall satisfaction with FL is shown in figure 3. The results show that 63% of students were satisfied with FL, however, only 42% indicated that they preferred and learned better over the FL in future study. Responses to the open-question on satisfaction with FL revealed that some students felt frustrated when they were not able to ask a question or receive immediate support when engaging with the asynchronous preparation activities as the asynchronous work *"...could frustrate me if I didn't understand"* and *"I prefer, having had difficulty with maths in the past, to be able to ask questions at the time I'm doing the work or I can find myself stalling or unable to continue. So, I preferred the face-to-face sessions in this module. Having said that I think that flipped learning is something I could enjoy doing in my degree pathway next year*." This is somewhat at odds with an observed under-use of the support made available to students.

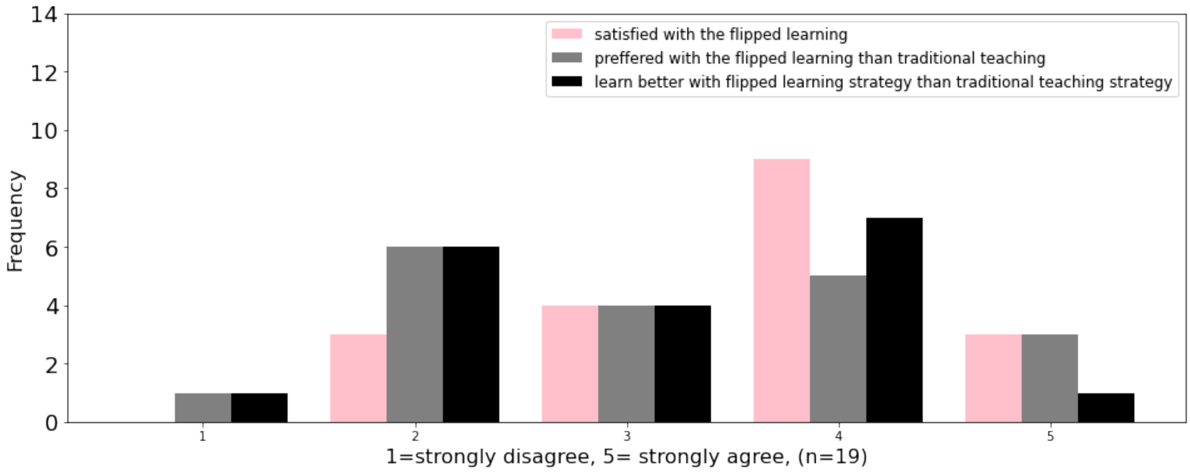

Figure 3. Students' response to the questionnaire regarding overall experience for FL

Table 2 compares student attainment in both groups on statistics assessments. Results show that there was no significant difference between the performance of the two groups using FL or TT when learning descriptive statistics. However, the M2 group achieved lower marks (67.3%) on inferential analysis comparing to the M1 group (73.5%). Although the mark difference is not statistically significant, the 6% gap between the groups cannot be ignored considering both groups have the same level of mathematical skills at the entry of the study.

Table 2. Performances on the statistics of the students in 2021-22

Group*	**M1 (n=30)**	**M2 (n=20)**	**M1 (n=23)**	**M2 (n=16)**
Mean of the GCSE at entry of the study (sd)	5.5 (1.47)	5.6 (1.49)	5.3 (1.81)	5.7 (1.57)
Assessment content	**Descriptive statistics**		**Inferential analysis**	
Mean mark (%)	73.9 (s.d.=16.0) (FL)	73.7 (11.0) (TT)	73.5 (20.1) (TT)	67.3 (17.4) (FL)
p-value (Two sample independent t-test)	0.957		0.313	
Cohen's effect size	0.016		0.333	

* Only the students that completed the tests were included in the means.

The lower performance of the M2 students in inferential analysis raises an important question on what type of knowledge should be flipped and what level of cognitive skills is required for learning the knowledge. Chaeruman (2018) proposed a model of criteria for determining appropriate FL strategy using literatures applied to a revised Bloom's Objective Taxonomy and stated that asynchronous activities should be limited to tasks that are easy to manage individually and require low level cognitive skills, which in turn, should be developed further in synchronous sessions (figure 4). It may be that the level of cognitive skill required for inferential analysis is outside of the range suitable for asynchronous activities used as part of the FL approach noting, that the level of cognitive skills required for the same knowledge could be different depending on the student's previous experience.

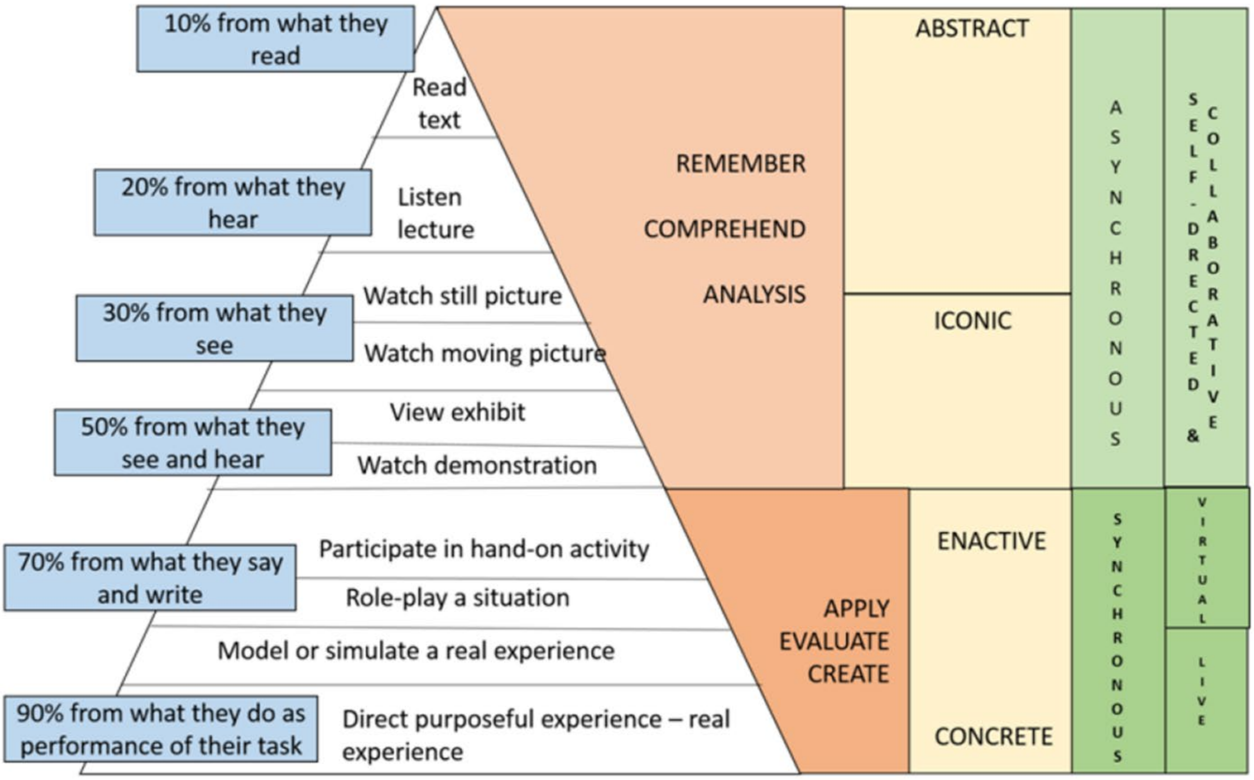

Figure 4. Model of criteria for determining appropriate blended learning strategy (Chaeruman et al., 2018)

Farmus (2020) reviewed literatures on the FL in introductory statistic course for undergraduate students and the results indicated that FL led to statistically higher student attainment than TT. However, all the studies were on undergraduate students who would be competent in mathematics comparing to the Widening Participation students in this study. Moreover, in another example of their highly cited study, Wilson (2013) reflected that although attempts were made to flip all the content when teaching statistics, what was achieved was a half or three quarters flip, and a lot of time was spent summarising the asynchronous course material during the synchronous sessions. This suggests that the design of FL may be limited by the cognitive skills necessary for independently study of the asynchronous materials which FL. Perhaps the balancing asynchronous and synchronous activities requires a tentative, an iterative process, where the teacher can carefully oversee students learning experience and performance and adjust the balance accordingly.

6. Summary and limitations

The first aim of the study is to examine if FL makes a positive contribution to learning mathematics for Widening Participation (Foundation level) students. This study showed that about two-thirds of Foundation students liked FL in general, reporting that FL encouraged independent study skills, allowed them to study at their own pace, motivated them to search for information on their subjects, and to build up their confidence for synchronous face-to-face class activities. This confirms the hypothesis that Widening Participation (Foundation level) students would find that a FL positively contributes to their learning of mathematics. These results broadly agree with the literature (Price and Walker, 2021) and show that FL can benefit Widening Participation (Foundation) students as they transition into HE, encouraging them to develop independent study skills and increasing emotional and cognitive engagement with mathematics.

The second aim is to question if the use of FL has a positive impact on student attainment when used to teach mathematics to Widening Participation (Foundation level) students. It was hypothesised that FL would improve student attainment or, at very least, would not have negative impact on them. However, the study demonstrated the contrary when assessing student attainment on inferential statistics. Therefore, careful consideration should be given to which modules and content can be taught using FL strategy. Firstly, this study advises that not all types of knowledge are suitable for asynchronous activity, and clear consideration should be given to students' cognitive ability and their academic skills; Chaeruman's model of criteria for determining appropriate content and difficulty level for asynchronous sessions may be useful in this regard. Additionally, the FL approach should be considered as an iterative approach, with consideration given to how real-time adjustments can be made to the volume and difficulty level of asynchronous activities; obtaining regular feedback from the students when teaching may help to address this issue and align the FL approach with the student's competency, knowledge, and cognitive skills. Thirdly, appropriate training should be provided to those who may struggle with time management due to the importance of self-regulated learning strategies with FL delivery (Gronlien et al., 2021). As it was mentioned earlier that demographically Foundation students most are from families with low household income or low socioeconomic status, many of these students may have not gained sufficient skills for academic study, often due to disrupted educations. Therefore, time management training may help to raise student awareness of the expectations of FL learning and to help them understand asynchronous study does not mean they must manage the study completely on their own (i.e. they should take advantage of additional support opportunities). Lastly, this study suggests that not all students naturally embrace FL.

The authors recognise that the study has limitations. This study took place at a Foundation programme in a research-intensive university, the structure of the programmes may be different at different HEIs. The number of students who responded to the questionnaire was small and does not represent the full programme cohort. However, the overarching purpose of this article was to draw colleagues' attention to the use of FL in teaching mathematics to students from Widening Participant backgrounds and to discuss the potential benefits and challenges. It is no longer feasible to consider university students as a homogenous group and there remains work to do in finding appropriate teaching strategies to support accessibility for the increasing diversity of students.

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CASE STUDY

Student Video Curation

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Abstract

In the academic year 2020-21 Middlesex University maths students accessed all learning sessions remotely. Each of these interactive sessions was live-streamed, recorded and uploaded to our Virtual Learning Environment, providing hundreds of hours of recorded, unedited maths lectures for students to review. This case study reports on a project (partially funded by an IMA Education Grant) in which we invited undergraduates to reflect on their remote learning experiences and curate these video lectures. Students were asked to identify the most engaging, useful and interesting segments, and categorise and explain their choices in free-text comments to help us develop our approach to remote lectures and video resources. A total of 33 video clips were identified by students across levels 4 to 6 on our specialist BSc Mathematics and BSc Mathematics with Computing programmes. In this paper we will discuss our findings, illustrate with example clips, identify themes in the student choices, and conclude with tips to produce engaging content. We will also discuss applications of video curation as a social pedagogic tool for the current Generation Z students. We will argue that sharing how students interact with digital learning resources can help address the significant digital divide in education.

Keywords: Lecture capture, Student agency, Video curation, Student voice, Lecture evaluation.

1. Introduction and background

Video is increasingly used in university teaching. A recent systematic review on lecture capture (the "synchronized audio and visual recordings of live lectures, which students can download to view at their own leisure") reports that at least 86% of UK universities used some form of lecture capture in 2017, up from 71% in 2016 (Lindsay and Evans, 2021). The COVID-19 pandemic has subsequently caused a wide-ranging and rapid adoption of lecture capture. A survey recently published by the Joint Information Systems Committee (JISC) (2022) of 33,726 students between November 2021 and April 2022 reports that 68% of students have accessed recorded lectures. Further, the survey reports only 42% of students would prefer to be taught "mainly on site" leaving universities to consider the appropriate blend of teaching modes for the future but suggesting that lecture capture will have a large role in this future provision.

Lindsay and Evans (2021) argue that a thorough discipline-specific investigation of effective lecture capture is urgent and undertook a review of the literature focusing on mathematics. They conclude there is some evidence suggesting lecture capture contributes to attrition in on-campus lecture attendance of around 23-30%, and also cite two studies, Zimmerman, Jokiaho and May (2013) and Yoon and Sneddon (2011), who observed 30% of students stating that they perceived lecture capture was a substitute for live attendance. Further, the review suggests that substituting live lectures with lecture capture is negatively associated with student attainment, while there is a positive association if lecture capture is used as a supplement to lectures. There are many discipline-specific reasons why mathematics students in particular may benefit from reviewing lecture recordings: traditionally maths students are expected to multitask in note-taking while engaging with the cognitive demands of understanding lecturers' arguments. Further, the hierarchical nature of mathematics requires that each lecture is understood before the next can be effectively accessed.

The JISC survey (2022) also reports 93% of students surveyed, regularly used a laptop for learning, but very few had access to peripheral devices to help with online learning (such as additional microphones or cameras). Further, for online learning, 51% of students had a poor internet connection, 15% were encumbered with data costs, 16% had no appropriate area to work, and 12% had no suitable device to engage with online learning. Even if students had equitable access to technology, there is a significant "digital divide" in how this technology is used: Generation Z students from lower income families spend more time online but are less likely to use the internet for learning and are less likely to develop digital skills compared to their peers from higher income family (Ipsos MORI, 2018). As universities increasingly use technology such as lecture capture in learning the digital divide could make education less equitable. Consequently, it is important that we close this divide by encouraging all students to develop the digital skills implicitly needed to excel in their courses.

1.1. Partial recording of lectures

Middlesex University mathematics staff have been integrating lecture capture into their provision since 2016. This began as videoing key sections in *Mathematical Analysis* lectures where staff made short recordings of what they regarded to be the key sections of the lectures. In this compulsory second year undergraduate module, specialist mathematics students are expected to understand quite technical proofs before being able to themselves prove related but previously unseen results in analysis. As students are still developing their proof writing abilities, we were motivated to make a strong distinction between the formal statements of the proof and the narrative that explains the strategy and construction of the proof. In a lecture this narration is typically verbal while the formal statements are written, meaning that students will only hear the narration once and may be more concerned with transcribing this narration than engaging with it. Our solution was to point a video camera at the whiteboard during these key sections and upload the resulting videos to our Virtual Learning Environment (VLE) so that students could access the narration at leisure and engage without the pressure of transcription.

Although there were significant technical limitations in the audio quality, legibility of the whiteboard and length of the videos these initial experiments were very popular with students. In an end-of-module questionnaire completed by 7 out of 12 students on the course 4 out of 7 currently accessed the videos at least monthly, while 6 out of 7 intended to access the videos at least monthly in the future (for revision, for example). Further, 5 out of 7 students highly rated the usefulness of the videos, and 3 out of 7 credited the videos as a significant contributor to their mastering of the course. Notably, 6 out of 7 students wanted video recordings to be introduced to their other modules.

The distinction between formal proof and narration is increasingly prevalent in modern mathematical education materials. For example, Jones, Megeney and Sharples (2021a) describe using handwritten digital ink to provide "pedagogic commentary" annotations to typeset mathematics. The textbook market is similarly developing as universities are adopting "long-form" textbooks such as Cummings (2019a), which contain sections such as "Scratch work", "Proof idea" and "Pre-proof trick" before beginning a formal proof, compared to the traditional textbooks “with terse proofs of those results and not much else” that Cummings wittily characterises as “sage on the page” (Cummings 2019b).

1.2. Recording entire lectures

From 2018 Middlesex University mathematics staff were able to produce high-quality video recordings of live lectures thanks to an investment in tablets and styluses for staff (see figures 1,3 and 4 of Jones, Megeney and Sharples, 2021a). This meant that all the lectured content, questions, and critical conversations were captured and could be reviewed by students. These videos were between one and three hours in length and were unedited and uncurated other than being organised by module and week on the VLE. There was no noticeable drop in attendance (one student reported “The recordings are very useful, even though I attend the lectures”) and our VLE statistics showed that on average each student accessed each video 3 times following the lecture (see Jones, Megeney and Sharples, 2021b). Students’ attitudes towards the videos were highly favourable, for example reporting “My favourite thing about the teaching at Middlesex is… the video recording of lectures for our modules” and “All the explanations are on the video, you can really see what the lecturers are doing” (see Jones and Sharples, 2020) and module evaluation surveys made it clear that maths students wanted similar videos for all their modules.

Staff adopted the practice of video lectures at different paces. Universal adoption followed the introduction of the Technology Enhanced Learning thresholds in 2019, a university policy designed to “provide a consistent inclusive student experience” that required each learning session to be “captured in a way that allows students to independently meet the learning outcomes”. At the onset of the COVID-19 pandemic and the resulting lockdowns, maths staff were adept at using iPads to present and record lectures and simply had to connect the iPads to online meeting sessions at home rather than projectors on campus. As this was a relatively seamless shift (other than student access to devices, which was resolved through an iPad loan scheme – see Jones, Megeney and Sharples, 2021a) we opted to deliver the entire 2020-21 academic year remotely, and still deliver around 25% of lectures online in the 2022-23 academic year.

Universities have largely completed the technical elements of adopting lecture capture and more research on what constitutes effective lecturing in this format is needed. This research must include student perceptions, as there is often a gap between lecturer and student perceptions of effectiveness. For example, modern pedagogic approaches leave students “unconvinced as to whether flipped lectures are better for learning” (Novak, Kensington-Miller and Evans, 2017), while perceptions about the quality of mathematical explanation are “largely consistent” across lecturers and undergraduates (Evans, Mejia-Ramos and Inglis, 2022). In this case study we make inroads in understanding student perceptions of lecture capture.

2. Methods

In the academic year 2020-21 Middlesex University maths students accessed all learning sessions remotely. Each of these interactive sessions was live-streamed, recorded and uploaded to our VLE providing around 1400 hours of video. We invited undergraduates to reflect on their remote learning experiences and curate these video lectures to find the most engaging, interesting and useful segments and to explain their choices. Thanks to funding from an IMA Education Grant, we were able to offer students £13.71 per hour of video curation. We recruited six undergraduates from our BSc Mathematics and BSc Mathematics and Computing programmes; one first year (OfQual Level 4), four second years (OfQual level 5) and one third year (OfQual level 6).

Student curators would meet online via the Zoom platform for scheduled video curation sessions. An initial session trained students on the curation process: curators would access the video lecture archive (hosted on the university's MDXPlay video platform and the VLE) and either from their memories of lectures or simply by searching would identify relevant clips of the whole lecture video. Curators would then fill in a webform to identify the clip, choose a category, and write some sentences to explain their choice.

Curators were instructed to "find the best, most interesting, most useful video clips to help us develop our teaching", and were told to look out for video clips that

- helped you get knowledge of the syllabus;
- had a style that worked well for you;
- helped you understand a difficult concept;
- helped you become "unstuck";
- had particularly interesting content;
- were particularly engaging;
- were good lecturing;
- or had other notable features.

This work was done individually within a Zoom "breakout room" shared with the other curators to allow for discussion. A supervising lecturer remained in the main Zoom room to offer support if necessary but to avoid interference only entered the breakout room when requested to do so by the curators. Beginning in June 2020, at the end of the academic year, curators met on 5 separate occasions.

3. Results, thematic analysis and discussion

A total of 33 video clips (5/21/7 clips at each of OfQual levels 4/5/6) were identified across a range of undergraduate modules. These modules are all 30 credit, 12-week compulsory modules except for the 15-credit, 12-week optional module *Combinatorics*. All these modules were delivered as 3 hours of live recorded lectures per week. However, to respond to staff unavailability many modules replaced one week of live lectures with pre-recorded content. Except for a single clip from *Groups and Rings* all the clips were chosen from live recorded lectures rather than pre-recorded videos.

The shortest clip selected was 10 seconds long (a mnemonic for remembering the difference between permutations and combinations) and the longest was 14 minutes (a worked example of job allocations as an application of combinatorics). The median length was 5 minutes 15 seconds (see Figure 1).

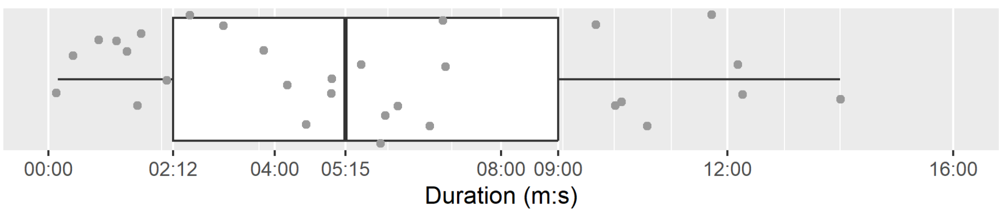

Figure 1: Distribution of chosen clip length (data is jittered in the vertical direction to prevent over plotting).

Curators categorised the clips into pre-defined categories and provided free-text comments for each clip. We identified the following six themes from the free-text responses: Examples, Explanation, Recap/Overview, Student-Led, Visualisations, and Technology (see Table 2). Where we have the appropriate permissions, the clips have been collated by theme into six short videos of approximately 25 minutes each (Sharples, 2022). We relate the emergent themes to the pre-defined categories in Figure 3, where it is evident that very engaging lectures tended to be student-led, and that lectures in styles that worked well or helped students become 'unstuck' covered a wide variety of themes.

Table 2: Number of clips as categorised by emergent themes

Emergent Theme	Number of clips
Explanation	8
Technology	7
Student-led	6
Examples	5
Recap/Overview	5
Visualisation	2

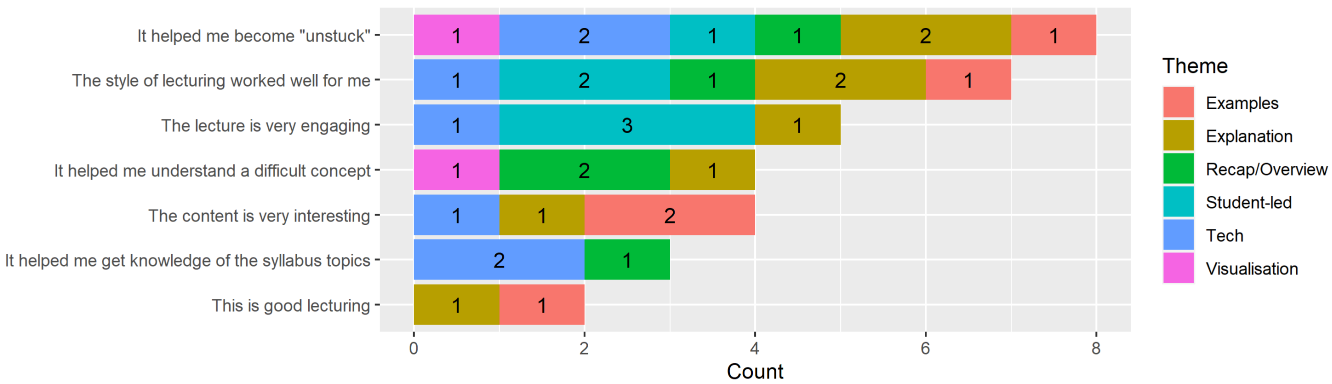

Figure 3: Student's categorisation of chosen video clips (y-axis) with themes identified from the free-text responses (colours).

Curators chose video clips from throughout the academic year (see Figure 4) with a notable spike in weeks 3 and 13. This is perhaps reflective of week 13 lectures which, as the first lectures after the Christmas break, tend to focus on the review of previous material and overview of forthcoming lectures with motivating examples (see below). Further, the week 3 spike contains a cluster of clips in the "student-led" theme (3 out of the 5 clips): by this time in the year students typically have the pre-requisite knowledge to lead elements of the lectures.

We now discuss each theme in turn. It should be emphasised that curators were not specifically asked about the online, remote or recorded aspects of their lectures. The pre-determined categories were chosen to encourage curators to consider the lecture content rather than the mode of delivery or ability to review. In fact, there was only one comment referring to online delivery (see section 3.2), and the only comments about retrospective viewing concerned written materials rather than video recordings (see section 3.6).

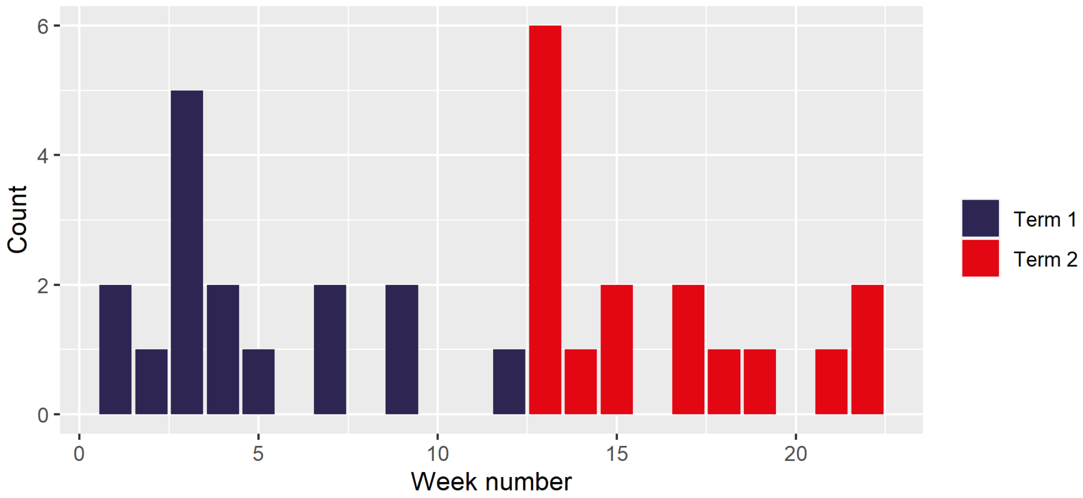

Figure 4: Distribution of clips chosen by teaching week.

3.1. Examples

Five of the clips were grouped as “worked examples”. These were a step-by-step implementation of an algorithm (*Discrete Maths and Geometry* - level 5); parametrisation in the complex plane (*Real and Complex Analysis* - level 6); normal subgroups (*Groups and Rings* - level 5); and two combinatoric applications (*Combinatorics* - level 6). From the comments one student particularly valued the visual showing of the lecturer’s thought process.

From Figure 3 we see that examples could have very interesting content but were not regarded as engaging. This may be because examples tend to be discrete, minimal, exemplar applications of theory which may be interesting but are often presented passively.

3.2. Explanation

Eight of the clips were grouped as “good explanation”, making this the largest theme. Further, from Figure 3 we see that this theme appears in nearly all the student-selected categories for inclusion, reinforcing the idea that good explanations are fundamental in teaching mathematics. The chosen clips were applications of Lagrange’s Theorem to cyclic groups, and exploring the group of symmetries of a triangle (*Groups and Rings* - level 5); real-life applications of discrete maths, and analysing the complexity of determining graph connectivity (*Discrete Maths and Geometry* - level 5); how to manipulate generating functions *(Combinatorics* – level 6*);* proving properties of divisors (*Logic and Structures* – level 4); counting permutations and combinations (*Data and Information – level 4)*; and an intuitive explanation of vector spaces (*Vectors and Matrices* – level 4).

Notably, one student remarked that being online they were hesitant to unmute to ask questions about small details as “sometimes it feels like a nuisance”. This style of slow, detailed explanation of every step, with the lecturers’ thought process outline was identified as a helpful style of good lecturing. One student also remarked that explicit links between topics helped them understand ideas that they found hard previously. Another student remarked that the real-life applications of discrete mathematics were the “biggest reason I did well in this module”.

3.3. Recap/Overview

Five of the clips were grouped as “recap and/or overview” where students had indicated that either the topics were being revisited or an overview of coming lectures was given. These were an overview of abstract analysis, a recap of set theory, and a review of open and closed balls in the discrete metric (*Mathematical Analysis* – level 5); recap of properties of prime numbers (*Advanced Algebra* – level 6); and a recap of sampling methods (*Data and Information* – level 4). Clips identified with this theme were taken from lectures within the first four weeks of each term.

Notably, one student remarked that the links between the abstraction of analysis and the abstraction of group theory was valuable. Another student remarked that the mnemonic device of “permutation begins with a ‘p’ and the position matters” was valuable. Finally, a student commented that the repetition in a clip (finding closed balls in the discrete metric with various radii) was helpful.

3.4. Student-led

Six of the clips were grouped as “student-led”, where either the lecturer is primarily responding to student questions or supervising student activities. These were students applying Dykstra’s algorithm on a shared virtual whiteboard (*Discrete Maths and Geometry* – level 5); lecturer sharing and providing commentary on a student’s work on sequences (*Mathematical Analysis* – level 5); line-by-line diagnostic of a student’s LaTeX submission (*Problem Solving Methods* – level 5); students listing elements of symmetry groups and calculating orders, working through homework questions on basic groups, and students finding inverses of group elements (*Groups and Rings* – level 5). We see from Figure 3 a strong relationship between “very engaging” and “student-led” clips of lectures. Students seem most engaged when a peer is leading the session, or when peer’s work is being discussed.

The comments suggest that working primarily from students’ written submissions, using shared virtual whiteboards or scribing for individuals/groups of students is an effective way of running a video lecture. Students comment that lecturers were “able to instantly spot our mistakes and explain what we had missed” even saying “I found this more useful than even being in-person as the lecturer was able to watch our every line.” Similarly, with a LaTeX assignment “screen sharing this way was a more efficient way of [debugging code]”. Interestingly, the students making these comments were not those whose work was being discussed in these clips. The more collaborative examples were in fact scribed by the lecture but described as “great because it was very engaging with the students” and is “more memorable and useful” when “the whole class was contributing to find a solution”. A student remarked that working from a peer’s submission “allowed us to gain confidence in our work and also fill in any holes in our understanding”.

3.5. Visualisation

Two of the clips were grouped as having visualisations that the students found noteworthy. These included a visualisation of Riemann integration (*Real and Complex Analysis* – level 6); and a visualisation of automorphisms (*Discrete Maths and Geometry* – level 5). Interestingly, these chosen visualisations were hand-drawn by lecturers in real-time during the live lectures. In comparison students didn’t remark on the other high-quality pre-prepared graphics, including the frequent use of Tikz and Desmos resources in these or other modules. Figure 3 shows that visualisations are valued in helping students understand difficult concepts and to become “unstuck”.

3.6. Technology

Seven of the clips were grouped as having a “high tech” approach, perhaps using specialist software or more advanced features of the universal iPad provision for maths undergraduates. These were the use of Geogebra graphing and augmented reality to explore multivariable calculus (*Real and Complex Analysis* – level 6); the use of shared persistent virtual whiteboards as a replacement for lecture notes (*Mathematical Analysis,* and *Discrete Maths and Geometry* – level 5); the provision of “phone-sized” notes, and demonstrations of using the RStudio Integrated Developer Environment (IDE) (*Problem Solving Methods* – level 5). From Figure 3 we see that “high tech” elements of lectures are valued by students for a variety of different reasons, which supports the importance of technology enhanced learning for mathematics.

The comments about the persistent virtual whiteboards (Miro boards) were very positive. Students wrote “the Miro board… was helpful to look back on afterwards, a system like this … is really useful”, and “the Miro board… is great… I could look back on it for reference and notes, which made revision easier”. However, it seems important to students that they are given the opportunity and support to adapt to these new technologies: one student wrote that the lecturer “referring back to the Miro boards for definitions instead of the notes made me more comfortable with using the Miro board”.

Other formats of lecture notes, such as the “phone-sized” notes (produced from a LaTeX class file that renders 9:16 aspect ratio documents) were noted by one student as making “revising more accessible for me and allowed me to revise in more unconventional places”.

Finally, the demonstrations of writing R code were well received, particularly the techniques on using the IDE rather than the code-writing itself. Students commented that the video “showing how you can find all details about a command [was] extremely helpful every time I forgot something” and that “this was needed because we hadn’t used R since the first semester.”

These student observations suggest that lecture capture may also give valuable, unintended technology demonstrations (such as with the Miro software, and use of the RStudio IDE detailed above), which may help address the divide in digital skills documented by Ipsos MORI. A “technology enhanced” lecture may (inadvertently) contain the set-up and use of multiple pieces of software, adjusting settings, locating and logging in to resources, file management, searching the internet and troubleshooting. By recording and involving students in this authentic use of digital skills we provide exemplars of the digital skills students required to excel in a modern, blended mathematics degree.

On returning to campus Middlesex University mathematics staff further incorporated technology into face-to-face lectures. Most lectures are audio and video recorded in their entirety and later made available to students on the VLE. This has been achieved through retaining iPads as the primary tool of delivering lectures in a face-to-face setting (Jones, Megeney and Sharples, 2021a). Many staff also use Miro boards to deliver material through importing slides and/or digital ink and organising into sections (perhaps non-linearly). Lectures involve navigating these virtual collaborative whiteboards, adding commentary through digital ink or pasted computer output, setting students tasks in dedicated collaborative sections of these virtual boards, and providing real-time feedback. Multiple students can work on the boards in real-time, and even upload existing work (e.g., photographs of paper documents) for immediate feedback and class discussion. Some students prefer to work individually on paper but are gently encouraged to contribute work after they receive individual feedback during the session.

4. Conclusions

Having the opportunity to revisit their online lectures has enabled students to give a critical appraisal of the elements that they have found particularly useful for their learning. We summarise our findings with the following suggestions:

1) Slow, highly detailed explanation that include the lecturer's thought processes are desirable. Students can be particularly reluctant to interrupt online or recorded sessions to ask questions.
2) Virtual whiteboards with notes and a record of the lecture commentary are desirable as a single source for the module content. But students should be trained in the use of these technologies.
3) Visual aids are perhaps more memorable and useful if they are constructed in real-time rather than as high-quality pre-prepared graphics.
4) Repetition of key ideas may still be important, even for recorded lectures.
5) Student-led elements of lectures are highly appreciated whether working together on virtual whiteboards or providing commentary on students submitted work. Students find these discussions helpful even if it is not their work being discussed!
6) Students appreciate recaps and overviews that provide links between modules and wider areas of mathematics.
7) Videos of lecturers' incidental use of technology can be used as exemplars for the discipline-specific digital skills we need to encourage students to develop in order to excel.

Finally, the video curation exercise itself could be a useful way of getting students to engage with lecture capture, and a further study could investigate this. Students could collaboratively curate lecture videos by adding communal bookmarks, comments and questions on sections if such functions are available on the VLE. Ipsos MORI (2018) also comment on the potential negative effects of social media use by generation Z students, but perhaps creating an explicitly academic, productive social media environment built on video lectures could show some benefits.

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CASE STUDY

Reflections on Designing and Delivering an Online Distance Learning Programme in the Mathematical Sciences

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Abstract

In 2013, the University of Glasgow set out a Blended and Online Learning Development scheme focussing on fully online distance learning programmes and blended programmes. In 2017 the School of Mathematics and Statistics within the University of Glasgow developed part-time, online distance learning programmes (PG Diploma/PG Certificate/MSc) in Data Analytics. The programmes have used considerable innovation in terms of course content, assessment, course management and delivery, and in student support. In this case study, we will reflect our experiences of developing and delivering online distance learning programmes and provide future recommendations considering the recent expansion of remote learning across higher educational institutes globally.

Keywords: Blended and Online Learning, Data Analytics, Learning Technology.

1. Introduction

In response to the University of Glasgow's Blended and Online Learning Development scheme, the School of Mathematics and Statistics within the University of Glasgow developed part-time, online distance learning (ODL) programmes (PGDip/PGCert/MSc) in Data Analytics and an online distance learning MSc/PGDip/PGCert in Data Analytics for Government programme in collaboration with the Office for National Statistics tailored for public sector organisations (Office for National Statistics, 2022).The programmes' targeted audience comes from all over the world, is already in employment and has professional experience from a variety of sectors. Furthermore, the programme is accessible to students coming from a broad range of backgrounds, educational experiences, and levels of knowledge in programming, mathematics, and statistics. Our students also tend to be older and more likely to have caring responsibilities, when compared to traditional on-campus undergraduate and postgraduate programmes. These characteristics, along with large time-zone differences, present unique challenges when designing and delivering a programme of this nature and developing a teaching style to meet the needs of such a varied audience is continually of high importance.

The aim of this paper is to share our lived experience of designing and delivering an ODL programme over 5 years, providing valuable insight to others who are considering launching, or have recently launched, ODL programmes in Mathematical Sciences. We will discuss the learner characteristics and expectations of students who have studied on our programme, and the key design principles that have shaped our programme. We will also discuss some of the learning technologies we have adopted, student experiences of these, and the vital role a learning technologist should play in the development of an ODL programme. Finally, we will highlight some of the challenges we have faced and discuss potential solutions to mitigate these.

2. Learner characteristics and perceptions

Factors that influence a student's choice to study online, as opposed to being forced to study remotely, for example during the COVID-19 pandemic, include age, education history, employment and personal commitments, suggesting that the nature and demands of online learning is different to that of on-campus learning with a greater emphasis on self-directed learning for online students (Roddy *et al*., 2017). During the 2020/21 academic year, we conducted a small study to understand student demographics and perceptions of online learning. Ethical approval for the study was granted by the College of Science and Engineering ethics committee (application number 300200272). Here, we present the results from 21 of our online distance learning students.

The median age of students was 34 and ranged between 24 and 56. 29% of students identified as female, 67% identified as male while 4% preferred not to respond. 81% of students worked full time and the remaining 19% worked part time while studying. 48% of students identified as having caring responsibilities, 48% did not identify as having caring responsibilities and the remaining 4% preferred not to answer. 43% identified as British, 33% European, 10% North American, 5% South American, and 5% Asian while 4% preferred not to respond. Although these statistics are for a self-selected sample of students registered on our programme, from our experience these demographics are reasonably representative of our ODL student population (unpublished data).

To determine students' learner characteristics and perceptions of online learning, the Online Learning Readiness Scale (OLRS) (Hung, Chen and Own, 2010) was used, alongside some open-response questions. The OLRS consisted of 18 5-point Likert scale questions ranging from strongly agree, agree, neutral, disagree and strongly disagree. The responses to these questions are presented in Figure 1.

95% of students strongly agreed that they were open to new ideas and 90% of students strongly agreed that they were motivated to learn. This contrasts with a study conducted by Pearson and Wonkhe (2020) who surveyed 3,500 students who experienced remote learning during the COVID-19 pandemic and found that 71% said they would struggle with motivation to learn. Reassuringly, 100% of students either agreed or strongly agreed that they were confident performing basic functions, managing software, and using the internet. Most students were also confident in self-directed learning, with 75% or more agreeing or strongly agreeing that they can carry out their own study plan, manage time well, set learning goals and have high expectations of learning performance. Again, this contrasts with findings from Pearson and Wonkhe (2020) who found that half of respondents would have difficultly managing time and keeping track of everything. We believe that these characteristics of our ODL students are crucial to their success on the programme and distinguish them from a more traditional learner. However, 15% of students disagreed that they have confidence posting to online discussions or seeking help when faced with learning problems and 30% of students either disagreed or strongly disagreed that they were not distracted by other online activities.

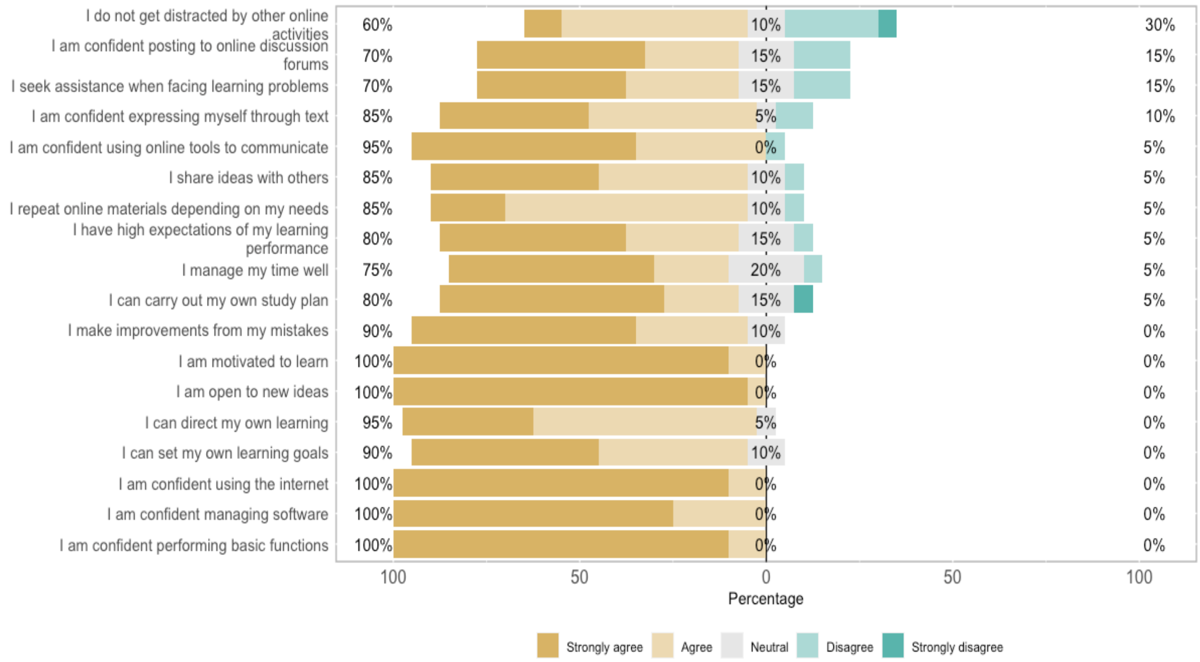

Figure 1. Summary of the results from the Likert scale questions from the Online Learning Readiness Scale. Percentages given on the left-hand side indicate the percent who either agreed or strongly agreed, the percentages given in grey indicate the percent of neutral responses and the percentages given on the right-hand side indicate the percent who either disagreed or strongly disagreed for each question (given on the x-axis).

Students were also asked the following open questions:

- What aspects of online learning did you like? Please explain why.
- What aspects of online learning did you dislike? Please explain why.
- Do you feel elements of online learning contributed to your performance in courses (positively or negatively)?

We have summarised student responses using thematic analysis to identify key themes. Categories were identified based on descriptive coding and then collated into meaningful themes (Saldana, 2021).

Theme 1: Freedom and flexibility

Students commonly noted the flexibility of online learning made their learning possible. They didn't have to travel or commit to a full-time on-campus programme. Students commented on their work-life balance. For the most part, students noted that being able to set their own timetable made it possible to study while working.

> *"I liked not having to travel and the flexibility that online learning offers. It helps with work life balance."*

Theme 2: Assessments

All courses in this programme are continuously assessed. Students noted the importance of providing the assessment dates and when course materials would be available in advance to help them organise their schedule. The continuous nature of assessment may have acted as a reassurance to students, especially within an online setting.

> *"The dates for assignments, dates for release of course material, course agenda, etc are very important (and these were communicated well) because with the distance, and also part-time nature of the course meant that it's really important to feel organized"*

Theme 3: Connection and interaction

Most students commented that while the freedom and flexibility around online distance learning made further education possible for them, the interaction, or lack of, with their peers and lecturers created additional barriers in comparison to learning on-campus. Generally, communicating remotely may not have been as effective as in-person. Students also noted that discussing problems online or over email was not always effective.

> *"I sometimes didn't understand a topic and tended to skim past it. This may have been the same on-campus as well, but the distance / lack of people to talk to probably didn't help"*

Theme 4: Learning material

Students noted that the weekly learning material was the main connection to the programme. Students commented on the structure of the learning materials, usually a PDF with embedded tasks and short videos that explain the main concepts and relevant examples. Several students noted that due to their work commitments or local time zone, they could not attend any synchronous sessions but found the recordings useful.

> *"I found the mixture of modalities to be very helpful. The text is a must for understanding the mathematics, but online lectures are also really useful."*

Although we have identified some common learner characteristics and elements of our programme which have contributed to positive experiences and success for our students, it is equally important that we have identified areas for further consideration. In particular, some students identified hesitancy in seeking help or posting to online forums and there was a general feeling of lack of interaction with peers and staff. This will be discussed further in section 5.

3. Design principles and considerations

Planning, preparation, and development of a successful online programme takes time, with each course requiring an estimate of between 6-9 months (Hodges et al, 2020), or over 100 hours' design time (Kolowich, 2013). It is also important that online learning is supported in online pedagogy and that design principles not only align intended learning outcomes with content delivery, assessment, and activities but also build in opportunities for interaction with instructors and students. Some of the key design principles considered when designing this online programme are discussed below.

Given the expected audience for this programme, incorporating as much flexibility as possible was fundamental. Global Online Academy (GOA) (2020) reported that 82.54% of their summer programme students want flexibility and 58.92% want asynchronous experiences in their online courses, with only 0.38% and 2.89% hoping these elements wouldn't be a focus, respectively. Our fully accessible course material (see section 4) is released in two-week blocks, and is asynchronous, allowing our students to study at a time that suits them and work ahead if desired.

Our assessment structure is also designed with flexibility in mind, with most courses being assessed fully by various pieces of work during each course (continuous assessment), including online quizzes, written reports, programming assignments, and mini-vivas. Deadlines for assessments are generous, with a minimum of 10 working days between an assessment being released and the submission date for most assessments. Assessment and feedback calendars are also published for each course individually in advance of the courses beginning to allow students to plan their schedule around these deadlines.

We know how important it is for students to feel connected and supported throughout their university journey, and this is no different for our online students (Wilcox, Winn and Fyvie-Gauld, 2005). GOA (2020) reported that 93.47% of their online learners expected to feel connected with academics, and 83.17% expected to feel connected with their peers. We have a variety of different methods for interaction. These include regular, optional live sessions which allow lecturers and students to discuss the course material and go through some of the practice tasks as a group; one-to-one appointments that students can book with a course lecturer to discuss individual questions, and discussion forums where students are encouraged to discuss concepts from the weekly material with one another. Students are also encouraged to set up informal methods of communication with one-another (e.g. WhatsApp) and peer study sessions. However, in our experience this is best done organically and driven by the students themselves, rather than forced upon them. Another key connection which should not be overlooked is that of the student-academic adviser relationship. Regular, early contact with an academic adviser can be imperative in student retention and in the potentially isolating world of online distance learning, the importance of pastoral care should not be overlooked (Hilliam and Williams, 2019).

The key design principles listed above align with the Universal Design for Learning (UDL) framework (Meyer, Rose and Gordon, 2014) which aims to address the variability found in student's learning and provide a learning environment that allows for successful learning for all students. It is based on three main principles: Multiple Modes of Representation, Multiple Means of Action, and Multiple Means of Engagement. Based on these three principles, curriculum design would provide multiple ways to allow learners to acquire information, demonstrate their knowledge and motivate them to learn. Although UDL has not been specifically developed for designing online courses, the fundamental concept of UDL to incorporate different modes of learning into course design to allow all leaners to flourish is essential for a successful online programme given the diverse learners that these courses attract.

4. Importance of a learning technologist

Digital technologies are now an integral part of the student experience and have been promoted as having the potential to transform teaching and learning (Conole, 2014). When designing ODL programmes, integration of technology enhanced learning approaches is common and most often necessary for such programmes to succeed (Zhang and Nunamaker, 2003). For learners engaging in online learning, it is important to consider the two concepts of the "digital visitor" and the "digital resident", as proposed in White and Le Cornu (2012). Online learning requires effective engagement from the learner, and utilising appropriate technology enhanced learning and teaching (TELT) methods to assist with the learning experience of both the digital visitor and resident.

With the growth of digital technologies in teaching, and a specific focus on building digital capability and developing digital practice in further education and higher education from Jisc (Jisc, 2020), there has been a focus on pedagogy based academic support roles such as learning technologists (Englund, Olofsson and Price, 2017). The learning technologist role involves supporting the active use of technology for learner engagement and to expand the range of learning and assessment opportunities, though the role can incorporate other factors such as streamlining of administrative tasks (Oliver, 2002). Since the inception of this ODL programme, the learning technologist has played a key role in the development of learning technologies implemented on the programme. The tools mentioned below would only have been possible with the technical expertise of the learning technologist. Many academic teaching staff lack the technical expertise and time required to develop such tools, highlighting the importance of the skill set of the learning technologist to provide bespoke teaching technologies. We conducted a small survey of lecturers in 2020 to assess preparedness for online teaching and only 43% of respondents agreed that they were prepared for online teaching while only 36% of respondents agreed that they understood the university's accessibility policies. Ethical approval for the study was granted by the College of Science and Engineering ethics committee (application number 300200272).

Within our asynchronous course notes, we provide students with short lecture-style videos which provide an illustrative description of the materials that follow. These videos are developed within our bespoke recording studio using our custom built "light board", developed by the learning technologist, which consists of a glass board which faces the camera. This setup allows the lecturer to write solutions to a problem while directly facing the camera, avoiding the need to turn to face a board. This recording is then flipped so that the text is facing the correct way. See for example:

https://www.youtube.com/watch?v=b6R79xKUcZc&t=189s

This approach is useful for working through structured equations and diagrammatic explanations (McCorkle and Whitener, 2020). A short study was carried out to gather students' impressions of the light board content, finding similar outcomes to Southard and Young (2018) that students like the contextualised problems often shown in these videos and a preference for this delivery style over alternative formats.

Both digital accessibility and UDL focus on inclusive educational practices. This can raise several challenges in terms of learning material design. Some common issues which can occur are consistency in course materials across a programme, interpretation of figures, reading and typesetting of equations, and choice of colour palettes for plotting. Our course materials are provided to students in both a PDF format and a recently developed accessible HTML format:

https://bold-web.maths.gla.ac.uk/mdatagov/assets/pdfs/sample_materials/PSF_week8_samp.pdf

https://bold-web.maths.gla.ac.uk/mdatagov/assets/html/week-8.html

These notes are split into weekly units and contain full written explanations of weekly topics, worked examples, additional practice tasks and pre-recorded lecture videos. Both formats are created using a bespoke formatting tool developed by the learning technologist which allows the integration of mathematical typesetting, inclusion of statistical programming code and output, and incorporate our unique ODL programme branding. The accessible HTML notes include a sidebar with a table of contents to facilitate easy navigation and solutions embedded in with tasks to avoid excessive scrolling to the end of the document. Accessible features such as colour scheme, word and line spacing, and word size are available in an options pane which allows the student to modify the notes to their requirements. Though this tool is designed specifically for the programme, there exist tools such as RMarkdown (Allaire et al. (2022)) which create HTML formatted notes which can incorporate some of the accessible features mentioned above. An initial study shows that students enjoy the tidier layout of these notes, attaching task solutions to the task and contents menu useful additions for study. Features such as colour theme and font size are used regularly by students (McArthur et al, 2022). Displaying appealing material facilitates learning, especially for ODL students who rely on written material as their principal source of learning. Both sets of materials have been designed to include features that focus on simplicity and can be widely used by all students. The study also found that students use both formats for personal study, favouring the PDF for personal annotation, and the adaptability of the HTML notes for different modes of study using different device types such as tablets and mobile devices.

5. Challenges and suggestions

This paper has discussed the experiences of designing and delivering a successful ODL programme. We will conclude with a discussion of the main challenges we have faced and some suggestions for those who have recently launched, or are considering launching, an ODL programme in the mathematical sciences.

Firstly, as identified in section 2, some emerging themes from our cohort when asked specifically about interaction included a feeling of no community, not seeing friends, lack of interactions, no communication with peers, no connection with peers and no connection with lecturers. This is not unique to our ODL programme and lack of interaction has been identified as a major barrier to the success of such online distance learners (Muilenbury and Berge, 2005). Creating a sense of community with online students can improve success and retention in online programmes (Berry, 2019). In online distance learning programmes, instructors also identified community beyond course work as important for student success (Bolliger, Shepard and Bryant, 2019). In our experience, frequent live sessions, offering one-to-one support and lecture-style videos where students can see the course lecturer can help to build relationships between learners and lecturers. It is also essential to provide pastoral care through an academic adviser. Learner to learner interaction can be harder to control and, in our experience, should be allowed to happen organically, rather than forced. However, there are areas where this can be facilitated, such as encouraging students to introduce themselves at the beginning of the programme via a student forum, encouraging students to respond to each other's posts, facilitating peer-to-peer study sessions and engaging with a class representative.

The time and effort required to develop and run a successful online distance learning programme should not be underestimated. Creating high quality online material for a diverse audience can be time consuming. Student retention can also be challenging, particularly in the first few months of the programme due to misalignment with student expectations often related to time management. We have found that early, frequent contact can get students on track and that creating similar routines that face-to-face students experience, for example weekly release of course material and optional live sessions, can help students to manage their time and create their own study plan.

Online learning has never been more topical since the COVID-19 pandemic forced many programmes usually delivered face-to-face to be delivered online. Although interest in online learning was increasing pre-pandemic (University Business, 2017), online learning platform Coursera's 2021 Impact Report showed more than 20 million new learners registered for courses in that year globally - equivalent to total growth in the three years pre-pandemic (Coursera, 2021). This has led to a more competitive market in ODL programmes. It has also raised discussions as to whether the pandemic has lowered the quality or perception of online learning (Bates ,2022). It is therefore imperative that ODL programmes are carefully designed and supported in online pedagogy so as not to reinforce this negative perception.

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RESEARCH ARTICLE

Common Pitfalls in Quantitative Research – A Game of Family fortunes

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Abstract

Common pitfalls in quantitative research were examined with two audiences using a Game-Based Learning (GBL) approach to support the engagement and interaction of participants. The researcher asked the UK mathematics and statistic community to determine the game's answers. This approach ignited an enthusiasm to discover the benefits, which was later delivered at the CETL/MSOR annual conference. The paper explores the design and delivery of the Game-based learning session and evaluates how this action research can benefit teaching quantitative concepts in the future.

Keywords: Game Based Learning, Quantitative research mistakes.

1. Introduction

This paper evaluates a session delivered to two audiences; the session delivered was called "the common pitfalls in quantitative research". One audience was a group of novice and experienced researchers, and the other was an audience of statisticians and mathematicians at the annual CETL/MSOR in 2022. The session was designed to incorporate the common mistakes students make during quantitative research to highlight that errors are often made when planning research. Following a request to put together a workshop about quantitative research for novice to experienced researchers, it was decided that any information delivered should be placed in an active and enjoyable format.

Metcalfe's (2017) research on learning from errors highlights the importance of making errors to support the learning process and although the session did not allow errors to be made, it helped facilitate a safe environment to discuss common pitfalls or mistakes in quantitative research. Whilst there has been research about the common mistakes found in journal articles, there is limited research explicitly examining students' common mistakes of quantitative research planning and analysis. Kovach (2018) wrote about statistical mistakes that she had seen when editing journal articles. She felt that authors needed to provide a more robust analysis to provide readers with enough accurate statistical information to evaluate the analytical research. The research, although insightful and valuable in terms of the common mistakes, was only one researcher's insight into what she felt were the common mistakes to avoid in quantitative research. Similarly, Kim and Lee (2018) also explored the common pitfalls in sports journal articles stating their concerns and how they could be managed. The article is relevant in that they found common mistakes. However, they mainly focussed on the analysis end of the quantitative research and less on the planning problems students face with quantitative research. As well as this research, many books outline how to carry out quantitative research and include ways of minimising common mistakes. However, there is little mention of what common mistakes are made.

The researchers had their own opinions of the common mistakes seen in student work, but it was limited to their experience. Therefore, a collaborative understanding using experts within different institutions across the UK was completed via a questionnaire. This approach allowed the researcher to explore the main pitfalls practitioners find within student work which would then be used as the basis of the family fortunes game. Generating the questionnaire provoked intrigue within the mathematics and statistics community and the researcher was approached to present the session at the Annual CETL/MSOR conference. When referring to the delivery of the session both were completed in a similar format albeit to different audiences.

The family fortunes game was chosen because the topic had more than one right answer and enabled participants to guess the answers. This game-based learning (GBL) approach was adopted to improve audience interaction as it is an active teaching approach placing the students at the centre of the learning process. Wiggins (2016) defines GBL as learning and teaching using actual games to facilitate content. Literature has demonstrated that GBL can improve student perception of learning (Hosseini *et al.*, 2019), student motivation and performance (Subhash and Cudney, 2018). Holistic elements of GBL delivery have also demonstrated an impact on learning. Ariffin *et al.* (2014) proposed that if ethnic and cultural elements are portrayed in the GBL environment, it positively correlates with motivation to learn. GBL has been researched extensively within higher education and in a variety of disciplines, including engineering (Markopoulos *et al.*, 2015), nursing (Adamson *et al.*, 2018) and mathematics (Naik, 2017). The family fortunes game was perceived to be the best format to engage participation and offer interaction to formatively assess the audience's knowledge.

With the away day audience in mind, the chosen game helped to incorporate social cohesion and support those with little quantitative experience. Discussing the common pitfalls of quantitative research allowed the teams to share ideas and learn from each other. Whitton (2012) defines this concept as collaborative gaming, where a group works together to find the answer to a question or concept. This social constructivist approach enhanced group discussion and was a supportive environment for novice researchers to be involved in the session.

2. Method

The methods section examines the methodology used to research the answers to the common pitfalls in quantitative research and then outlines the session's delivery, including the teaching approach.

2.1. Research to explore the common quantitative pitfalls

The research to collect the common pitfalls in quantitative research is a single exploratory case-study methodology. The single design is appropriate as the researcher investigated a single issue and did not attempt to describe or explain causality (Yin, 2017). It was felt that these answers from the research would offer a credible insight into common pitfalls in quantitative research using an action research approach.

2.2. Collecting and analysing the results

The approach chosen to collect practitioners' thoughts was a questionnaire with three open-ended questions. The researcher chose this methodology to get the opinion of as many quantitative practitioners as possible without pre-empting the answers. The use of open-ended questions had both advantages and disadvantages. The main advantage of this research was that, as previously mentioned, participants were not given a pre-determined set of answers, allowing them to think and respond to the questions with their own thoughts and words (Allen, 2017). In addition, the approach provided 'a rich description of respondent reality at a relatively low cost to the researcher' (Jackson et al., 2002). The disadvantage of this approach was mainly the time taken to analyse the findings, as the answers needed interpreting and grouping in key pitfalls themes. This approach also could lead to researcher bias in understanding the responses and their grouping (Guba and Lincoln, 1994).

Other methodological approaches considered and rejected were interviewing practitioners about their opinions or providing a survey with pre-determined answers for them to mark. Interviews were not an option for this research as the time scale was limited, and the researcher needed a complete list of practitioners to determine a representative sample. Using pre-determined answers was excluded as although the lead researcher had her own opinions of the answers, it was unknown if the list was exhaustive.

The questionnaire was emailed to two user groups if statistics practitioners -Sigma and Allstat. Sigma is a network for excellence in mathematics and statistics support' (SIGMA, n.d.), and Allstat is a UK-based JISC mailing group for the statistical community created for the Higher Education Authority (HEA) (HEA, n.d.). These two lists cover mainly the UK but are worldwide in their membership. Using these two groups meant sending out a request to complete a questionnaire was straightforward and time efficient. However, using email lists means the lists are incomplete, and those not on the lists may have different answers to those that responded. Not having access to all practitioners is a limitation of this research, although the researcher found that the participants' answers were expected from her knowledge.

The three questions focussed on different stages/areas of quantitative research where common mistakes were made; planning and designing a quantitative study; creating a questionnaire; and mistakes when analysing and reporting results. Respondents were asked to provide their top three common mistakes, as it was known that there could be numerous answers - these focused respondents to think about the most common mistakes rather than any. Three answers for each question enabled a larger population of responses. The questions were: -

1. What are your top 3 common pitfalls that students have within their quantitative research in terms of their research design and method of research?
2. What are your top 3 common pitfalls that students have when creating a questionnaire?
3. What are your top 3 common pitfalls that students have when analysing and reporting their analysis?

An inductive thematic analysis was used to group responses into common pitfalls. An inductive approach was appropriate as the research looked 'for patterns and relationships in the data' (Woo et al., 2017). The 'thematic analysis involves the searching across a data set, be that a number of interviews or focus groups, or a range of texts to find repeated patterns of meaning' (Braun and Clarke, 2006). Firstly, the researcher read and familiarised herself with the responses and created initial common pitfalls groups; the researcher then reviewed the results again, revising the pitfall groups and defining them.

2.3. The teaching sessions

The workshop was shared with two different audiences. The first was staff within the Library and Learning Services Department of the University of Northampton and the second was at the CETL/MSOR 2022 conference. The first audience consisted of 18 staff members with a range of research experience and the second audience mainly of 40 mathematics and statistics practitioners.

2.4. Teaching Approach

The data gained in the questionnaire was used as a basis of the family fortunes game in both sessions. The researcher shared the game on the classroom digital display (Figure 1.) whilst the room was split into two teams.

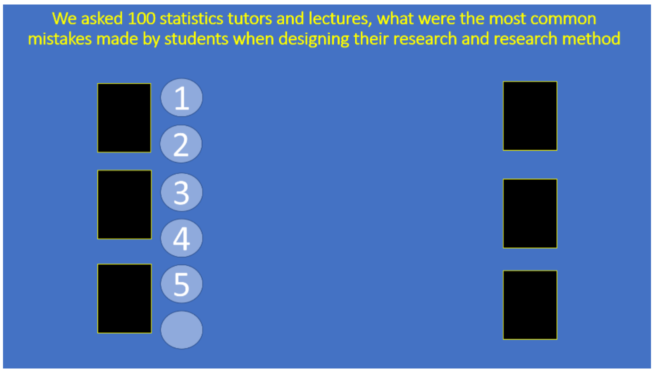

Figure 1. Family fortunes beginning screen

For the first part of the game, one team member came to the front of the class to play 'fastest finger first'. The first question was read out to the two nominated team members and the player to hit the buzzer first answered. The game was adapted from the television version to allow the players to collaborate with their teams. If the answer given was the top answer on the board, the team could choose to continue to play or pass. The other team could guess an answer if the team did not get the top answer. If this answer was higher than the first team, they were offered the option to play or pass. Once a team decided to play, they took control of the board and had to guess all relevant answers to the question.

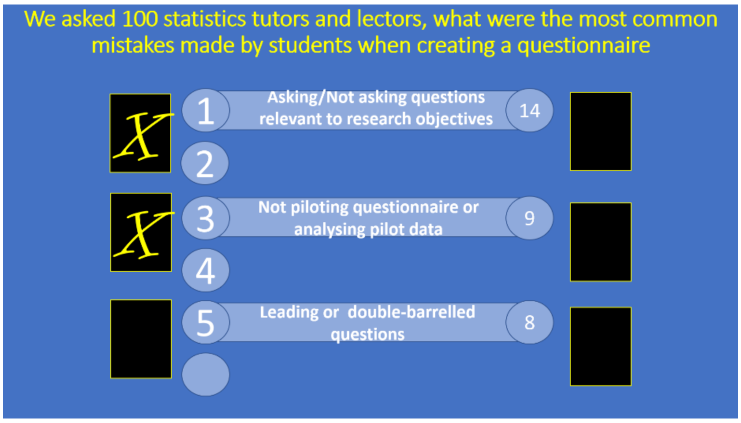

Figure 2: the family fortunes game part way through. The team has got three answers so far and two incorrect answers.

Once the team got an answer correct, they continued to find the other answers. A loud sound was activated and a yellow cross signified any incorrect answer given (figure 2). The game ended once the team correctly guessed all answers. If the team answered the questions incorrectly three times, the control of the board moved to the opposing team. This team then only needed to give a correct answer to win the game.

2.5. Facilitator reflections and participant feedback

As with any action research, it is essential to understand how the facilitator and participants felt the session went, whether they learnt anything from the session and whether any improvements to the teaching methods used. Following both teaching sessions, an email was sent to the participants and the email lists asking them what went well and what could be improved. A total of six participants from both sessions provided feedback.

3. Results & Discussion

This section will outline the results of the questionnaire, the facilitator's reflections and the participant's session feedback.

3.1. The questionnaire

Fifty-three quantitative practitioners responded to the questionnaire relating to the common mistakes, providing between 121 and 132 responses per question. Each of the question's responses were aggregated into categories. Table 1 is an example of the answers contributing to the "Ambiguous or badly worded questions" category highlighting which responses were collectively placed in each theme.

Table 1. All responses categorised in Question 2 response "ambiguous or badly worded questions"

Ambiguous or badly worded questions	**13**
Ambiguous questions	7
Lack of precision in wording	2
Questions are not distinctive	1
Questions don't ask what they think	3
Creating complicated or badly worded questions	2

Due to the format of the game, only the highest five categories were used, and the rest of the responses were grouped into 'other' category. The three questions results can be seen in in Tables 2, 3 and 4.

Table 2. Top 5 common mistakes in terms of planning and designing quantitative research reported

Misconception	Number of responses	Percentages
No/unclear hypothesis or objectives	17	14
Sample size not calculated/ wrong	16	13
Inappropriate design/no design	13	11
Sample not representative to population	10	8
Not planning analysis ahead of collecting data	8	7
Other	58	48
Total	122	100

Table 3. Top 5 common mistakes in terms of creating a questionnaire reported

Misconception	Number of responses	Percentages
Asking questions/ not asking questions relevant to research objectives	19	14
Ambiguous or badly worded questions	13	10
Not piloting questionnaire or analysing pilot data	12	9
Poor question scales including excluding N/A or Neutral	11	8
Leading or double-barrelled questions	10	8
Other	67	51
Total	132	100

Table 4. Top 5 common mistakes in terms of analysing and reporting results reported

Misconception	Number of responses	Percentages
Using or not using p-value, significance, intervals, effect size	17	14
Wrong test	16	13
Analysis not linking to research	11	9
Not writing statistical findings correctly	10	8
Not doing/doing too many doing wrong - graphs and tables	9	7
Other	61	49
Total	124	100

The top five answers gave just over half of the results within each question. The "other "category, outlined in each question, saw 48% (n=58), 51% (n=132) and 49% (n=61) of answers to questions 1 to 3 respectively. Although there were some common themes, each practitioner outlined their own opinion, which meant more categories. These categories were still valid mistakes, but for the game format, the answers were designed into the top 5 mistakes using the number of responders to dictate this calculation. For example, question 2, "having an exhaustive list of options in a question" was reported by nine respondents and "the questionnaire needed to be shorter" by eight respondents. These were common mistakes, but they didn't quite make the top five.

3.2. Facilitators Reflection

Ahead of the two sessions, I felt apprehension as I did not know if the audience(s) would be able to answer the questions. I expected the session to be engaging and was not disappointed. Both audiences engaged with the activity, and the sessions, from my view, were fun. The away day audience struggled to find the answers, and towards the end of the activity, I offered hints to support their answers. Only a few more experienced researchers in each team found the missing answers. This insight may mean that this activity may work better as a formative assessment approach at the end of a teaching session to check students' knowledge rather than as a teaching approach.

The more knowledgeable CETL/MSOR audience were also engaged with the activity. The audience was so engaged that I felt, as the presenter, that my engagement levels within the activity also rose. The room appeared to be 'buzzing' with excitement and enthusiasm. Although the audience were experts, they found finding the top five answers challenging as they all had their own opinions. Each team got 4 out of 5 answers for each question before the game was passed to the other team, adding to the excitement of the game.

One of the main issues with both sessions was the time allocated to complete the game. The away day session ran out of time with only two questions being answered, and the CETL/MSOR conference overran, with the organiser allowing the game to be completed. From my reflections, each question takes 10 minutes to complete, even with an experienced audience. Therefore, the time allocated for the session needs to be 30-40 minutes. If time is limited, it would be more productive to only offer one question at a time to ensure the interest of all participants is held because some of the audience motivation dropped in the away day session.

The research was insightful for practitioners as it can be used in teaching to help positively rectify common mistakes. For example, the top results in the first two questions included that students did not create hypotheses or ask questions related to their hypotheses/aims of the study. This research clearly showed these areas as a focus when teaching quantitative analysis. The final question reported students' lack of knowledge when calculating their statistical findings, with students not knowing which statistical tests to use for their interpretation and reporting. A flow chart or guide may be helpful in supporting students who fail to understand this aspect of their research.

3.3. Participant Feedback

All six participants providing feedback gave positive experiences of the sessions and how the sessions could be improved. From the six respondents, there were common responses within the feedback that were both positive and negative. This section will explore their feedback.

The participants found the game fun and enjoyed the game's competitive element. They also thought about how it could be used to teach the topic. All six respondents found the session fun and engaging and felt it created a positive environment to collaborate with others. This finding is in line with other research where students found a game-based learning approach fun and motivating (Chan *et al.*, 2017; Al-Azawi *et al.*, 2016). A couple of the quotes below show both the fun element as well as how it engaged the participants:

> *'Activities that involve the audience are always good from an audience member's point of view. It encourages you to think about what is being presented'*
>
> *'It was fun (for us); it got us thinking - including "What would other people think/say?"; it was informative ("Oh, I didn't think of that !")'*

The game's competitive element also came out as positive within the feedback. Two quotes below show the emotional competitive value of the game:

> *'Wish that we won!'*
>
> *'The family fortunes format allowed us to work as a team to provide answers but also added an element of gamification as we were in competition.'*

This positive competitive view agreed with Burguillos (2010) research which suggested 'that the combination of game theory with the use of friendly competitions provides a strong motivation for students; helping to increase their performance'.

The last comment highlighted the engagement element, the respondents also thought about the teaching practice and how it would work in other classes. The feedback expanded on this, exploring whether it would be an effective way to introduce a topic of mistakes and how it could be used to teach novice researchers. One participant suggested that this would be good as a starting point that could lead to a discussion of what errors students might make.

The feedback also outlined how the teaching approach could be improved. The key elements to focus on enhancing were the timing of the teaching, the approach to grouping answering being different to how the participants might group them and the problem that more than the top five answers would be helpful. Most feedback mentioned that the session overran or that the time constraint meant there was no time to expand on the answers. This feedback can be seen in a couple of the feedback quotes below:

> *'Obviously the time constraints of the talk meant that you weren't able to expand too much on how you might use the game.'*
>
> *'There wasn't enough time for the activity so it seemed rather rushed and so wasn't as effective as it could have been.'*
>
> *'I believe we ran a bit short of time during the event, but I really liked the format.'*

Two participants felt the answers for the questions used different wording to that given in the answers meaning that the presenter had to match the audience's responses to those in each question, which caused confusion.

> *'As an audience member, I felt there was a mismatch between the language used in the activity (answers given by M&S tutors) and the language used by the audience. This made it confusing to take part as I wasn't sure what was meant by some of the responses on the screen and there seemed some confusion from the presenters over which response on the screen should be matched to the audience suggestions.'*
>
> *'Perhaps ensure that the questions have a relatively well-defined (closed?) set of possible answers, to avoid excessively vague wordings of responses?'*

The feedback for improvement was that the game approach of only the top five answers was too narrow. One participant's feedback suggested that it would have been good to see more of the answers as it was a topic that was hard to narrow down into categories.

4. Conclusion

Who knew that a session request to speak about quantitative research on an away day could generate such an impact? The GBL design was adopted for this request, and the data required for the game was analysed. The enthusiasm of the mathematics and statistics community to share their knowledge on the common mistakes was remarkable. This enabled insight that benefited the community by offering ideas that could help the future teaching of these concepts.

Using the GBL as an approach was a positive experience for both the facilitator and the participants. When thinking about translating this approach to classroom teaching it is crucial to ensure enough time is allocated to complete the game. Given time constraints, it maybe more beneficial to separate the game into parts relating to the teaching and to keep students attention and manage time. The GBL was great, but when working with concepts which participants have less experience and knowledge, it would be better to complete the GBL as a formative assessment after the content has been taught. This way, all participants will have the ability to engage in the game.

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CASE STUDY

Authentic by design: developing mathematicians for the talent economy

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Abstract

The graduate skills expected of mathematics students from employers has changed over the past decade. Traditionally, mathematics graduates are recognised for their logical approaches, critical thinking and analytical skills as well as their ability to solve complex problems. The nature of the employment market is also changing with many industries increasingly seeking digital and technology-driven employees. Digitally fluent graduates with a broad skill set are highly sought after. For mathematics programme teams this mean that these skills need to be updated for the modern economy. Previously Middlesex University's mathematics programmes have embedded problem solving and communication skills in two modules. In this case-study we will outline how the programme team has developed our approach to teaching these skills to enhance students' skills.

Keywords: Problem solving, authentic assessment, Moore's method, students as partners, best of old and new.

1. Introduction

The landscape of both the employability skills expected from mathematics students and university education in general has changed drastically since the BSc Mathematics and BSc Mathematics with Computing programmes at Middlesex University were first validated in 2013. Increasingly mathematics graduates have pursued careers in areas related to data science and financial technology (Prospects, 2021). These careers place a greater emphasis on the requirement for applicants to be technologically literate, so they can disseminate technical material to a non-technical audience, as well as the ability to collaborate and be creative.

While traditional mathematics students are viewed as being highly skilled in critical thinking and problem solving, graduates often find it difficult to demonstrate and evidence their creativity and ability to communicate complex ideas and concepts. Authentic assessment has been defined by Guliker et al. (2004) as 'an assessment requiring students to use the same competencies, or combinations of knowledge, skills, and attitudes that they need to apply in the criterion situation in professional life'. This raises questions relating to what authenticity means for mathematics assessment and how programme teams can design schemes that provide tangible opportunities for students to evidence these skills. The use of authentic assessment is a key institutional priority and it is noted that there is an increased emphasis on authentic assessment within the sector (Pitt and Quinlan, 2022).

Emerging from the pandemic, universities are embracing blended and hybrid approaches, and enhancing learning, teaching and assessment using technology and digital tools. These competing demands have placed undergraduate mathematics programmes in a challenging position. Space must be found in already crowded curriculums for new material to ensure that graduates are suitably equipped for this new employment landscape. However, ways must be found to make assessment among even the purest mathematics modules, such as analysis and algebra, more authentic.

In this case study we will discuss the approaches we employed to teaching undergraduate mathematics students to support the development of skills that are valued and needed for employment within the talent economy. This approach draws on the best of the old and new: retaining mathematical rigour, creative problem solving, and construction and communication of arguments, whilst considering how each of these can be evidenced and demonstrated for a graduate mathematician in the current employment context.

Key elements of the approach include:

- An intellectually demanding mathematics curriculum;
- Problem solving and communication themes;
- A learning, teaching and assessment strategy that is flexible, inclusive and supported by technology;
- The use of portfolios to evidence professional skills.

This has resulted in the team articulating what authentic now means for mathematics and incorporating innovative teaching and assessment methods supported by technology to address these demands.

Sections 2 and 3 will outline the structure of the Problem Solving Methods and Communicating Mathematics modules, which were stand-alone core modules embedded within the original undergraduate mathematics programmes at Middlesex in 2013. These modules were created to support the development of employment skills in an authentic mathematical context. The associated module learning outcomes include ‘effectively work in a group to find solutions to problems’ and ‘demonstrate knowledge of how to communicate and motivate advanced mathematical topics through a variety of mediums’, respectively.

In section 4 we will discuss how the approaches evolved from the original design and validation in 2013 to the revalidation in 2020, including how we adapted assessment on the programmes and, more generally, based on what we learned from our approaches to problem solving and communication. This approach combines the best of the old and new: retaining mathematical rigour while incorporating innovative teaching and assessment methods to address these demands.

2. Problem Solving

When the undergraduate mathematics programmes were first validated in 2013, they were designed to explicitly incorporate elements of problem solving and communication. Both skillsets had their own dedicated modules. The module Problem Solving Methods at level 5 is discussed in detail in Jones and Megeney (2019). The module does not introduce new mathematical content, instead students apply mathematical and quantitative knowledge developed in other modules and from their broader experiences to solve mathematical problems. The teaching is inspired by Freudenthal’s ‘Realistic Mathematics Education’, see Freudenthal (1968, 1973) which emphasise the usability of mathematics as a focus for its development in teaching. Freudenthal talks about ‘mathematizing’ problems to solve them. We take a broader view of 'usability' to include common themes in mathematical arguments as well as the usual notions of applicable and authentic mathematics. At the start of workshops students are given a problem to work on in groups, sometimes specific mathematical problems, sometimes word problems that students need to mathematize. The tutor facilitates discussions with minimal but judicial input. When students have solved the problem, the class reflects on the approaches used with the aim of developing an understanding of the cognitive process that they use to understand and solve problems more generally. Stepwise approaches that are developed by students are linked to classic work by Polya (1957) as well as more modern approaches (Mason et al., 2010), (Bransford and Stein, 1993) and we use these texts to formalise students with their own internal understanding of the process of problem solving. The problem, solution, reflection cycle then starts again. Workshops are designed so that problems discussed have similarities and commonalities and students are encouraged to make links between these in class.

For example, students might be asked to explain why a number is divisible by 3 (or 9) if and only if the sum of its digits are divisible by 3 (or 9) – this requires mathematizing the problem. Or they might be asked to revisit examples from their first-year modules such as showing that $8^n + 13$ is always divisible by 7, or $5^n - 1$ is always divisible by 4. These latter problems are given in the first year and students solve them using mathematical induction – however there is a deeper reason they are true, for example $5^n - 1$ modulo 4 is equivalent to $1^n - 1 = 0$. The students then discuss - and the reader is encouraged to do the same - the relationship between these problems and the first problem in this paragraph. Commonalities such as the reduction to modulo arithmetic then become part of the students' problem-solving arsenal. These problems are authentic from the point of view of solving abstract mathematics problems, but other workshops include problems that have real-life interpretations.

The group coursework consists of an open-ended question, with some parts that hint at directions to study (as shown in Figure 1), and some that are entirely open. Students must formulate these problems mathematically and demonstrate a creative and critical understanding of the topic of the coursework; they then develop strategies to study their problems and attempt to solve them. Since the module does not include new mathematical content, the students are assessed entirely on their creativity and engagement with the problem-solving process. Mathematical calculations and arguments are given some credit, of course, but the emphasis is on originality, creativity, and reflecting on problem solving skills rather than just solving the problem. One advantage of this approach to the programme design is that module learning outcomes deal specifically with problem solving skills and so students can explicitly evidence where these problem-solving skills have been developed and assessed in the degree. Furthermore, it gives the programme team the opportunity to focus specifically on developing these skills in in an authentic way. More details of how the type of problems are chosen can be found in Jones and Megeney (2019) where the authors introduce themes to discuss common approaches to mathematical problem solving. Students find this approach very helpful with one graduate commenting recently on how it has contributed to their professional development:

> "*Being forced to think more creatively when trying to formulate a solution and becoming more patient when doing so has helped me not only in a professional setting but it has also helped me in a day-to-day basis also. The variety of complex topics I came across throughout the degree helped me become more adaptable when being introduced to new topics professionally*".

2. From 1998 onwards a number of control measures have been introduced. Your group needs to develop and study models that capture the following

   (a) Trapping and removing grey squirrels — two scenarios are proposed:

      i. a quota is fixed and grey squirrels are removed throughout the year at a rate to meet this quota;

      ii. traps are laid throughout the year and all grey squirrels are removed that are caught;

   (b) Red squirrels are re-introduced from habitats in Scotland — for a given number of years a quota is fixed and red squirrels are introduced throughout the year at a rate to meet this quota.

   Your aim is to develop models and to study the effect of changing the values of the parameters on the long-term sustainability of the red-squirrel population.

Figure 1: Sample question from Problem Solving coursework

3. Communication

The ability to effectively communicate and disseminate mathematics to a non-technical audience is becoming increasingly sought after by employers. In recognition of this we embedded and developed communication related learning, teaching and assessment activities throughout the undergraduate programme as well as in a core Communicating Mathematics module at level 6.

Traditionally communication related assessment may take the form of formal presentations, proofs and reports. When designing the Communicating Mathematics module, we expanded on these traditional communication mediums to include assessment activities which allow students to create mathematical videos, blogs, vlogs, flyers, and activity sheets.

Student feedback indicated that they valued having elements of choice within assessment tasks, but some opted for more traditional forms of assessment as their access to technology was limited when at home. Some students indicated that they only had access to suitable technology to complete these different forms of assessment on campus. This is particularly important for Middlesex given the demographics of our students. For example, our TEF (Teaching Excellence Framework) 4-year aggregate data for all modes of study, shows that 59.7% are from households that are located in neighbourhoods in the first or second quintile of the Index of Multiple Deprivation (IMD), an aggregate index used by the UK government to measure deprivation, which is 20 percentage points higher than the sector average. Furthermore, 43.6% were eligible for free school meals, compared to an average of 18% across all registered higher education institutions which is a 25.6 percentage points difference. This means that many of our students are affected by digital poverty.

Prior to the pandemic mathematics lecturing staff were equipped with iPads as part of departmental technology enhanced learning project called iF (iPads for feedback). The aim of the project was to enable staff to provide quicker more useful feedback on mathematical or notation heavy technical assessment. In addition, the equipment supported an enhanced approach to session capture.

During the pandemic students were loaned iPads which students retained for the duration of their degree. This has allowed the maths team to reflect on the design of learning, teaching and assessment strategies and provided opportunities for the team make use of digital tools. More important though is the knowledge that each of the students have access to identical hardware and software.

This has also allowed a more inclusive approach to assessment by providing more flexibility. Teams can confidently design flexibility into schemes around a common set of Apps. For example, the following is an assessment brief from for the Communicating Mathematics module:

> "*This communication brief requires you to develop an activity or resource that could be used to promote, or engage people with, mathematics.*
>
> *This can be done either by*
> - *a short mathematics activity with feedback sheet,*
> - *a blog (1000-2000 words or multimedia equivalent) or*
> - *a short video such as a screencast (2.5-4 minutes).*
>
> *The activity or video must link clearly with a mathematical concept or problem and be suitable to be used to engage people with mathematics."*

The assessment brief requires students to create an artefact (activity, blog or video) which forms part of their portfolio of evidence. Upon graduation students use these portfolios as evidence of their skill development and have shared examples with potential employers. One recent graduate using their communication project in a successful job interview as a data scientist, saying: "*Specifically, the panel were impressed with my communicating mathematics project."*

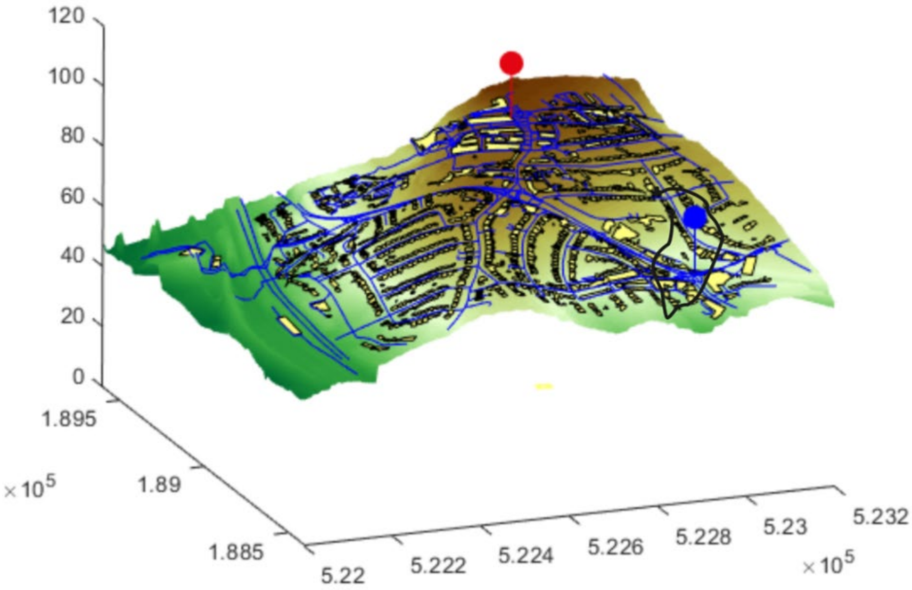
As part of the module assessment students are required to reflect on the work produced and the skills they used to create it. Here students are encouraged to recognise the skills they have developed whilst creating the work and align skills to those required for professional employment focusing on creativity, critical thinking, problem solving, collaboration, and use of technology. Feedback from graduates supports the approach with one commenting that their

> "*Communicating mathematics project expanded my communication skills, working on a project that had real world application bridged that gap for me*."

4. Authentic and Accessible Assessment

When the revalidation process began for the undergraduate mathematics at Middlesex University in 2019, we sought to build on the innovative learning, teaching and assessment approaches core to the Problem Solving and Communicating Mathematics modules and integrated these techniques more broadly into even the most pure of our mathematics modules. Our goal was to move beyond the view that problem-solving and communication were additional skills but rather as core skills that are important to their development as mathematicians.

As part of the revalidation process it was decided that exams would be removed from the programmes and replaced with more authentic assessment, such as projects, portfolios of work, and presentations, requiring students to use the same competencies, or combinations of knowledge, skills, and attitudes that they need to apply in professional life (Guliker et al. 2004). There was much discussion about what authenticity meant for mathematics especially for the purest forms, making it particularly important that the assessment made clear how it supported the development of skills needed for employment, in addition to assessing learning outcomes. For example, Figure 2 shows an excerpt from a level 6 analysis module where students ultimately are applying techniques from multivariable calculus. However, the context of the problem (in which the students must interpret their results) is the familiar topography of the university together with a discussion of Ordnance Survey co-ordinate systems, LIDAR (Light Detection and Ranging) altitude measuring from DEFRA (Department for Environment, Food and Rural Affairs), the analysis of open data, and polynomial approximation (see Sharples, 2021). This embeds a practical and current government-funded project into an otherwise abstract assessment, thereby making it more authentic. Core principles to our revised approach were to ensure all students can communicate mathematical ideas and concepts, collaborate on mathematical problems, demonstrate their learning in creative ways and have equitable access to technology to support their mathematical learning. By the end of their programme students will have developed a portfolio of authentic evidence to demonstrate their mathematical knowledge and skills in creative ways through authentic assessment.



4. From first principles (i.e. working directly from Definition 3.3 and without using other theorems) prove that f is differentiable at the point $\mathbf{p}$. — 5 marks

5. In fact **all** multivariable polynomials are differentiable at every point in the domain. Sketch an argument to show this. Either
   - write a formal argument,
   - draw an illustration,
   - record an audio explanation or
   - record a video explanation.

   Imagine you're trying to convince a mathematician of this fact.

   Pro-tip:

   You may recall last year we demonstrated all single variable polynomials $f : \mathbb{R} \to \mathbb{R}$ were differentiable.

   3 marks

6. We are using a polynomial to approximate the altitude of terrain near Middlesex University. In general would you expect the true altitude of terrain to be differentiable? If not, provide a mathematical description of a non-differentiable geographic feature. Either
   - write an explanation,
   - draw an illustration,
   - record an audio explanation or
   - record a video explanation

   to justify your answer. — 4 marks

Figure 2: Sample questions from Real Analysis coursework

This required us to revise the programme wide learning, teaching and assessment strategy which would support the development of the skills needed for the talent economy in a mathematical context. The strategy promotes the use of enquiry based methods for learning, collaborative problem-solving approaches, and assessment schemes that are varied, inclusive, accessible, authentic, future focused, and designed around common hardware and software.

Key elements within the revised overall programme design were:

- Balance of mathematical theory and practice within the overall programme design;
- Communication and creative problem solving embedded across the programme;
- Communicate mathematical ideas and concepts ;
- Providing choice of assessment activities;
- Collaboration and learning supported via online learning communities ;
- Reflection is embedded within modules and skill recognition is promoted;
- All activities are supported and designed around iPads and agreed Apps;
- The students develop a portfolio to evidence their skills.

To support this across the programmes the team sought to ground the assessment in real world application and/or clearly align to an employability skill. For example, the level 6 analysis coursework referenced above (see Figure 2) rigorously tested the learning outcomes while also allowing students to choose the medium of assessment allowing for personalisation and a more inclusive approach. These options allow students to build a varied portfolio of work which they can easily use to evidence the skills required by the talent economy. It is more inclusive and accessible and reduces the need for reasonable adjustments to be made.

5. Conclusion

This case study has outlined the journey the maths team has taken when designing its programmes to support the development of mathematical knowledge and skills.

Building flexibility into assessment encourages students to think creatively about how to best approach the problem while negating the need to make reasonable adjustments. The foundation of our approach is that students have access to identical hardware and software. This means we can write multi-modal assessment with the knowledge of what resources the students have access to.

It is noteworthy that many students who completed the real analysis coursework, see for example Figure 2, still elected to complete the assessment with formal written mathematical arguments. In focus groups students stated that the reason for this was related to familiarity with the various forms of assessment. Students stated that they felt a formal written mathematical argument was easiest because historically that is the form most of their previous assessments had taken whereas they believed a video submission, for example, would take a great deal more work to get up to the standard they would be happy to submit as part of summative assessment.

Students did appreciate being given an option of a different form of assessment within schemes with one saying:

> "*Mathematics as a subject is one that demands patience and creativity when trying to find solutions. I see being able to develop my level of patience when approaching new issues and understanding how to use the tools I am provided with more creativity is an invaluable skill."*

The response from students has been positive, with recent graduates specifically citing this approach as having a positive influence on their professional career. The feedback from students indicate that it would be beneficial to introduce student to these alternative methods for completing assessment at an earlier stage, so they gain more familiarity with them.

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