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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Contents

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EDITORIAL

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Welcome to this issue of *MSOR Connections*, the first of two to collect papers from presentations at the CETL-MSOR Conference held at Cardiff University on 7th-8th September 2023. The conference continued a long tradition of discussing reflective and evidence-informed innovative practice in all aspects of learning, teaching, assessment and support of mathematics, statistics and operational research within any discipline in higher education. Both the CETL-MSOR Conference series and *MSOR Connections* emerged from the work of the Maths Stats and OR Network, hence the overlap of interests and close collaboration between the two.

We open this issue with a series of fascinating examples of people adopting 'authentic' and 'project-based' approaches to teaching mathematics and statistics. Calvert and Warren take a citizen science approach to data collection, Derrick and Weir use an approach backed by e-assessment technology, and Smith draws inspiration from knowledge exchange study groups. One of the issues raised by Smith is how to develop in undergraduates the skills of communicating with different audiences, and Masterson et al. take up this theme, giving students a choice of communication methods used in employment and thinking about the impact of generative AI. Symonds and Mott consider authentic assessment from the point of view of the emerging area of degree apprenticeships, discussing the pros and cons of different assessment alternatives.

Mathematics and Statistics Learning Support will be a familiar topic to readers of this journal when offered to university students. The final two papers in this issue explore the offer of support to less conventional audiences. Mac an Bhaird, McGlinchey and Mulligan claim a 'win-win-win' by offering drop-in support for secondary school students, a practice that has become widespread in Ireland. And Smith and Papadaki offer a staff-facing service supporting those who deliver mathematical and statistical content, and discuss their work to build this into sustainable communities of practice.

I am grateful as always to the host of authors and peer reviewers whose collaboration resulted in the issue you are reading. As always, it is lovely to see this vibrant community at work, both in attending the conference myself and in seeing the papers that emerged from it. A second collection of papers from the conference will be the next issue of *MSOR Connections*.

MSOR Connections continues to be a venue for our community to share its innovative practice, and submissions are always welcome via the journal website – https://journals.gre.ac.uk/ – whether associated with a CETL-MSOR Conference presentation or not. The journal is also always keen to attract reviewers and we have some experience of supporting those new to reviewing, so please sign up via the website if you are interested in reviewing articles.

CASE STUDY

Towards practical learning using air quality monitors

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Abstract

In this study, we explore the use of a low-cost air quality monitor as an experiment within a first year undergraduate statistics setting. The aim is to enhance student engagement and to provide a basis for both individual and group assessments. A pilot, during the summer months of June-September 2023, involved 52 volunteer students who collected indoor and outdoor air quality data. The students shared their data and analytical insights. "*Fun/enjoyment*" was frequently mentioned in student feedback, suggesting this practical approach may improve student engagement.

Keywords: active learning, statistics, engagement, air quality monitors, volunteers.

1. Introduction and Background

This case study focuses on the potential of using an improved activity in a first-year statistics course offered at a UK-based distance learning university. Several qualification pathways including economics, data science and mathematics/statistics require students to take the course and a wide range of other students taken it as an option. The course currently combines the use of printed materials with online tutorials, asynchronous forums and individual feedback on assignments from tutors. Tutorials are intended to be interactive and make substantial use of polling to engage students. For several years a home experiment, where a student measures the lengths of the roots of seedlings they have grown, has formed a part of one of the four assignments on the course.

The original learning objective for the experiment was to "*appreciate the requirements in setting up, maintaining and completing a small scientific experiment*". Participation in the experiment has shown a decline over the past few years, with current engagement at approximately 30% of active students. Students consistently express dissatisfaction with the experiment, based largely on lack of relevance and a perceived trivial nature.

A replacement activity was sought that had greater relevance, was capable of supporting both individual and group work assessment, that contributed to personal and university commitments to health and ecological issues and could run as a theme throughout the course. In the 1990's, when graphical scientific calculators were relatively expensive, the university supplied all students on an introductory mathematics module with a T1-83 graphical calculator. With this as precedence, it was hoped to issue students a monitor to use and re-use that would provide a stronger scientific element to the experiment.

The American Statistical Associations' Guidelines for Assessment and Instruction in Statistics Education (GAISE) College report (Aliaga et al, 2012) contained several key recommendations which included using projects, group problem solving and discussion activities to encourage more active learning in Statistics. Empirical evidence supports the benefits of active learning in terms of a possible 6% improvement in exam scores. Lugosi & Uribe (2022), Freeman et al. (2014), Theobald et al. (2020), Nguyen et al. (2021) all support the benefits of active learning in terms of around an 6% uplift as well as potential improvements in student engagement and enjoyment. Similar problem solving and team-based learning are seen as excellent approaches for statistics education in higher education in the UK (Jones & Palmer, 2021).

Statistics group work, on the level 1 statistics course, could contribute to several of the university's employability framework elements. The employability framework is summarised in figure 1 and the intention is that all students have the opportunity to develop employability skills. The Royal Statistical Society and The Institute of Mathematics and its Applications, both accrediting bodies for qualifications in which this statistics course is compulsory, require students to have the opportunity to develop problem solving, communication and collaboration skills.

A final major consideration, concerning an alternative experiment, is the potential to contribute elements to other applied statistics courses, courses in other areas of the university and outside the university. An experiment that generated real, relevant data to students could contribute to analysis on second year undergraduate statistics courses such as time series and multiple regression. Furthermore, the choice of a topic which has value in environmental courses, and which has a citizen science appeal to a broader range of students, would perhaps increase the 'value' of the data.

Fine particles in the atmosphere can affect the health of individuals and of our environment (Engel-Cox et al, 2013) and there is a growing contribution of 'citizen science' projects in the field of pollutants and climate change (CERC, 2021; EEA, 2019). Therefore, a practical replacement home experiment that collected atmospheric data might be viewed as relevant to students and foster an interest beyond the boundaries of their academic work.

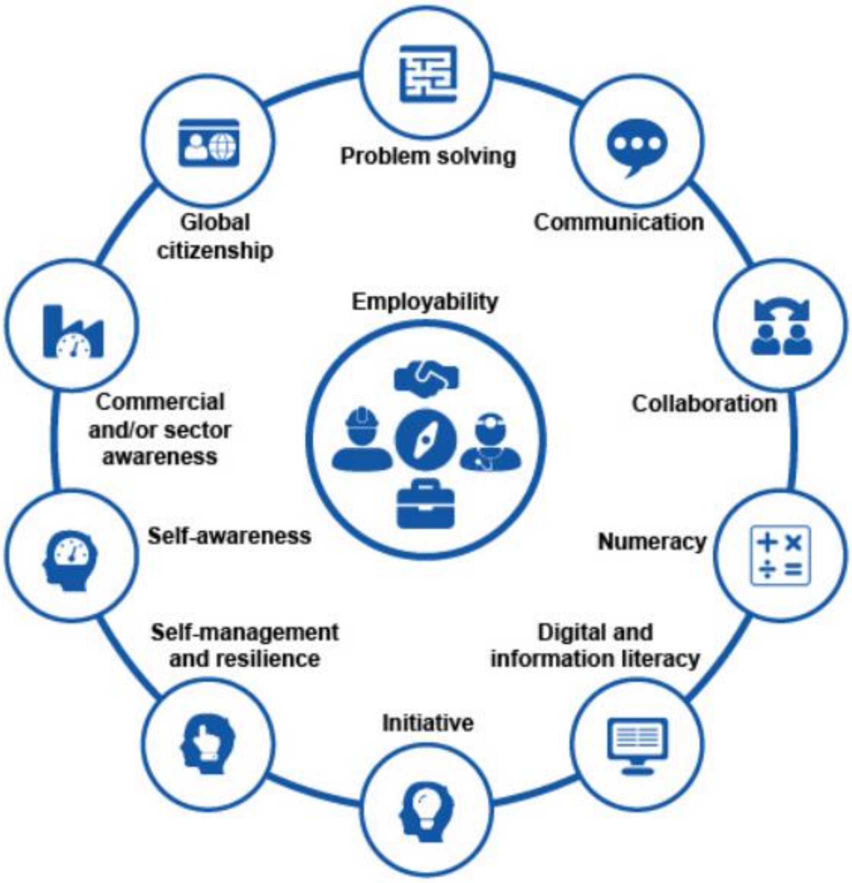

Figure 1. Employment Framework repository (source: The Open University, 2020-2023).

2. The pilot methodology

Mathematics and Statistics undergraduate students were recruited as volunteers during the summer of 2023 to collect and analyse data on atmospheric particulate matter. The aim was to evaluate the potential of this experiment as a possible replacement for the existing seedling experiment, A closed forum, accessible only to those taking part in the pilot, was the platform for sharing analyses and views on the new experiment. The forum also helped areas of joint interest emerge and hence potential group work topics.

A two-page information document was issued to any students expressing interest in the pilot. The document covered items such as safety when taking readings; the evolving nature of the pilot; the level of commitment required over the summer; and using the database. Students would only be allowed to enrol as volunteers when they confirmed they had read this document.

Legal advice indicated that students would need the express permission of the property owner and others in the household to collect indoor data. It would be impossible for us to ascertain this had been obtained on a course with 1,800 students and hence it was decided the main experiment had to be to ask students to collect outdoor data. However, as an additional activity in the pilot, students were also invited to collect indoor data with the proviso that they obtained the property owner permission.

Air quality figures are based on an average of readings taken at least every minute to provide typical real-world conditions. For the pilot we needed to provide an outdoor, portable monitor able to store readings and download them to a university server and capable of providing readings every minute.

A bespoke database was developed, enabling secure data upload and download for students. The database was required to enable students to share their data, compare it to those of their peers and to test hypotheses that the student defined and wished to investigate.

3. Results

3.1 Volunteers

A single invitation to volunteer was placed on all the websites for the statistics and mathematics courses. This resulted in 52 mathematics and statistics undergraduate volunteers across the UK and abroad. There were no financial incentives, but volunteers were informed that they could retain the monitors, if they wished to keep taking readings beyond the formal period of the pilot. We had more volunteers than monitors and so the volunteers were asked to return the monitors when they had completed their data collection. At the end of the pilot, 10 of the students had opted to keep the monitors, 16 were returned and the whereabouts are unknown of the remaining 17 of the 43 issued for student use. Of the original 52 volunteers, nine never registered to use the database and an additional three registered but failed to upload any data; these 12 volunteers were considered as non-participants in the pilot.

3.2 Air quality monitors

The intention was to produce a monitor internally but this proved impossible in the time scale. Hence we used a commercial monitor that cost on average £100 and which recorded data each minute including: temperature, humidity and two different sized particulates (PM2.5 and PM10). The monitor was powered by a rechargeable, internal battery or via a cable to mains electricity.

Information was stored in the monitor and students transferred the stored files, along with date/time of readings via cable, to their own machines. Subsequently students then loaded the data, along with location information, to the database. Only one monitor was found to be faulty although the temperature readings were misleading if the monitor had been left in direct sun. Monitors were delivered to student home addresses by standard mail systems and were packaged in an envelope that also contained a pre-paid return envelope. None arrived damaged and none were lost in the post. The monitor is shown in figure 2 with a pen shown for scale.

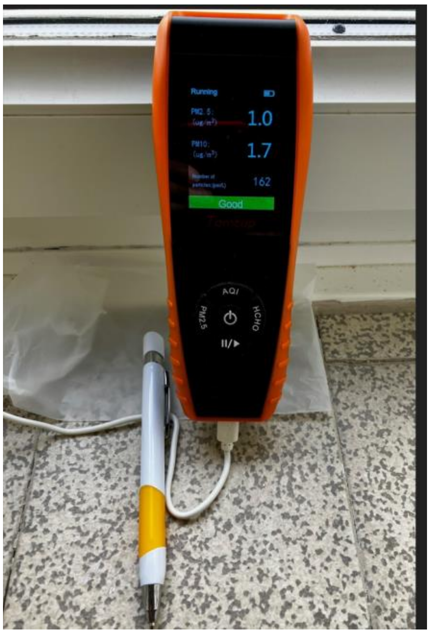

Figure 2. Commercial monitor

3.3 Taking readings, using the database and themes from forum posts

Posting on the forum was high, even though the pilot was taking place during the summer break, demonstrating students were clearly engaged and interested. Collection of indoor data only required the monitor to be plugged into a power supply, left for seven days and then the students had to upload seven files to the server. Outdoor data collection needed the student to power up the monitor each time and about 1-4 hours worth of readings were collected.

Thirty nine students posted on the forum; thirty six loaded 107 162 minute readings of outdoor data into the database and 33 loaded indoor data. Total data loaded was 571 845 minute readings.

Overall themes can be effectively split into 3 or 4 main categories. Volunteers expressed their positive feelings stating: enjoy/ment (14 mentions), fun (9), exciting (3), happy (14) in relation to taking part in the experiment. Indoor readings were affected by cook/ing (41) with the kitchen (18) and extractor (8) being noted along with fry/ing (12) and food (6) preparation in general. Database (47) and the processes of download/ing and uploading were also recurrent themes. Students also discussed pollution (16) and the effects of PM on health (5) noting the instances linked to traffic (5).

Many of these themes were interwoven in the forum threads and across time as students approached the experiments in their own time and dipped in and out of the measurements. Overall the tone of the forum was very positive, and volunteers suggested many possible ideas for comparative experiments or different ways to analyse and consider the data. These views are encapsulated in a sample of the quotes shown in section 3.4, below.

3.4 Student views

Some students expressed surprise at how much they were enjoying the pilot and several commented on the value of being able to see their own data and that of other students.

> *“Thanks for all this. I’ve been playing with the data in Minitab - really interesting. Can’t believe that post-exam I’m this interested in using Minitab! For future M140 experiments I think there’s definitely more interest for me in being able to see my data in comparison with others. “I felt M140 made efforts to use data that students could relate to, such as prices and wages. There are however limits to how current data can be and how much the data is appropriate to individual students.”*
> Student 1

> *“The use of the air monitors meant that I was dealing with MY data, and it was current. It made me think much more about the circumstances of collecting data e.g. several people have commented about the impact of cooking on indoor data. It has encouraged me to experiment with different circumstances.”*
> Student 2

> *“I found this experiment to be so much fun and much more interesting than the seedlings! The best part for me is the ability to collect so much data for myself, as well as access to tons of data from other students. The possibilities are endless and with such a large dataset I imagine it could be used in most units of M140.”*
> Student 3

Students were specifically prompted for views on the suitability of the air quality activities as a replacement to the existing seedlings experiment.

> *“I have few comments about the statistics side of use for M140 as I am not a statistician and hate doing statistics. I loathed M140 and found it really boring, especially as it is compulsory module I would have not have chosen if I could have avoided it. I found the experiment to measure seedlings frustrating as the first lot didn’t germinate and the second lot were fragile, bent and virtually impossible to measure. I just made the results up in the end.*
> *“I think from my point of view the air quality measuring would be a huge improvement, especially if it formed a recurring theme throughout the module. There would need to be lots of background information available so people could understand what the various measurements meant and the implications for human health, the environment etc. I have got really interested in the whole thing and am keeping the monitor for a bit to do some investigation of whether high particle counts in the countryside might be caused by pollen.”*
> Student 4

> *“I have run another week indoors, and uploaded the data. I had the monitor in the same place as before but this time with a new cooker hood/extractor fan in the kitchen but also with a wood burning stove going in the evening in the living room where the monitor was for the last 3 days. Having had some spectacular PM readings frying bacon without a cooker hood in the first indoor week, the results this time round have persuaded my partner of the benefits of using the new cooker hood! I was surprised that the wood burning stove produced a lot less particles than the cooker hood-less bacon frying.*
> *“I shall be returning the monitor now. Have really enjoyed participating in this and as others have said I think it has great potential for M140 - though as a smallholder with a large veg plot I rather enjoyed growing mustard!”*
> Student 5

4. Discussion and conclusions

This pilot, undertaken at a distance learning institution, faced both unique challenges and advantages in terms of organisation and implementation. All communication had to happen asynchronously; we could not hold a physical meeting for the students to meet each other and to bounce ideas around with each other. But on the other hand, students were used to volunteering and comfortable with working in forums. It was relatively easy to recruit 52 volunteers, with no financial incentive, to think about statistics in their summer vacation.

In terms of scaling up to all students on the first-year statistics course, there are three broad areas to consider: the monitor, the database and the incorporation into teaching materials. A suitably priced monitor, whether built to an OU design or an existing commercial monitor, has still to be agreed, and it would be included in the current dispatch of course materials to students from our warehouse. Students would keep the monitors rather than return them for re-issue. Monitor costs are directly related to student numbers.

The database would require re homing on a different university server that was able to deal with a greater student loading. Little change would be needed to the current design of the database as it is already fully compliant with security and IT standards. The process of moving the database to a more permanent location is underway and will be relatively low cost although there will be ongoing maintenance costs which are largely independent of student numbers.

The biggest area, regardless of student volume, is that new assessment and teaching materials would have to be developed. These, and the existing student facing materials, would need to go through our formal learning development and accessibility, design and approval process. The intention was that the new experiment would be suitable for group work, and this is potentially more difficult to arrange at a distance learning institution than at other HE establishments. We will be separately trialling group work using the existing experiment and a parallel database, with volunteer students and tutors in March/April 2024.

A clear limitation of the piloting was that it was undertaken by volunteers in the summer recess. There is no way to ‘prove’ if participation would be greater than the current level of 30% of active students. However, the topic would seem to have wider appeal than the root lengths of seedlings grown in the light or the dark. Engagement was high, with 43 of the 52 volunteers registered to use the database and 39 successfully uploaded data. Ten students opted to keep the monitor to take further readings. The forum was very active and additionally some students directly emailed staff members.

The experiment actively engaged students in terms of generating their own hypotheses; communicating and collaborating with other students to investigate ideas; problem solving (especially in terms of the database); and working on the global issue of particulate levels. The data collected certainly involved data suitable for regression, time series and geographical analysis and the potential contribution to other environmental focussed courses is still being investigated.

The benefits to the students in terms of academic and professional development seemed considerable with many having concrete links to employability skills such as problem solving, critical thinking, and collaboration (see figure 1). Students seem to value the opportunity to take part in the investigation of a better experiment for future students and to explore their own questions about comparisons of their data to that of fellow students.

5. Ethics Statement

This study was considered a low-risk study and meets The Open University Human Research Ethics Committee (HREC) criteria for exemption from formal review (reference number: HREC/4775/Calvert: air quality monitoring), http://www.open.ac.uk/research/ethics/.

6. Acknowledgments

The major acknowledgment is due to the students who freely gave of their time and efforts and comments. Also to the Pathfinders project team (SWIM team) who investigated the build of a monitor internally, partially funded the purchase of the commercial monitors and built and supported the database. The School of Mathematics and Statistics for also partially funding the purchase of monitors and to Dr C. Rolph for advice on experimental design.

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CASE STUDY

Project-based learning integrated with e-Assessment

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Abstract

This paper explores a recent move towards project-based learning for a first-year undergraduate statistics module at the University of the West of England, Bristol. The course is aimed at students specialising in Mathematics and Statistics. A classroom-based end of module project week was developed with the focus on project-based learning, supported by Dewis-R data generation and e-Assessments. Simulation of a practice-based environment with a dedicated working area and daily deadlines is incorporated to enhance the activity. Students are faced with a highly relevant statistical analysis task, that is large and has not had the prior data screening or cleansing that they may be accustomed to in basic didactic teaching. Indications are that the project-based learning approach, assessed during a project week with supplementary e-Assessments and a final report, is well received and leads to improved student outcomes.

Keywords: project-based learning, e-Assessment, statistics.

1. Introduction

This case study focuses on an end of module week-long assessment activity on an introductory statistics module. Students are tasked with identifying and implementing appropriate statistical analyses, that allow the delivery of a report that satisfy research questions supplied by a client. This is an example of project-based learning, which involves the use of real-world problems with authentic complexity beyond that taught in basic textbooks (Solomon, 2003). This approach is gaining in popularity in higher education with widely accepted potential for strong student outcomes (Guo et al., 2020), and many studies have demonstrated empirical evidence in favour of it (Kokotsaki et.al., 2016).

Project-based learning shall be referred to as PBL throughout this paper, and not to be confused with either problem-based learning or practice-based learning. In problem-based learning students discover concepts and principles through a real-world problem, whereas in our case these concepts have been previously taught. Practice-based learning arises from problems within a genuine working environment, whereas we are working in a simulated setting.

Without due care and attention to data checking and preparation, analyses may be flawed and worthless. For example, a fundamental step often overlooked in statistics textbooks and courses is the work required to get data into a format suitable for analyses. A move towards PBL can be of great benefit towards learning statistics, changing the student perspective from simply performing a statistical test as directed, to thinking about the entire analytical process. PBL can provide effective active learning of introductory statistics to non-specialists (Marshall, 2019; Karpiak, 2011; Tarmizi and Bayat, 2010).

Real-world statistical analyses cover all the essentials of PBL identified by Larmer and Mergendoller (2010). Among these essentials, statistical consultancy offers meaningful and compelling work, with different choices to explore and a final product to present to a client. Statisticians also require strong 21st century skills such as communication and collaboration. Of note is the need for PBL to enhance feedback and revision, we will demonstrate how this can come via classroom interaction and supplemented by e-Assessments.

A limitation of automated e-Assessments is that they install an algorithmic view of statistics which may be perceived to conflict with PBL (Pearce and Derrick, 2019). However, a well-formed automated e-Assessment can not only provide summative assessment, but also give students immediate assurance of correct approaches or feedforward based on any common mistakes that are made (Sikurajapathi et al., 2020).

This paper provides a case study showing how e-Assessments can be used within a PBL and assessment approach for students specialising in Mathematics and Statistics, followed by discussion of the effectiveness of the methodology. The e-Assessment system used is Dewis-R, developed at the University of the West of England, Bristol (UWE). This is a subsidiary to the Dewis system used at the same institution but allowing for R code to be used in the programming environment. Dewis-R is a fully algorithmic web-based e-Assessment system (Gwynllyw et al., 2020). The Dewis-R system is already used to assess non-specialists in statistics (Weir et al., 2017). In the academic year 2022-2023, over 2,000 UWE students were using Dewis-R e-Assessments across three faculties plus federation colleges.

2. Implementation

The focus of this paper is on an end of module PBL week designed as the final assessment of a core first-year mathematics undergraduate module called ‘Statistical Investigations’. Historically the final assessment was a traditional written exam involving SPSS output supplied to the student, and manual calculations. Now the students are examined throughout the academic year by a series of computer-based in-class e-Assessments that deliver data to be analysed in SPSS, with a concluding week to replicate real world application of the taught materials together with some new skills. All programme resources and contact time are diverted to the module for the week, students have no scheduled teaching on other modules. There are contact hours every day, and the project is designed to be completed as part of a standard 35 hour working week. The module is completed a few weeks before the end of term allowing students more time to focus on other modules with traditional end of year exams.

The PBL activity that is inspired by a real statistical consultancy project conducted by one of the authors. The lecturers on the course play the role of management for a consultancy business, scheduling the contact time as meetings designed to progress towards project completion. Students are given the opportunity to work in a designated community space from 9am to 5pm, in a manner that simulates an office-based environment. A key feature of the week is promoting best practice within industry, this includes information prior to the start of the week of the standards required by management to ensure that students are active members of the team (e.g. attendance or apologies for absence).

There are 12 hours of formal contact time split across five days, scheduled at the start of every morning and afternoon. Each session starts with up to 1.5 hours of instructor led discussion and small group activities. Following this, the students are free to build upon developments from the session either independently or in groups.

The project design is such that most of the techniques taught during the academic year are needed and students will need to identify and perform appropriate parametric tests or their non-parametric equivalents. Real world challenges and best practice are introduced to the students during the week.

Each day has one or two summative deliverables with a deadline of 8pm that day. To give instant feedback on progress, this includes four small e-Assessments available from 5pm. Students are permitted one submission attempt for each daily engagement activity and must take personal responsibility to submit these before the deadline. The highest weighted task is a final report of no longer than eight pages due after the completion of the week.

The report is due one to three weeks after the completion of project week, depending on the timing of the Easter Holidays. A daily breakdown of activities within project week is given below.

2.1 Monday

The consultancy scenario is introduced that concerns an employer wanting to know the reasons behind a high employee churn rate. Students are briefed to design and author an appropriate questionnaire that considers potential analyses to address the clients' needs and comprises:

- A question asking about the employee's intention to leave;
- Two questions for each of three latent variables regarding aspects of employee's attitudes;
- Two questions regarding the employee's work status;
- Two questions regarding the employee's demographic makeup.

In line with good practice procedures, students are presented with an activity log template to maintain records of key activities during the week.

The daily engagement assessment is an individually authored Qualtrics questionnaire with supporting synopsis.

2.2 Tuesday

Students are provided with a bespoke data set that is larger than they have experienced before, containing over 100 respondents to the final questionnaire determined by the academic. The data is supplied in a .csv format of messy data by design, typical of how data is received in practice. This means that students need a preliminary effort to format data so that it can be analysed by SPSS. Student focus is on data set creation, and univariate exploratory data analyses. As part of best practice procedures, one of the requirements is that syntax is required for these tasks.

The same 22 variables are given to each student, but with a different number of responses and different signals within the data. The datasets are generated using Dewis-R. As part of the generation of multiple bespoke datasets for the cohort, the following are included by design for each student:

- A unique set of data values;
- Some missing values (missing completely at random);
- Varying combinations of 'significant' and 'not significant' variables;
- Varying distributions of variables in terms of skewness and kurtosis (normal and non-normal);
- Either equal variances or non-equal variances, for relevant bivariate comparisons;
- A variable with observations outside an appropriate range;
- Variables supplied in string format that need to be converted to numerical;
- Likert style responses that form part of a summed Likert scale, where some are reverse coded;
- Variables that have categorical responses with low frequency counts.

Students obtain their bespoke dataset via the Dewis-R interface (figure 1).

Figure 1. Dewis-R interface for student collection of bespoke dataset.

Set-up as a formative e-Assessment, students are instructed to open the dataset and report the number of respondents and number of variables. This confirms that each student is working on their own unique dataset. Submission acts as receipt that students have collected the data, those that have not submitted can be contacted by the module team. The student username and unique dataset number is included to allow academics to access the dataset and solutions for each student if necessary. The dataset number remains constant throughout all e-Assessments for that user.

There are two summative daily engagement checkpoints: SPSS syntax to create and clean the dataset; an e-Assessment relating to univariate analyses. An example of a summative e-Assessment is given in Section 2.3.

2.3 Wednesday

Bivariate analyses of the dependent variables are required. Student focus is on identifying the correct tests to perform and the interpretation of the results.

An example summative e-Assessment is given in figure 2.

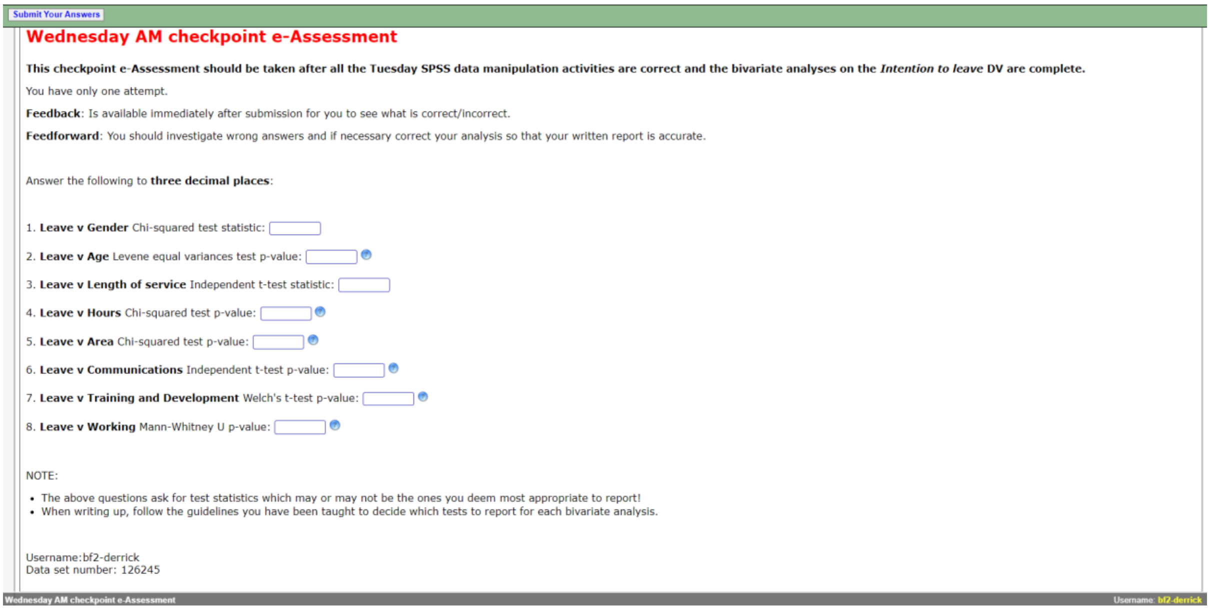
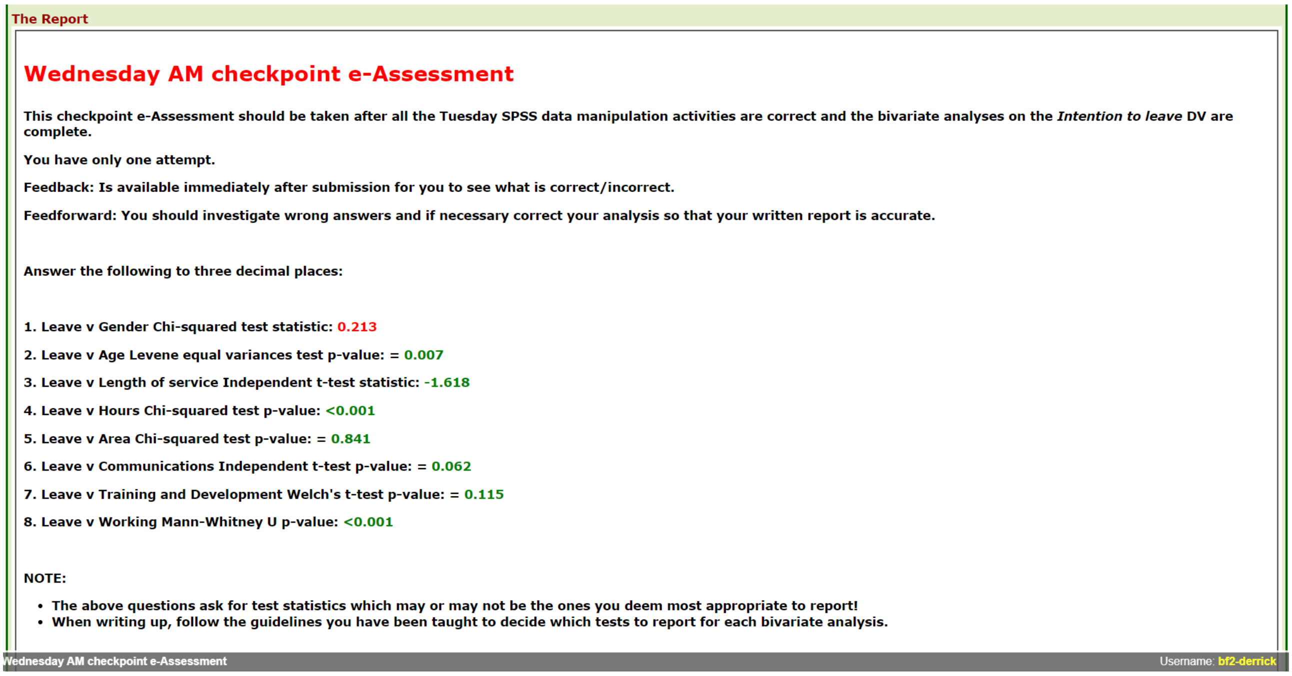


Figure 2. Example of Dewis-R checkpoint e-Assessment.

Upon submission, students are greeted with options to view their feedback (figure 3) and feedforward (figure 4). Students can view their feedback and feedforward at any time after the deadline, even if the deadline was missed.


The Report

Wednesday AM checkpoint e-Assessment

This checkpoint e-Assessment should be taken after all the Tuesday SPSS data manipulation activities are correct and the bivariate analyses on the *Intention to leave* DV are complete.

You have only one attempt.

Feedback: Is available immediately after submission for you to see what is correct/incorrect.

Feedforward: You should investigate wrong answers and if necessary correct your analysis so that your written report is accurate.

Answer the following to three decimal places:

1. Leave v Gender Chi-squared test statistic: 0.213
2. Leave v Age Levene equal variances test p-value: = 0.007
3. Leave v Length of service Independent t-test statistic: -1.618
4. Leave v Hours Chi-squared test p-value: <0.001
5. Leave v Area Chi-squared test p-value: = 0.841
6. Leave v Communications Independent t-test p-value: = 0.062
7. Leave v Training and Development Welch's t-test p-value: = 0.115
8. Leave v Working Mann-Whitney U p-value: <0.001

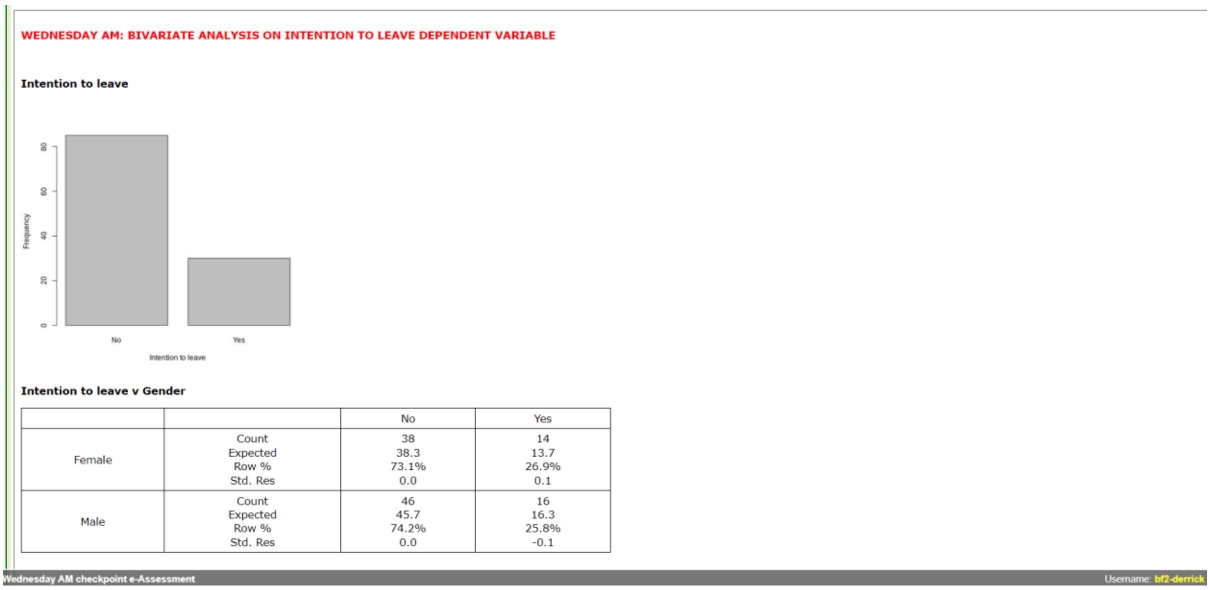
NOTE:

- The above questions ask for test statistics which may or may not be the ones you deem most appropriate to report!
- When writing up, follow the guidelines you have been taught to decide which tests to report for each bivariate analysis.

Wednesday AM checkpoint e-Assessment Username: bf2-derrick

Figure 3. Example feedback given to student upon completion of e-Assessment.

The feedback in figure 3 details the numerically correct answers for different statistical tests. Students are also given a report which details which question/s they answered incorrectly. Students can then look at any feedforward supplied for the questions. The feedforward in figure 4 gives an indication to how the answer to the first question may be arrived at, which may be useful for diagnosing mistakes and subsequent adaption for part of their final report.



		No	Yes
Female	Count Expected Row % Std. Res	38 38.3 73.1% 0.0	14 13.7 26.9% 0.1
Male	Count Expected Row % Std. Res	46 45.7 74.2% 0.0	16 16.3 25.8% -0.1

Figure 4. Example feedforward given to student upon completion of e-Assessment.

In this example you can see the correct Chi-squared value (figure 3) and the supporting additional information shows a table of counts (figure 4) which should trigger understanding of how the answer was derived and prompt the student to correct any data errors. Many parametric and non-parametric statistical tests are covered in the e-Assessment, and students are directed to look at the module materials including e-Assessments completed during the year for guidance to which statistical test may be appropriate for their report, based on their unique dataset.

A small but previously unseen urgent client request surfaces towards the end of the afternoon, to further mimic industry working conditions and test student resilience.

There are two daily summative engagement checkpoints: an e-Assessment based on analyses of the categorical dependent variable; an e-Assessment based on analyses of the scale dependent variable, including the additional client request.

2.4 Thursday

Multiple regression analysis of the continuous dependent variable is developed, with discussion of model assumptions. Some new challenges are included for linear regression analyses with categorical explanatory variables of more than two levels.

All the statistical analyses are completed by the close of business on Thursday, and thus the remaining focus is purely on the report write up.

The daily summative engagement checkpoint is an e-Assessment relating to regression analyses.

2.5 Friday

Student focus is on succinct report writing for the target audience, considering formal statistical reporting, appropriate style and content. The delivery includes group discussions with comparison between group ideas on the content to include in a client-orientated report, and quizzes that ascertain and challenge misconceptions about how the report should be written, e.g. at the outset many students believe that mathematical theory of their applied techniques should be included.

The daily summative engagement checkpoint is the activity log detailing daily activities.

To simulate workplace colleague dynamics, we state that from close of business on the final day tutors are away on holiday and/or busy working on other projects, fully entrusting the student to submit the report for the client when it is due.

3. Discussion

Having adopted this PBL approach, academics on the programme have found that the cohort progress from the first year with far greater key transferable and technical skills than students on the equivalent module prior to the move to PBL. There is a distinct observable improvement in students’ confidence and readiness to tackle statistical analyses of large, messy, and missing data.

Students are encouraged to work in groups on common analytical ideas, while being assessed separately. This collaboration is made possible because the unique datasets ensure that the most appropriate choice of statistical tests differ among students, and the subsequent interpretation of results require each student to have a bespoke response.

While the structure of the week facilitates peer collaboration, the use of Dewis-R to generate unique datasets means that students cannot rely on peer collusion to ascertain and report on statistical output.

This leads to some interesting reports to mark, thanks to different conclusions which are often obtained via unique and sometimes innovative student approaches.

The project is devised in such a way that all students receive similar challenges, but differences within the datasets encourage students to find their own solutions and express their individuality. For example, one challenge implemented is that some students may have ages recorded as below 16, whereas other students may have ages recorded as greater than 80; another example is that some students, by design, need to report the independent samples t-test, whereas other students need to report the Mann-Whitney test. In addition, a student will have significant results to report relating to a subset of the variables within their dataset, whereas other students will have different subsets of variables leading to significant results. The bespoke offering to each student arises from a combination of many of the separate challenges that have been programmed, but the similarities in what may be considered reasonable student approaches to each challenge ensures that every bespoke assessment is congruent to each-other and the learning outcomes; there has been no perception of unfairness reported by students.

The five principles for the future of assessments (Jisc, 2020) are core to the adopted assessment strategy:

1. **Authentic.** Students are active learners, with interactions and technology that they will experience in their careers, including general communication skills, computing skills, and specialised statistical software.
2. **Accessible.** The e-Assessments have the benefit of a familiar format, allowing students to report results in a standardised manner. Students have a high degree of familiarity with Dewis-R e-Assessments because they are used both formatively and summative throughout the module, based on Weir et al. (2021). Students can practice these questions an unlimited number of times and revisit them as necessary during project week.
3. **Appropriately automated.** In addition to the Dewis-R e-Assessments, appropriate analyses are generated by the system for the academic to cross-check against their final report.
4. **Continuous.** The Dewis-R system records all student interactions and results throughout the week, assisting with both short-term student monitoring and long-term identification of threshold concepts.
5. **Secure.** The student footprint reveals exact timings of entering and completion of assessment. This is not an assignment that could be readily completed by artificial intelligence, which is becoming a concern about some assessments.

The presence of e-Assessments with automated feedback allowed academics to promptly intervene for any students that were struggling, this intervention is facilitated by the daily timetabled contact with students and local working environment throughout project week.

There are challenges timetabling a large group of students in their own space for the whole week, but we deem it necessary to have this community working environment to emulate practice-based learning. There were some information technology issues experienced mid-week by some of the students, reflecting challenges that can be faced when working authentically. It was great to see students overcome challenges as part of a community of workers, building their overall resilience.

Students were given plenty of forewarning of an intense week replicating a 9am to 5pm office style working environment. Some students had to juggle childcare and other commitments and took individual responsibility for this. Those that needed to miss meetings forwarded appropriate apologies, this is an example of how the simulation of a professional environment embedded a professional response from the students.

Engagement was high throughout the week, with attendance far greater than experienced for a typical hour of formal contact time during the academic year. Many students also remained working on campus outside of timetabled contact hours in the area reserved for them. Students recognised the need to be working full time to reach the targets of the next sessions and/or daily assessments.

Students performed very well in the project week daily activities, as these were designed to retain engagement rather than be onerous tasks. The final report represented a bigger challenge for the students, given that this is their first attempt to write a formal statistical written report. Nevertheless, with the high work ethic initiated during the week and the dedicated report writing session, the students were able to produce good reports.

Student feedback shows a consistent theme of this project week being a "*good*" and "*challenging*" experience, with key comments referring to the week being "*demanding*" but "*enjoyable*" and "*rewarding*".

4. Conclusion

This paper details a project-based learning approach, integrated with summative e-Assessment, for the teaching of Statistics.

Dewis-R is used to generate bespoke datasets. This provides each student with individual problems, that are solved through collaborative active learning. Using the e-Assessments, students can introspectively examine their methodology and correct it where appropriate.

Project week fosters a community of learners met by enthusiasm from students and lecturers alike. The partial e-Assessment approach reduces the marking burden during the week and assists in monitoring student engagement which can lead to timely academic intervention if required. However, challenges for teaching in this manner on this basis include the high volume of preparation involved, the intensity of the week, and scheduling constraints.

This end of module project week has improved student cognitive outcomes and behavioural outcomes. Since the move to PBL, we have for the first time recruited several completing first year students to provide paid consultancy work on behalf of the university. We have found that this novel form of assessment is very well received by students with positive feedback.

The concept of using Dewis-R to provide each student unique PBL based challenges has subsequently inspired other well-received assessments within the university, including formative assessment in the second year of the same degree programme, and summative assessment on a postgraduate data science programme. This includes additional data challenges such as other forms of messy data, and extensions to other types of analyses. We strongly believe that this PBL approach is superior to historical traditional methods. Further embedding and extensions of the PBL principles demonstrated in this paper is recommended for these modules and beyond.

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CASE STUDY

Applied Data Analysis: A Problem-based Learning Approach

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Abstract

This paper examines the transition of a conventional multivariate statistics module to a problem-based learning module, first implemented in 2021. The primary objective was to enhance students' problem-solving skills, bridging the gap between mathematical concepts and real-world applications. The approach was implemented to instil a deeper understanding of real-world data analysis, emphasising the interpretation of domain specific problems in mathematical terms and the production of reports for industrial stakeholders.

Findings indicate that the integration of problem-based methods not only improved students' comprehension of statistical techniques but also fostered a more profound appreciation for their practical utility in diverse professional contexts. The problem-solving cycle, a central component of the approach, guided students in critically analysing complex challenges and formulating data driven solutions. Furthermore, this study emphasises the potential for replicating the industrial study group experience within an undergraduate teaching environment.

Adopting a problem-based learning approach in the teaching of data analysis empowers students to apply their analytical skills effectively to real-world scenarios, strengthening their capacity to communicate insights and solutions to industrial stakeholders. The study underscores the value of aligning educational practices with the demands of data-driven industries, providing students with a competitive advantage in future research and the job market. The study is descriptive and reflective in nature.

Keywords: problem-based learning, knowledge exchange, Study Groups for Industry, multivariate statistics, applied data analysis.

1. Introduction

For continued industrial advancement and economic growth, the UK requires an informed pipeline of graduates in mathematics related disciplines to feed roles in research and employment. The Bond report (Bond, 2018) outlined several recommendations to achieve this aim including incentives for academic engagement with small to medium enterprises (SMEs) and resources for industrial engagement via study groups for example. Established centres for doctoral training (CDTs) for postgraduate researchers and at least one centre of excellence to foster direct engagement between mathematicians and industrial partners.

Critical real-world problems can all be solved using mathematical techniques, it is therefore imperative that university education is aligned to inspire the new generation of enthusiastic and creative researchers desperately needed. Current learning tends to be narrowly focused on theoretical aspects and often overly sanitised, historical data sets. Little or no consideration is given to the wider issues presented on application and execution in non-mathematical domains.

Knowledge exchange (KE) describes a two (or multi) way exchange of information and skills between academia and practitioners be they industrial partners, policymakers, or service providers. Critical skills include understanding the stakeholder requirements, formulating a mathematical problem and communicating findings in domain appropriate language.

2. Undergraduate mathematics

Typically, the focus of undergraduate teaching in the mathematical sciences is on the more theoretical aspects of topics, theorems and proofs. Whilst this supports greater understanding of processes in general, model assumptions and error estimation for example, it does not incorporate all required elements of mathematical applications in industry.

On validation of the BSc Mathematics degree at the University of Huddersfield in 2018, the course was designed with four distinct streams of learning. Namely, the calculus, statistics, technical competencies (including programming and linear algebra) and the professional streams. The professional stream includes a year one problem solving module where students study real industry problems and present their findings in a report to the stakeholder, a group project in year two and final year individual project. Initially the final year module Applied Data Analysis (ADA), within the statistics stream, was designed as a traditional multivariate statistics module, the theoretical partner to the 'Big Data Analysis' module which runs in parallel. However, on anticipating the first final year cohort (2021/22) it was abundantly clear the module was outdated. During the four years from validation there had been not just the Covid 19 pandemic but an exponential rise in the need for appropriately skilled data analysts and data scientists. Throughout this period, I became increasingly involved in KE in particular study groups for industry, both online hosted by the award-winning Virtual Knowledge Exchange in Mathematical Sciences (VKEMS) team, funded through the Rapid Assistance in modelling the Pandemic (RAMP) continuity network and in person, e.g., European Study Groups for Industry (ESGI). Study groups require the facilitator at least to engage with the entire problem solving cycle: formulating the problem mathematically to reporting to industrial stakeholders.

Traditionally we teach only a fraction of the necessary skills, most crucially students are generally not involved with formulating the research problem and communicating findings in non-technical language.

As the primary aim is to equip undergraduate students with the necessary skills to solve real-world problems it was increasingly apparent a change of teaching approach was necessary. None of the key problem-solving skills are trivial and require nurturing alongside the more commonly taught elements such as using computing packages. It was with this in mind, and many study group experiences, the decision was made to restructure the module and hence the assessment regime to reflect realistic procedures and meet industry needs.

Hence the decision to switch to a problem-based learning format and replicate study groups and the problem solving cycle (figure 1) as illustrated in Spiegelhalter (2019).

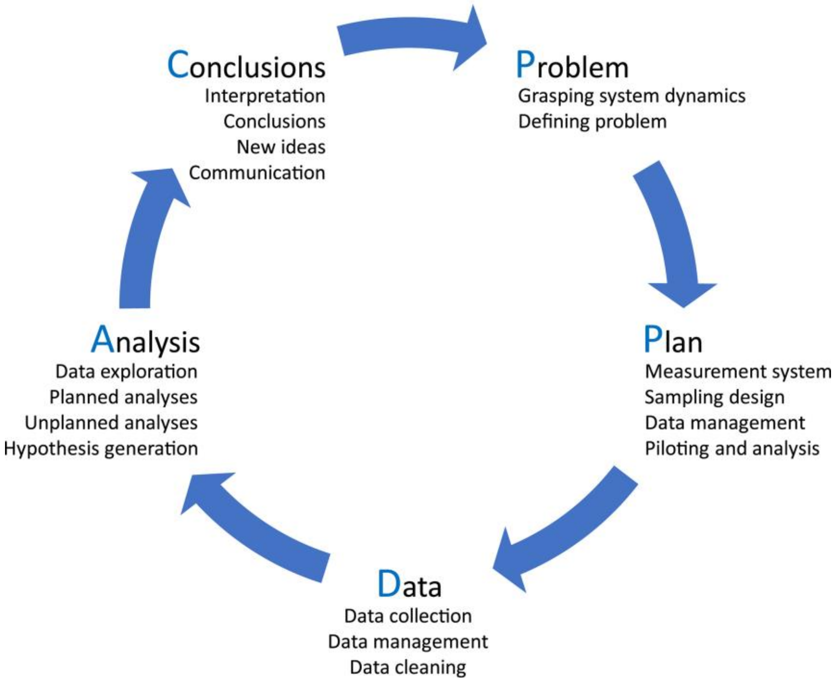

Figure 1. The Problem Solving Cycle PPDAC.

3. Problem based learning

Problem based learning (PBL) is an inherently student-centred pedagogy whereby students learn through the experience of solving open ended problems, pioneered by Barrows (1996) and extensively researched since, notably by De Graf et.al. (2003) and Wood (2003). The final year ADA module is ideally suited to a PBL approach. Additionally, PBL offers an opportunity to replicate study groups within the undergraduate taught programme so enhancing fundamental research skills.

Advantages and disadvantages of PBL are well documented (Newman, 2005; Yew and Goh, 2016) and include deeper understanding of techniques and development of critical thinking skills through active learning and application to real-world problems in varied domains. Working collaboratively fosters communication another key skill nurtured in study groups and introduced to the module teaching. Drawbacks of PBL relate to difficulties in problem choice and design to enable full coverage of the syllabus. These are overcome by the module leader’s frequent involvement in study groups for industry and wider research activity. Although suitably redacted, sensitive information omitted, and problems adapted to complement level of study.

4. Study Groups for Industry

Study groups, initiated by Oxford in 1968, are a long-established means of KE. Groups of academics and sector experts work intensively on stakeholder problems for short periods, typically one week maximum. Following which problem findings are presented as a technical report to the industry partner and, usually, submitted to a repository such as *Mathematics in Industry Reports* (MIIR) (n.d.).

Study group problems vary considerably in both domain knowledge required and mathematical area. During the period between enrolment of our first mathematics cohort and their progression to final year, I engaged with many sectors and industrial experts including local authorities, NHS providers, the hospitality industry, SMEs, and government departments. My experiences include an equally broad range of mathematical applications, some evidently mathematical such as ‘Estimating the risk of satellite collisions in densely populated orbit shells’ (Transfinite Systems ltd. ESGI # 162; July 2020) and others less so. For example, the City of Edinburgh Council problem ‘Homelessness prevention’ in January 2022 (V-KEMS Study Group, 2022a) and more recently modelling tourism flows in the city of Edinburgh for ‘Traveltech for Scotland’ (ESGI # 171, July 2023).

Formulating a mathematical problem in a social sciences context presents different challenges to those of applications in physics or engineering domains. Although in any application time spent understanding the relevant processes and fundamental definitions is crucial to understanding the problem and identifying potential data sources. Homelessness for example has a different specification for the local authority than, say the Shelter (2024) charity definition. Further, a large proportion of the homeless are not registered so suitable proxy variables need to be identified if possible. These issues are not isolated but are typical of real-world practice and should be incorporated within any applied data analysis course to better prepare graduates. Also noteworthy is the need for mutual respect between experts from all sectors, and communication in its broadest sense. Without good listening skills there is a danger the actual problem request is swamped by prior assumptions (Brewer, 1999; Brewer and Lövgren, 1999).

The VSG ‘Public Perceptions of Science’ (V-KEMS Study Group, 2022) aimed to bring mathematical scientists and other disciplines together to solve end user defined challenges with the aim of addressing the issues associated with the public perception of science. Problems were presented by the OSR (Office for Statistics Regulation), *The Times* newspaper’s scientific correspondent and the Winton Centre for Risk and Evidence Communication, Cambridge the need for improved communication skills for scientists at all levels was highlighted. The ability to disseminate information appropriate to the audience, in non-technical language, must be addressed. Additionally, a need for media training was identified as essential. Themes further expanded in January 2023 workshop ‘Communicating Mathematics’ (INI, University of Cambridge, January 2023). Furthermore, effective communication is critical to success of projects during the research phases, exercising intellectual humility and avoiding academic arrogance is key to initiating truly collaborative research with experts from other fields and domains (Krumrei-Mancuso et al., 2020; Porter and Schumann, 2018). Abandoning prior assumptions and prejudices is crucial to blend interdisciplinary expertise with maximum potential. Intellectual humility’s impact on learning is naturally also apparent, recipients more receptive to constructive criticism and benefit accordingly (Wong and Wong, 2021) with evidence of high grade averages.

5. Compelling evidence for educational updates

Misconceptions during COVID 19 pandemic, especially the difficulties in communicating uncertainty in predictive models, in conjunction with findings from the VSGs ‘Public Perceptions of Science’ and ‘Homelessness prevention’ motivated a significant change in approach to the ADA module. As detailed in the Bond report *The era of mathematics* (Bond, 2018) there are a rising number of challenges that require mathematics, hence a need to address the shortfall in appropriately qualified individuals. Further, education should meet industry requirements in equipping graduates with the necessary skills to tackle read-world problems.

Moreover, with the rising culture of fake news and conspiracy theories, deliberate and accidental miscommunication and misinterpretation of scientific findings, there is a need for the scientist to effectively articulate consequences and communicate actions to industrial practitioners and other non-subject-specific interested parties.

Incorporating discussions around topics currently reported in the news and on social media adds even greater relevance to study material. The current student population is more diverse than ever before and presents a rich blend of views and perspectives. Additionally, creating a relationship rich community (Felten and Lambert, 2020) fostering belonging, well-being, motivation and success. To this end, and to highlight the growing need to fact check reported statistics in the news, weekly discussions based on the More or Less podcast (BBC, 2024) were introduced and proved extremely popular. Further iterations also included comparisons of communications styles and formats and critical reviews. These were usually issued in advance of sessions and discussion as a class and in groups facilitated. More specific KE was also added as a workshop.

6. Practicalities

Although the module remains a course in multivariate statistics fundamentally, it has been repackaged to include the essential research and communications skills necessary for practical application of techniques taught. The reading list was extended accordingly to include report writing skills (Murray, 2017) and (Freiberger and Thomas, 2023). David Spiegelhalter's *The Art of Statistics* (Speigelalter, 2019) was also highly recommended. With just two two-hour sessions a week the students are expected to prepare material in advance in a semi-flipped style, thus allowing more time for debates and optimising the professional decision processes. I didn't throw the toy data sets away, they were used firstly with reduced dimensionality for pen and paper calculations, then with full dimensionality for MATLAB demonstrations and practical exercises using linear algebra (LA) style model constructions (Chartier, 2015). Subsequently, resources were reviewed, and practical applications were executed on chosen real-life data sets for example from the *Government Open Data* (n.d.) resources.

7. Summative Assessment Update

Clearly, with the change in delivery and adoption of a problem-based learning approach, there was a need to also update the assessment structure. Initially an equal split between a single case study assignment and examination, updating to a proposed series of reports required application to the School Validation Assessment Panel, with pedagogical justification for the changes. A necessary inconvenience to gain maximum benefit from the new module teaching format. Once approved, assessment was updated to a series of three written reports roughly equally distributed across the teaching period. Turnaround is tight to allow sufficient feedback discussion and implementation of related improvements prior to the next submission date. A more extended period of reflection would be ideal and currently consideration is being given to linking the first and second coursework with a slightly earlier submission date for the first to assess understanding, resource choice and problem formulation prior to further analysis and full report at the second submission point as illustrated in figure 2. Submission dates are equally spaced across the twelve-week period, coursework 1 in week 4, coursework 2 in week 8 and coursework 3 in week 12, and contribute 30%, 30% and 40% respectively.

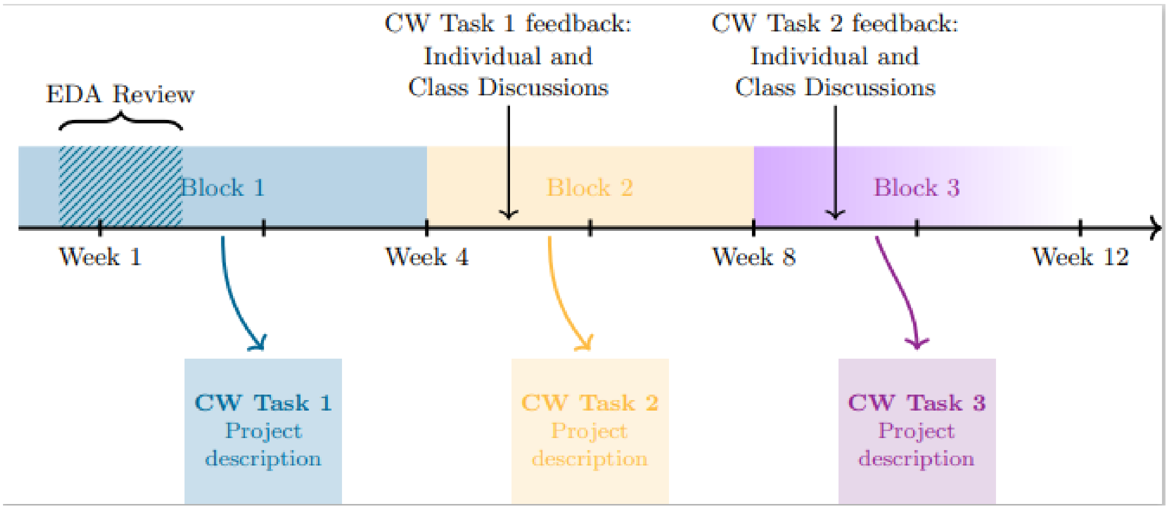

Figure 2. Assessment schedule Schematic.

Cohorts are small, with fewer than twenty students so both attention to individuals and intensity of marking is manageable. Average marks are generally higher than the average across all final year modules but typically have much greater variation and spread of grades, see table 1.

Table 1 Summary Statistics for Module Results.

Academic year	Mean	Standard deviation	LQ	Median	UQ	Max.	Min.
2021/22	71.3	11.5	62.5	68.0	75.8	94	59
2022/23	67.4	14.6	61.0	68.0	74.0	95	45

8. Reflections

It is probably unsurprising that the elements which were best executed were those we used to routinely assess. Generally analytical aspects were reasonably well understood although the computation and use of technical packages proved more problematic for some but was manageable. It should be noted that specific software was not dictated with the general advice being to use whichever was most apt for the task. This itself produced lively debate on preferences particularly with respect to ease of execution, formatting, and output quality. Students are taught RStudio, Python, and MATLAB throughout their studies and whilst some embrace all platforms others tend to adhere to a particular favourite. Conclusions in technical terms were often weak or insufficiently evidenced and model validation similarly less rigorously executed, omitted or incomplete. Typical of previous experience in similar modules.

Greater challenges were met in the more bespoke aspects of the problem-solving cycle. Crucially, the skills industry really needs when they employ ‘data scientists’, ‘data analysts’ or academic researchers.

Communicating findings in non-technical language proved to be particularly challenging. This tended to be an unsupervised section as students completed reports pre submission deadlines and notably improved across the assessments. Hence the inclusion of specific communication-based activities in further module iterations which has had some beneficial impact. Another challenging aspect is the formulation of research questions, bridging the domain-maths-domain bridge, and formulating mathematical solutions with caveats to address presented problems. Again, further exposure to example scripts has some efficacy. Approaches include extended analysis of the More or Less podcast topics, for example, identifying and accurately stipulating any statistical facts in context with reference to assumptions and limitations of the reported problem. Also, journal articles, minus abstract, are used to develop abstract writing skills, student versions are subsequently compared and further discussed alongside the author version. The latter has the added benefit of relevance to a compulsory course component, the Final Year Project dissertation.

Still, there is no doubt, mathematicians are generally very good at the mathematics of problem solving but less good at interpreting problems in mathematical terms and communicating findings, hence converting findings into recommendations for industry purposes.

In summary, I believe this to be a successful, although difficult process at undergraduate level, and am generally seeing excellent results with glowing feedback across all grade bands. Students gain demonstrable problem-solving skills, plus transferable research skills for progression to postgraduate study or the workplace.

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CASE STUDY

Authenticity in Learning, Teaching and Assessment

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Abstract

Mathematics graduates traditionally are recognised for their problem solving, critical thinking, and analytic skills. However, the methods often used to hone these skills at university are often abstract and decontextualized. This can often create a disconnect between expected capabilities of a mathematics graduate from employers and the actual problem-solving skills required in their career. In this case-study we will outline how the programme team has developed our approach to authentic learning and authentic problems to bridge this gap and ensure graduates are prepared for the workforce.

Keywords: authentic assessment, mathematics education.

1. Introduction

Historically, graduates of degrees in mathematics have garnered recognition for being in considerable demand among employers, attributable to the competencies cultivated throughout the course of their academic studies. The QAA Subject Benchmark Statement (QAA, 2023) summarises these graduate outcomes, describing a typical mathematics degree as enabling students to "*develop graduate attributes which include an enhancement of many general skills, such as numeracy, IT skills, critical understanding and assessment of complex problems, and the ability to identify and analyse problems leading to formulation of solutions, as well as subject-specific skills such as mathematical modelling, data analysis and numerical methods*." However, it is often the case that skills such as critical thinking and problem solving are developed in a more abstract setting than can be communicated to non-mathematicians. Anecdotal evidence, from employers with whom Middlesex University consulted when designing the degree programmes and from students that have graduated from the degree programmes, suggest that what mathematics graduates often lack is evidence of using these problem-solving skills in a real-world setting and an ability to communicate their results to a non-mathematical audience. One particularly useful approach to enable this is the use of authentic assessments. This has been noted in the literature; Pitt and Quinlan (2022) state that "*[a]uthentic assessments can … generate products that showcase students' capabilities more richly than grades alone, making them potentially useful for rethinking how student performance is communicated to [employers]*".

Middlesex University has always emphasised applied, practical skills with a view to ensuring that graduates are prepared for work. The university's stated signature pedagogy is primarily concerned with active, practice-based learning and inclusivity through technology. As a result, the mathematics team have incorporated these philosophies into our BSc Mathematics and BSc Mathematics and Data Science programmes.

Gulikers et al. (2004) describes authentic assessment 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 is especially difficult to pin down given the diversity of graduate destinations that a typical graduate from mathematics degrees end up in. This, therefore, raises the question: what does authentic assessment mean in mathematics?

In this case study we will present part of an approach taken to answer this question, namely to allow flexibility in the form students can submit their coursework, whether this takes the form of traditional written mathematical coursework, a written discussion, or a multimedia presentation. This approach allows students to enhance their creativity and communication skills while ensuring they build a portfolio of evidence of their skills for potential employers. This is what we will call authentic assessment since the assessment can take the same format as tasks they would be expected to perform in the workplace.

Middlesex University students are loaned iPads and Apple Pencils throughout their degrees, with common software installed on each one. This common platform enables the team to utilise industry standard tools, such as RStudio Server, into our teaching and assessment. Embedding industry tools and the use of real-world data provides students with the opportunity to enhance their problem-solving skills in a more applied setting. Problems fitting this description we will call authentic problems since solving the tasks themselves will involve a similar skillset to those they are likely to encounter in graduate positions.

In this case study we will discuss the approaches we employed to teach and assess mathematics undergraduates in an authentic way. We will make a distinction between authentic assessment and authentic problems in sections 2 and 3 and discuss how this was made possible through the common platform. Section 4 will explore potential approaches to scaling these approaches to larger modules and the difficulties brought on by Large Language Models (LLMs), such as ChatGPT.

2. Authentic assessment

The landscape of assessment in Higher Education has changed drastically since the CoViD-19 pandemic. In response to the necessary move off campus and the inability to have in person examinations many universities began to embrace authentic assessment. Middlesex University in particular, mandated the removal of all end-of-year examinations that were not required by professional bodies for accreditation university wide. The maths team made the decision to remove exams and replace them with authentic assessment at the point the undergraduate mathematics programmes were being revalidated in 2020, prior to the university making the same decision. Authentic Assessment is often defined in a similar way to the Gulikers et al. (2004) cited above. Villarroel et al. (2018) distilled more than 100 articles on authentic assessment published between 1988 and 2015, concluding that authenticity in assessment can be summarised by the following three criteria:

- **Realism**. Authentic assessment emphasises the practical relevance of problems to the professional setting, communicating assessment briefs more closely aligned to the language graduates might encounter in the workplace.

- **Challenging**. Assessments might be less well-formed, requiring students to demonstrate higher-order thinking skills such as problem solving, critical thinking and critical understanding.
- **Self-evaluative**. Transparency, for example, of marking criteria allow students to develop self-reflection and self-evaluation.

Middlesex University internal guidance similarly defines authentic assessment as having the following characteristics:

- Is realistic;
- Requires judgement and innovation;
- Asks students to 'do' the topic;
- Replicates or simulates the context in which adults are tested in the workplace;
- Assesses the student's ability to efficiently and effectively use a repertoire of knowledge and skills to negotiate a complex task;
- Allows opportunities to rehearse, practise, consult resources, and get feedback.

When we began to incorporate authentic assessment into our programme we had to do so in a way that respected the university's definition of authentic assessment. Our interpretation of the above definition was that students should be given the opportunity to enhance their employability skills while still testing their mathematical ability. What resulted was pieces of coursework in which students could choose the format in which they could submit their coursework. Many of these formats reflect the kind of task graduates may have to complete in the workplace, including:

- Traditional written coursework;
- Written discussions;
- Multimedia submissions.

Staff may encourage students to consider submitting in one of these formats. This approach had a number of advantages. First it gave students the opportunity to decide if they want to target an employability skill as part of a piece of coursework, and if so, which of these they would like to work on. Second it promotes inclusivity among students by allowing them to select the format of submission that they believe best reflects their mathematical ability. To help aid consistency of marking across formats, and to remain true to the philosophy that assessment should reflect workplace tasks, there will be marks available for the overall presentation of submissions in any format. Marks for the presentation of a submission regardless of format prioritises the clarity, correctness and mathematical rigour of the problem-solving method rather than good video editing skills or the use of graphics. We do however appreciate knowledge of appropriate software for submissions, for example LaTeX for written submission. This has the added benefit that this reduces the need to make reasonable adjustments for the assessment since it is built in. Finally, it allows the students to exercise their creativity in selecting their format of submission.

These innovations were welcomed by students, with one student even using one of their multimedia as part of a successful job application which was cited by their employer as a highlight of their application. More detail of this work can be found in the paper Masterson et al. (2022).

3. Authentic Problems

Authentic problems are distinct to authentic assessment, or at least our implementation of authentic assessment. An authentic problem is a problem which is similar in format and context to the kind of task a student can expect in the workplace.

Section B

Work with your lecturer to identify a topic that is of interest to you, and find a dataset related to this topic that is appropriate to analyse.

Question 1: Provenance (Total 2 marks)

Describe your dataset.

- How trustworthy is it?
- How accurate is it?
- What could be done to improve the quality of the data?

Question 2: Data analysis (Total 18 marks)

Write R code to analyse the dataset, calculate appropriate statistics, and interpret your findings.

In particular you should demonstrate your knowledge and understanding of *summary statistics* and *confidence intervals*.

Your code should be commented to explain what it does in mathematical and statistical terms. You should refer to the mathematical and statistical theory of the course to justify any claims you make or assumptions about the data.

Show a draft to your lecturer by *Friday 17th November*.

Your lecturer will then set a follow-up question that should be addressed in your final submission (see Question 3).

Question 3: Personalised follow-up question (Total 10 marks)

This question will be set by your lecturer after reading your draft work. It will involve combining data from an additional dataset.

Question 4: Large Language Model comparison (Total 5 marks)

Use a Large Language Model (such as ChatGPT) to attempt to write a data analysis similar to your solution to Question 2. (We will discuss possible prompts in the workshops). Copy and paste the prompt and output of the Large Language Model.

How does your data analysis compare? In what ways is it more useful?

Figure 1. Example of authentic assessment from a mathematical statistics course

It is important to note that an authentic problem is not simply an applied problem. An applied problem may be very well defined and therefore it is readily apparent to the student what techniques they are expected to utilise to solve the problem.

An authentic problem on the other hand will often:

- be vaguely defined;
- require experimentation;
- allow students to use every tool at their disposal;
- obligates students to attend structured guidance sessions.

This accurately reflects what will often be expected of mathematics graduates in the workplace, particularly those whose work colleagues do not have strong backgrounds. For example, one can imagine that it would not be unusual for a maths graduate working as a data scientist to be asked to analyse a dataset by their project leader or line manager with no further instruction. In this scenario, they would likely do some descriptive analysis and probe the data before reporting their findings to their manager seeking further guidance on what analysis the manager would like them to perform. These situations are likely very common for many of our graduates. Therefore, our assessment should be preparing them for situations just as these.

On our programmes there is a dedicated Level 5 Problem-Solving and Communication module where students gain familiarity with the nature of these open-ended problems in class. Thus, students have the confidence to tackle these open-ended problems when they begin to encounter them in summative assessment later in the academic year.

Figure 1 shows an example of an authentic problem from our second year mathematical statistics module.

This assessment closely reflects what a student may be expected to do if they're asked to analyse a dataset in the workplace. They must make some explicit judgement on the quality and source of the data. The brief is open ended. They must send draft to their lecturer to receive guidance and a follow-up question, replicating the employee manager dynamic. Finally, they must compare their report to that produced by a LLM such as ChatGPT. This serves two purposes: first it will discourage the student from using an LLM to produce their own report. More importantly, this is also authentic since a job applicant may be expected to demonstrate why their work is superior to that produced by AI.

While statistics may readily lend itself to this approach, it is still possible in pure mathematics modules. Figure 2 shows another example from a multivariable calculus module.

In figure 2 we see many of the same features again: judgement required, open-ended brief, and opportunities for consultation. Furthermore, they are again instructed to make a comparison to what is produced by ChatGPT. If a student were to choose a banana for this assignment and compare their solution to that produced by ChatGPT they would obtain output similar to that shown in figure 2.

This parameterises the surface in figure 4. Clearly this is not a banana! Students witnessing output such as this should be more aware of the limitations of LLMs and hesitant about using is to wholly complete their own coursework.

4. Larger Modules

There is the question of how such method would scale to larger modules. The method of having lecturers as project managers would seem to be quite demanding on staff time at a time when staff have increasingly large workloads. One of the advantages of in person exams, despite their inauthenticity, is that they are incredibly time-efficient for staff.

The received wisdom we got from an experienced colleague was that examinations are 10 times faster to marks than to sit. If we were to take this ratio as a given the below assessment breakdown would represent the same workload of 18 minutes per student for staff:

- 180 minute written exam;
- 120 minute exam and 6 minute viva;
- 60 minute exam and 12 minute viva;
- Three vivas of 6 minutes.

Allowing for more vivas would present more opportunities for authentic assessment reflecting the workplace with the lecturer playing the role of project manager. Vivas have long been used to assess students understanding of material and naturally lend themselves to this approach. Furthermore, past research from the team has shown that our students generally prefer having conversations with their lecturers to assess their ability over end of year examinations (Masterson et al., 2022).

It is this approach that we plan to utilise on one of our service modules in the forthcoming academic year. The team administer a service module for the Business School in Middlesex. The module typically has 120 students enrolled on it. Previously this module was assessed with a two-hour exam with sections A and B. Assuming our colleague's ratio these should take 12 minutes to mark each. Generally, the questions were closed, quite prescriptive and did not allow for a lot of problem solving.

Considering the university removing non-professional body examinations from all programmes the assessment for this module now needs to be revised. What we are proposing is a hybrid approach. Our assessment will still have two sections. Section A will have closed questions and prescriptive and therefore test similar skills to the previous incarnation of the assessment. Section B will be a 6-minute viva which will test the student's problem-solving skills. This should be a format that would not additionally to staff workload while incorporating the principles of authentic assessment even for large modules.

Real world calculus

We will look at an applied problem using multi-variable calculus.

1. Look around campus or at home for an object to model in 3D. The object should be curved and have no sharp edges so that we can model it using a continuously differentiable surface parametrisation.

   Now, use the "GeoGebra 3D Calculator" App to define a surface parametrisation for the surface of your chosen object.

   > **Pro-tip**
   >
   > Finding a good parametrisation is an iterative process - you'll have to try lots of things!
   > Try to think mathematically about your object:
   >
   > - Is the object 'built from' a curve?
   > - Is your object a collection of circles?
   >
   > The commands in https://wiki.geogebra.org/en/Surface_Command will be really useful.

   Write a log of your thinking as you develop your parametrisation. This log should describe how you are building up the parametrisation from your observations of the object.

   Bring some draft work to the workshop in Week 10. Your lecturer can support you with this activity.

   Your submission should include:

   - A photo of your chosen object (using your iPad).
   - A .ggb file that contains the parametrisation.
   - The surface parametrisation written down using appropriate mathematical notation.
   - The log of your thinking as you developed the parametrisation.
   - A short video of your chosen object with the parametrisation overlayed on top. This can be done using the "Augmented Reality" (AR) feature of GeoGebra and making a screen recording of the iPad.

   15 marks

2. Use an optimisation technique to find the greatest value of the z-coordinate for your parametrisation. 5 marks

3. What is the surface area of your parametrisation? Write down an appropriate integral that would give the surface area, and simplify as much as possible.

   It will almost certainly be impossible to evaluate this integral by hand. You should use numerical methods (e.g. from https://www.wolframalpha.com/) to produce the final answer. Include the code that you use to produce the numerical solution. 5 marks

4. The university plans to build an MRI scanner nearby your object. This means that your object will be subjected to strong magnetic field **B** described by

   $$\mathbf{B}(x, y, z) = \begin{pmatrix} 0 \\ y \\ -z \end{pmatrix}$$

   Write down an appropriate integral to calculate the total magnetic flux through your object, and simplify as much as possible.

   It will almost certainly be impossible to evaluate this integral by hand. You should use numerical methods (e.g. from https://www.wolframalpha.com/) to produce the final answer. Include the code that you use to produce the numerical solution. 5 marks

Figure 2. Example of authentic assessment from a calculus course

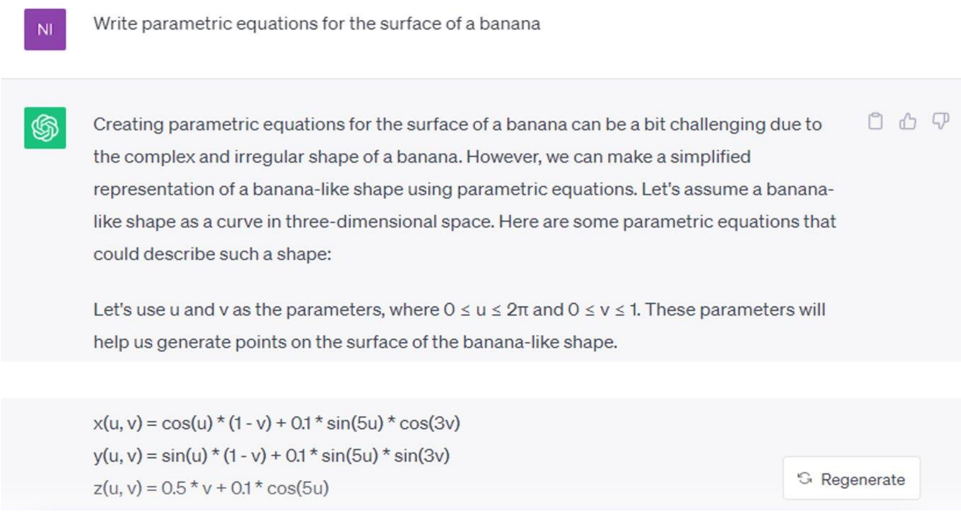

Figure 3. Extract from the dialogue of a ChatGPT request

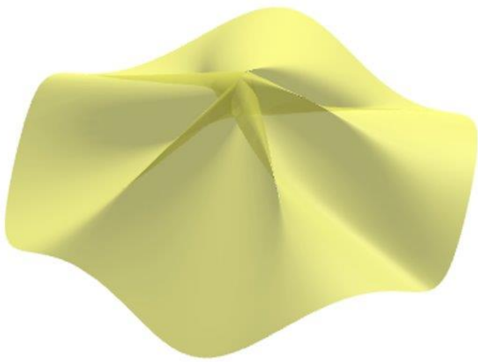

Figure 4. A ChatGPT generated banana

5. Conclusion

This case study has outlined the maths team’s approach to authentic assessment and authentic problems to support a student’s problem-solving skills and more adequately prepare them for the workplace.

Building flexibility into assessment encourages students to think creatively about how to best approach the problem while negating the need for reasonable adjustments. Importantly this flexibility uses formats which are typical of a professional workplace, motivating students to target formats which will enhance their employability skills. This approach is made possible because we know that each student has access to identical hardware and software.

Authentic problems reflect the kind of problems they will encounter in the workplace. Typically, these problems are vaguely defined and open-ended. These problems will require students to meet and consult with their lecturer who will act as a project manager. Lecturers will play an active role as the students complete their assessment by guiding students on expected content to satisfy module learning objectives and issuing bespoke follow-up questions making the assessment dynamic.

The ready availability of LLMs presents a great difficulty for universities. Our view is that rather than discouraging student from using LLMs we should, where possible, encourage students to actively compare their results with the output of an LLM. This will make students more aware of the limitations of LLMs, thus allowing them to articulate why their work is superior to that produced by an LLM. This is an authentic real-world problem since these students may have to justify why they should get a position instead of the potential employer simply using an LLM.

While this form of authentic assessment and problems could be extremely beneficial in preparing students for the workplace it is important to balance how these techniques scale against staff workload. However, with careful planning we believe that it is possible to implement this approach at scale with adding significantly, if at all, to the workload of staff. This is subject to future work of the maths team.

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RESEARCH ARTICLE

Creating authentic assessment in mathematics

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Abstract

Assessment of students' mathematics knowledge within higher education (HE) has normally taken a very traditional approach. Closed-book assessments have long been the favoured mode of assessment (Iannone & Simpson, 2011) which often requires students to recall facts, formulae, and methods. One could argue that this type of assessment is limited in its ability to effectively assess how well a student's ability to authentically use mathematics has developed. Due to the recent pandemic, many institutions were forced to rethink their assessment methods so that they could be delivered online and remotely. As such, there has been a renewed sense of need for more 'authentic' assessments for mathematics-based programmes.

In this paper, we will discuss our journey of creating more authentic assessments for apprentices enrolled on a new Data Science Degree Apprenticeship, particularly in mathematics/statistics. We will compare two years of delivery of the course; the first year of delivery which comprised of traditional assessment methods (coursework/exam) and the second year of delivery that used more authentic assessment methods. We will discuss the pros and cons of each model by reflecting on our practice and drawing on apprentices' feedback.

Keywords: authentic, traditional, assessment, mathematics, statistics, apprentices.

1. Introduction

Degree apprenticeships (DAs) form an extension to higher education level of the partly publicly funded British apprenticeship system and involve a period (typically between two and five years) of employment and workplace training alongside a part-time bachelor's or master's degree (predominantly taught remotely). The case for the development of a new degree apprenticeship in data science at the University of Nottingham was approved in 2019. Owing to the pandemic, the DA finally launched in September 2021, recruiting 30 apprentices from companies such as Experian, Ford, Toyota, Western Power (National Grid), and Rolls Royce. The original programme design was modelled quite closely on a more traditional in-person BSc in Data Science that had run up to 2018, but during 2021/22 it became apparent that this model needed to be considerably refined to take account of the needs of employers and apprentices. Part of this redesign was to create more authentic assessment opportunities to equip apprentices for the workplace by ensuring that learning and assessment was integrated into their activities. In this article 'authentic assessment' refers to assessment of learning that is conducted through 'real world' tasks requiring students to demonstrate their knowledge and skills in meaningful contexts' (Swaffield, 2011).

DAs are not yet widely offered within the UK and so, little is known about best practice in their design and delivery. In the 2022/23 academic year 46,790 apprentices were enrolled onto degree apprenticeships in England, which only accounts for 13.9% of new apprenticeships in England. However, the number of apprentices undertaking DAs has been increasing every year since 2017/18 when only 10,870 apprentices started DAs which was only 2.9% of apprentice starts in England (Department for Education, 2023). Utilising existing knowledge and experience from the programme team, the curriculum was refreshed for 2022/23 delivery so that the assessment was decoupled from the teaching. In addition, in response to employer and apprentice feedback, the assessment was made more authentic for the learner to avoid compartmentalising knowledge which can lead to a lack of understanding and an inability to draw upon knowledge and skills when faced with unfamiliar problems.

Since the curriculum refresh, the programme is split into ‘teaching blocks’ and ‘assessment blocks’, the latter of which assesses a range of different learning objectives from the taught content. ‘Traditional’ style assessments (such as closed book/open book exams) were replaced with a variety of ‘authentic’ assessments. Examples of authentic assessments used on the programme include:

- Portfolios
- Posters
- Presentations
- Statistical Reports
- Business Case Report

This research study investigates the effect of the change of assessment style on performance outcome. We investigate whether there was a marked difference in performance of the 2021/22 cohort (whose first year on the programme was assessed using the traditional style of assessment and their second year was assessed using authentic assessment). It also investigates apprentices’ attitudes towards both modes of assessment from two intakes (2021/22 and 2022/23) and seeks to discover whether one is more favourable over the other.

2. Rationale and relevant literature

Assessment is a critical component of higher education, serving as a tool for gauging student learning and performance. Traditional assessment methods, such as examinations, have long been the standard in evaluating students’ understanding of mathematical concepts. However, recent pedagogical shifts and advances in educational research have prompted a revaluation of these methods. Authentic assessments focus not on how much students remember but on how they can reflect what has been learnt in a new environment (Gibson & Shaw, 2011). Authentic assessment is a form of assessment which involves students conducting ‘real world’ tasks in meaningful contexts (Swaffield, 2011).

Lam (2013) has shown that when students are engaged in authentic tasks that mimic real-world applications of mathematics, their understanding and motivation increase significantly. Authentic assessments, by nature, bridge the gap between theory and practice, making mathematical concepts more accessible and meaningful.

A driving factor for changing assessment practices in this programme was to ensure apprentices are equipped with the necessary skills for the workplace. Traditional assessment methods, such as examinations, often have a focus on the ability to memorise and recall facts and formulae. On the contrary, it can be argued that authentic assessment methods in mathematics challenge students to think critically and apply mathematical concepts to solve complex, non-routine problems. This shift from memorisation to application has been shown to enhance problem-solving and critical thinking skills (Brookhart, 2010; Pellegrino et al., 2001) and hence these skills are more transferable to the workplace. Niss (1998) advocates this, suggesting that assessment of a broader range of skills can be attained through report writing, projects, investigations, and/or oral examinations. Implementing a range of assessment approaches allows students multiple opportunities to utilise feedback and demonstrate their learning.

A further benefit of authentic assessments is that they are deemed more inclusive, allowing for a broader range of learning styles and abilities (Tai et al, 2023). For example, traditional exams may inadvertently disadvantage students with test anxiety or different learning preferences. Authentic assessments can reduce test anxiety whilst providing an opportunity for students to showcase their mathematical understanding.

3. Methodology

The purpose of this research was to investigate whether there was a marked difference in the performance of apprentices completing mathematics authentic assessments versus traditional assessments in the DA. We also sought to understand apprentices' perceptions of the two different assessment styles in mathematics. We address the following research questions.

1. Did the change in assessment style affect the apprentices' results?
2. What were the apprentices' opinions of the change in assessment style?

The cohort of apprentices is small, so we cannot make statistically significant conclusions from our analysis.

3.1 Assessment analysis

The 2021/22 cohort of apprentices completed traditional assessment for the statistics aspects of the DA during their first year on programme (prior to curriculum and assessment changes in 2022). During their second year on programme, the same apprentices were assessed using authentic assessment methods in statistics. This cohort was unique since they were the only cohort who were exposed to both assessment styles on the DA. Therefore, we wanted to compare their module results for the statistics modules in both year 1 and year 2.

We also compared the year 1 results from the Probability and Statistics assessment in 2021/22 (traditional assessment style) with the year 1 results from the Probability and Statistics assessment in 2022/23 (authentic assessment style). This was to investigate whether there was a difference in the performance of the two different cohorts who were exposed to the two different assessment styles for Year 1 on programme.

For both analyses the mean, median, minimum, maximum, lower quantile, and upper quantile were compared to see how these differed between assessment types.

3.2 Survey analysis

Three surveys were sent to all apprentices enrolled on the DA at the end of the 2022/23 academic year. Survey 1 and survey 2 were sent to the 2021/22 cohort to seek their opinion of the assessments in both year 1 (traditional assessment) and year 2 (authentic assessment). The response rates for surveys 1 and 2 were 50% (8/16) and 87.5% (14/16) respectively.

Survey 3 was sent to the 2022/23 cohort to seek their opinion of the assessments in year 1. 86% (12/14) of the apprentices completed the survey.

Each survey used a Likert scale to collate responses and apprentices were encouraged to give reasons for their responses. They were also encouraged to give any other constructive comments regarding the assessment.

Quantitative results from the responses for the questions from all three surveys were analysed graphically.

4. Results

We now present the results of the analyses. We will address our first research question "*Did the change in assessment style affect the apprentices' results?*" by comparing raw marks of apprentices from the two cohorts.

4.1 Quantitative Results

We first compare the performance of the 2021/22 cohort in their first and second year of the DA. The results of the cohort are summarised in figure 1. The boxplot indicates that there is a slight improvement in the performance from year 1 to year 2 with the change from traditional to authentic assessment. This change is not statistically significant, and we are working with small sample sizes.

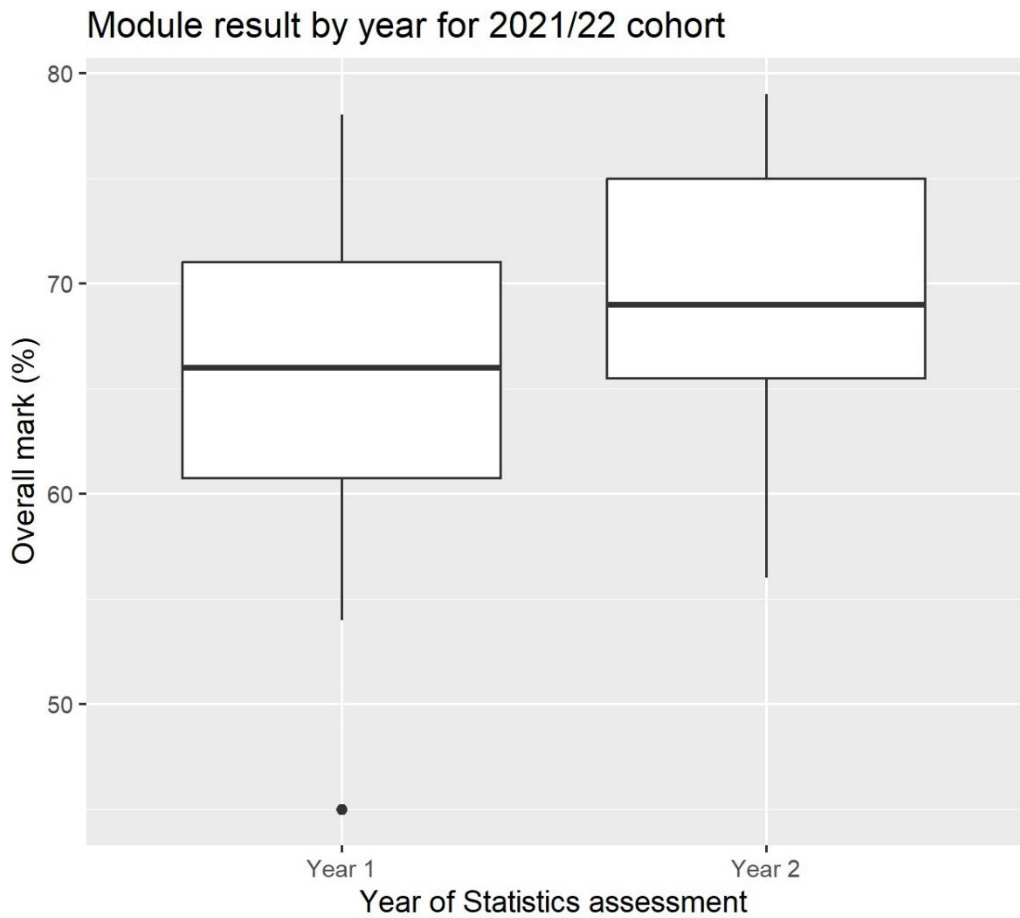

Figure 1. A boxplot that compares the Statistics marks of the 2021/22 cohort in their first and second years of the degree apprenticeship.

The analysis indicates that the change to authentic assessment has not improved assessment grades (but neither has it impaired apprentices' performance). Although most apprentices' marks in year 2 were within 5% of the mark they achieved in year 1, further investigation reveals 4 exceptions.

- "Apprentice 1"'s mark decreased by 7% in year 2.
- "Apprentice 2"'s mark increased by 6% in year 2.
- "Apprentice 3"'s mark increased by 7% in year 2.
- "Apprentice 4"'s mark increased by 18% in year 2.

We note that the performance of “Apprentice 4” was statistically significant. It could be that the traditional form of assessment in year 1 was not suitable as a way of assessing this apprentice’s ability or it could be the case that the apprentice had a better understanding of Statistics in year 2.

To further investigate the effect of authentic assessment on performance we compared the first-year marks of the 2021/22 cohort (assessed by traditional assessment) with the first-year marks of the 2022/23 cohort (assessed by authentic assessment). The results are shown in figure 2.

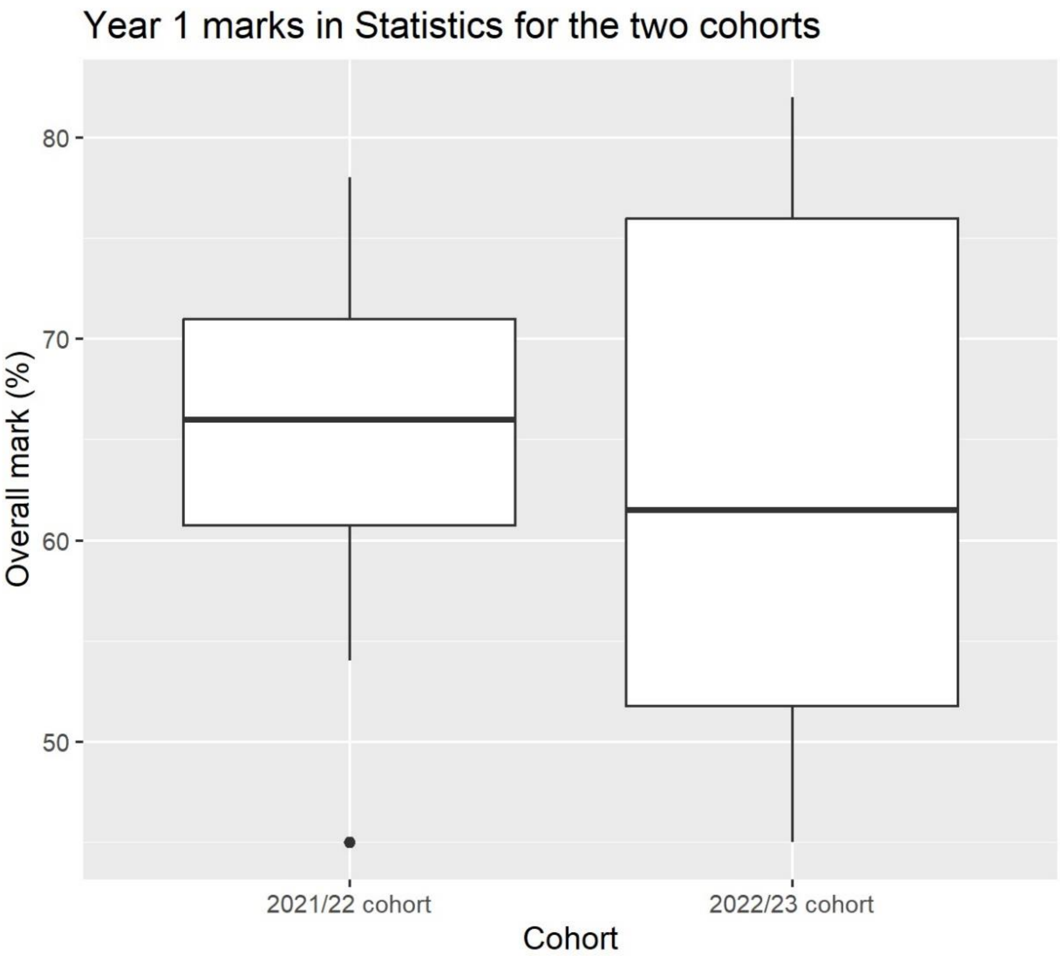

Figure 2. A comparison of the year 1 Statistics marks in 2021/22 and the year 1 Statistics marks in 2022/23.

The results indicate that the marks are more varied for the 2022/23 cohort than the 2021/22 cohort. The median and mean marks are similar for the two cohorts. It is perhaps difficult to draw conclusions from this analysis since the two cohorts comprise of different backgrounds and prior skills (for example the 2021/22 cohort comprised of many more mature learners than the 2022/23 cohort which consisted of mainly school leavers who has just completed their A-levels). However, since there is no significant difference in the average performance of both cohorts, we could assume that the use of authentic assessment is a suitable method of assessing learning objectives comparable to that of traditional assessments.

4.2 Qualitative Results

We now seek to investigate the second research question "*What were the apprentices' opinions of the change in assessment style?*"

In Survey 1, the 2021/22 cohort were asked to indicate which assessment style they preferred. 100% of respondents stated a preference towards the year 2 authentic assessment commenting that they appreciated the workplace application that authentic assessment lends itself to. Some of these comments can be seen below:

> *"I feel like this approach to learning is more representative of real-world application, as opposed to under exam conditions."*
>
> *"The assessments were designed to use the skills learned practically in problem scenarios. This can then be simulated at a workplace."*
>
> *"The year 2 assessment were more relatable to the workplace and therefore more appropriate to an apprenticeship."*

The graph in figure 3 summarises the responses from the same cohort 2021/22, indicating whether they found the individual assessments (comprising of a group presentation, business case report, statistical report, and R portfolio) in year 2 useful for embedding their knowledge.

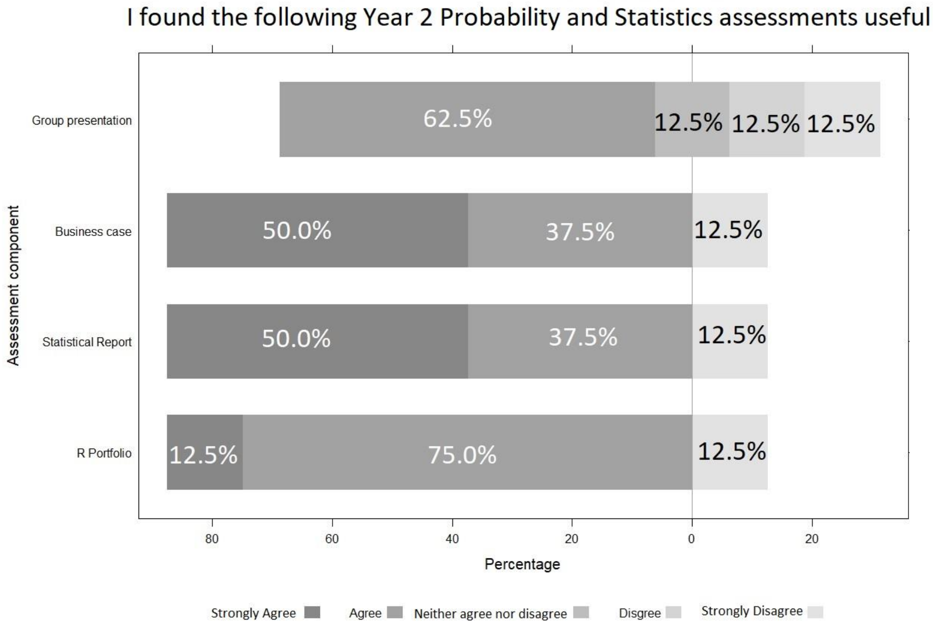

Figure 3. A Likert plot showing the responses of the 2021/22 cohort of apprentices. They were asked whether they agree or disagree with the statement "*I found the following Year 2 Probability and Statistics assessments useful*" for the four different Statistics assessments they completed in year 2.

Most apprentices selected 'agree' or 'strongly agree' in their responses to how useful they found each of the assessments in year 2. Interestingly, the group presentation was not as well received in comparison to the other assessments (25% of respondents selected either 'disagree' or 'strongly disagree'). In addition, it appears that some apprentices did not favour being assessed as a group.

This is perhaps not surprising since the literature suggests that group work can be a frustrating experience for some students (Hall & Buzwell, 2012).

> *"I found the content of the group presentation useful but did not like being assessed as a group."*

> *"Regarding the group exercise. I found it to be a bit like individual pieces of work we just stitched together, so there was no real element of group work. It could be that this was specific to our team though."*

In general, other comments from apprentices suggested that some of the assessments were too time-consuming and that apprentices would have benefitted from additional support in seeking out relevant data required for the assessments. Overall, the analysis suggests that the authentic assessment was well received, and any constructive feedback was linked to the logistical side of implementing the assessment (rather than the assessment itself).

One surprising observation was related to an individual response who has selected 'strongly disagree' for all four assessments, indicating that this apprentice did not like the new form of authentic assessment. However, analysis of their accompanying comments could suggest that perhaps they selected the wrong response on the scale.

> *"I think that all the assessments presented a good learning experience and a chance to apply and demonstrate our understanding of the probability and statistical methods."*

In survey 2, the same cohort (2021/22) were asked whether the different assessment blocks for the whole programme provided a positive experience. We can see in figure 4 that 78.6% of apprentices either agreed or strongly agreed that the Probability and Statistics assessment provided a positive learning experience. In fact, all assessment on the DA course were well received. The only exception was for the 'Synoptic Assessment'. Interestingly, this was the only assessment block that had a traditional assessment style component in the form of a multiple-choice test. Overall the apprentices' responses suggests that the second year was a positive learning experience for the majority of the cohort.

In the final survey, survey 3, opinions of the 2022/23 cohort (who completed the first year using authentic assessment only) were sought, as can be seen in figure 5. 75% of apprentices either agreed or strongly agreed that the Probability and Statistics assessment provided a positive learning experience. Again, similar to the analysis above, all assessment on the DA course were well received by this cohort with an exception for the 'Synoptic Assessment' (which contained a traditional assessment component in the form of a Multiple-Choice Test). Further analysis of the comments received suggest that some apprentices (two respondents) would have preferred to have been assessed via a test rather than a portfolio for statistics/probability; *"Multiple choice for stats not just portfolios".* It is perhaps worth noting, that this cohort of apprentices were mostly school leavers who have only ever been assessed using exams and have limited experience of working in industry.

Selected comments from survey 3 (from the 2022/23 cohort) indicate that apprentices found the authentic assessment in the DA useful for applying skills at work.

> *"I had fun with all of these and made the most of the courses as they helped with work and vice versa."*

> *"I was able to apply or [sic] my skills on this course"*

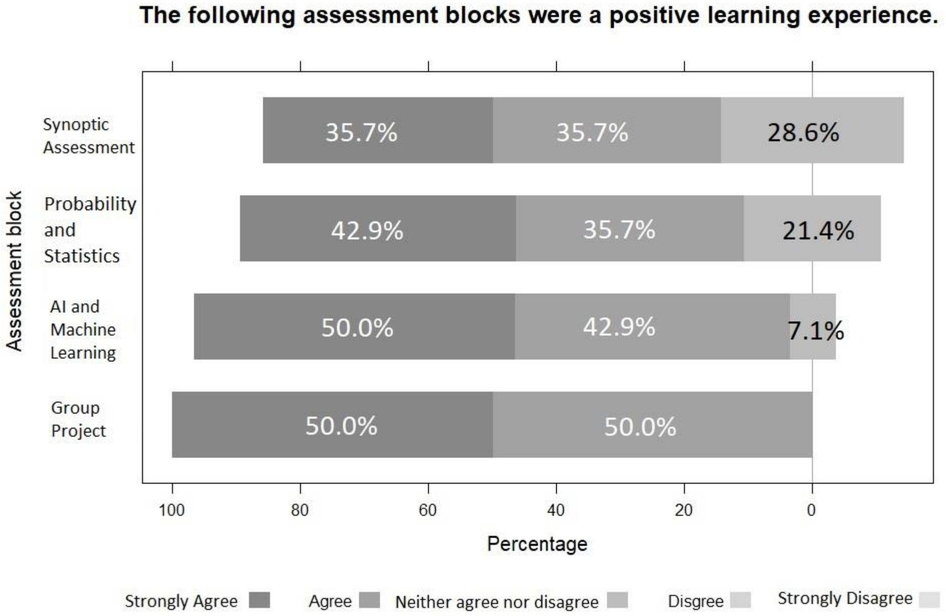

Figure 4. A Likert plot showing the responses of the 2021/22 cohort of apprentices. They were asked whether they agree or disagree with the statement "*The following assessment blocks were a positive learning experience*" for the four different assessment blocks in year 2 of the DA.

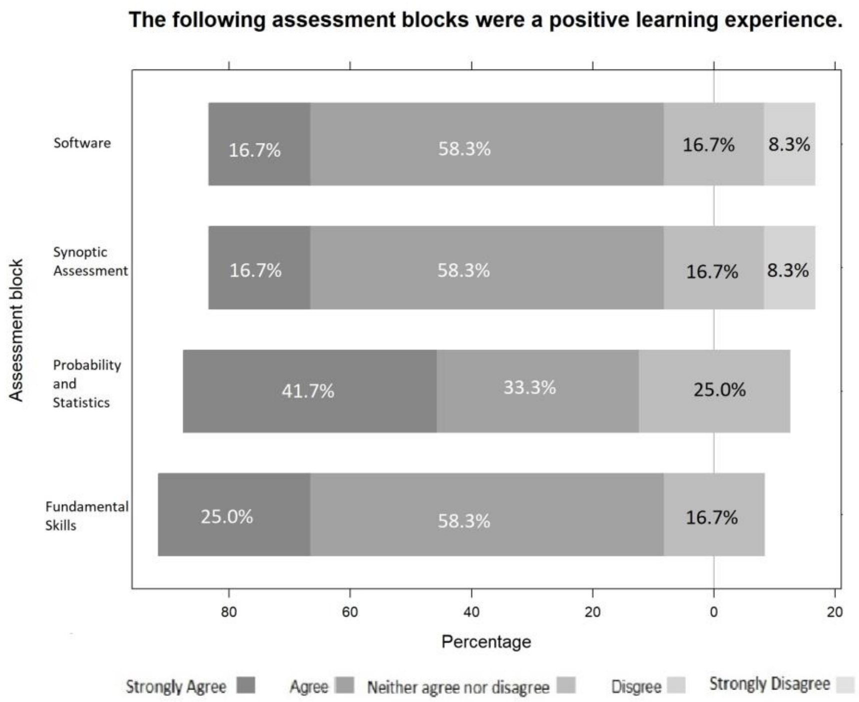

Figure 5. A Likert plot showing the responses of the 2022/23 cohort of apprentices. They were asked whether they agree or disagree with the statement "*The following assessment blocks were a positive learning experience*" for the four different assessment blocks in year 1 of the DA.

Constructive comments were related to the logistics of carrying out the assessment, such as timing of assessments in the academic year.

> *"Would be better if the assessments were spread out over year (not too many in exam season)."*

It is worth noting, that although assessment for the DA is more spread out over the whole year than a traditional degree (final assessment was due mid-July) we are still constrained by some university processes during the summer period for marking/progression of apprentices in terms of the degree qualification.

5. Discussion

Our analysis suggests that using authentic assessment was a positive experience for both cohorts of apprentices on the DA. Analysis of the qualitative data suggests that the use of assessments which mimic workplace tasks (such as writing statistical reports and giving presentations) made the DA content more accessible and meaningful to their individual organisations. For example, at the end of the academic year, both cohorts of apprentices were able to showcase work-based projects they had contributed to which utilised assessment and taught methods from the course. Whilst none of the comments were necessarily 'negative' there were some detailed constructive feedback with regards to the logistics of implementing authentic assessment. For example, spreading the workload more evenly in the academic year or replacing some of the more similar style assessments (business case report, statistics report) with an alternate authentic assessment such as on oral viva.

One consideration is whether the use of authentic assessments is disadvantageous to apprentices who excel in exams. However, one of the main aims of the DA is to prepare apprentices for industry by mimicking workplace tasks and, therefore, authentic assessment is more relevant and useful in this context. In addition, more apprentices seem to favour the authentic assessment over the traditional assessment (such as the multiple-choice test that is used in the Synoptic Assessment block for both cohorts).

The DA commenced in 2021/22 and we currently have three cohorts of apprentices. Recruitment numbers are significantly growing (annual growth of 300% from 2022/23 to 2023/24) which will undoubtedly involve more work to mark which adds to staff workload. We may need to implement automated processes or utilise more peer marking to assess apprentices effectively whilst also keeping the balance of authentic assessment. Further research could investigate whether the use of authentic assessment is also helping to develop other transferable skills in the apprentices' roles.

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RESEARCH ARTICLE

Win-Win-Win: Drop-in Mathematics Support for Secondary School Students

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Abstract

Mathematics Learning Support (MLS), which is available in the majority of Higher Education Institutions (HEIs) in Ireland and the UK, is traditionally available only to students of those institutions. In this paper, we describe a drop-in model of MLS at Maynooth University (MU) which has been available for secondary school students since 2009. This service is mainly staffed by volunteer undergraduate trainee teachers. Their feedback, the main focus of this paper, which has been collected over ten years, indicates that this experience has had a positive impact on their teaching practice. School students are also very positive about the support and MU enthusiastically endorses the service. We conclude that there are no obvious downsides to the provision of this type of support and we believe that more institutions should consider making it available.

Keywords: Mathematics Learning Support, secondary school, teaching practice, evaluation, effectiveness.

1. Introduction and Background

Mathematics Learning Support (MLS) is typically described as mathematical and or statistical supports which are available for HE students in addition to their lectures, tutorials and assignments etc. (Lawson et al., 2003). MLS is research-based practice, and evidence strongly suggests that appropriate engagement with MLS can improve student retention and progression, and it can also impact positively on student confidence in their own mathematical abilities and their attitude towards the subject (Matthews et al., 2013; Lawson et al., 2019). In Ireland, although the study of mathematics is compulsory throughout secondary school for the vast majority of students (O'Sullivan et al., 2014), there are widespread concerns about the teaching and learning of mathematics (Treacy et al., 2016, p. 398) and the high-stakes summative examinations (Leaving Certificate) at the end of secondary school. Therefore, in 2008-2009, as a result of MLS evaluations at MU which identified positive benefits for MU students of engaging with MLS (Mac an Bhaird et al., 2009), the first author proposed to extend drop-in MLS to local secondary school students.

He hoped that by offering MLS to school students, they might experience similar benefits to those reported by MU students, thus potentially easing any subsequent transition to mathematical studies in HE. MU approved the proposal and, from September 2009 to-date, except during COVID-19 restrictions, MU has provided two hours of free secondary school drop-in MLS each week during MU term time. To the best of our knowledge, this was the first such drop-in support for secondary school students in Ireland or the UK.

With the exception of a 2016 paper (Donlon and Ní Fhloinn), little is known of the impact of Higher Education Institutions (HEIs) providing drop-in MLS for secondary schools. In our paper, we provide details of the MU service and summarize some other examples of MLS provided by HEIs for secondary students. We present an analysis of tutor surveys and a brief summary of student feedback. We close by considering the benefits that the provision of this service provides to the volunteer trainee teachers, the students, and to the institution, in terms of outreach and visibility.

2. Background: The secondary School Drop-in Model at MU

The secondary school drop-in was set up in 2009 to mirror, in so far as possible, the undergraduate drop-in support established in 2007. In this sense, students do not need to register or make an appointment and can come and go as they please. They complete an attendance sheet with their name, school, and year of study. This data is anonymised and then used to report engagement to the university. During sessions, we promote an informal non-judgemental atmosphere, where students can ask questions on any aspect of their mathematical or statistical studies. Attendance varies but, typically, there are 30-40 students present each week. The majority of attendees come from Maynooth or neighbouring towns which have public transport to Maynooth. Students are encouraged to work collaboratively and to attempt problems before asking for help. During the sessions, we have three senior tutors in charge. They are paid on an hourly basis, which is the only cost of the service and is covered by MU Admission and Maynooth Access Programme (MAP) Offices. More recently, these tutors are qualified teachers who also have previous experience of this service as volunteer trainee teachers. Having reliable people in these positions has been key to our success.

When this service was established, it was identified as an opportunity for undergraduate trainee teachers to gain valuable teaching practice and, after consulting with MU Department of Education, we decided to target those who were starting the second year of their four-year Science or Mathematics Education degree. Each summer, we contact those who achieved a 1st class honours in their first-year mathematics. In the majority of cases, they are happy to be involved. Frequently, those who volunteer in second year ask to help again in subsequent years. This results in between eight and 14 volunteer tutors being available each year. All tutors must be vetted through the Garda Síochána (Irish Police) system to work with children. We establish a rota system, so volunteers attend every second week, averaging ten evenings total across the academic year. Tutors are put in pairs for initial sessions so they can assist each other. We provide a brief training session for these volunteer tutors (from now on referred to as tutors), advising them on how drop-in works, what to do, what not to do etc., as they normally have not used the Mathematics Support Centre (MSC) in their first year of study. The main advice provided is that tutors are not expected to know all the answers and should never guess if unsure. They should either try to work it out with engagement from the student or seek assistance from another tutor. These mathematical discussions provide opportunities for students to see the processes involved in mathematics, rather than being something static that you simply know or do not know.

Linking to our website (https://www.maynoothuniversity.ie/mathematics-and-statisticsmathematics-support-centre), we advertise the service via multiple routes including social media, parent groups, mailing lists, local media and through MU's School Liaison Officers. Each summer we send letters, along with an information sheet and posters, to the principals of every school who had a student previously use our service.

3. Literature on Mathematical Supports in HE for Secondary School Students

Though not directly linked to HE, there is some research which considers "*teaching mathematics after hours*" in Ireland (O'Meara et al., 2019). They found that many teachers are providing extra mathematics tuition outside regular school hours. Several reasons were given, including pressure to get the syllabus covered and needing time to practice problems, leading to suggestions that the class time allocated to mathematics in secondary school is insufficient. Perhaps these issues are also recognised in HE, as there is a wide range of MLS for secondary school students provided by HEIs across Ireland. We briefly describe some of these here.

In 2015 Dublin City University (DCU) established a drop-in service, largely based on the MU model. Donlon and Ní Fhloinn (2016) report on 2015-16 structures when one two-hour session per week was offered. Each was staffed by 10-15 volunteer pre-service mathematics teachers, mostly in their third or fourth year. Around 70-80 students, allotted rooms based on their year of study, attended each week. Surveys of both the school students and the tutors provided very favourable feedback. For example, almost two-thirds of student respondents were positive about sessions helping their mathematics, and slightly more than half were positive about sessions impacting their confidence when doing maths. Almost all reported that they liked the freedom to choose the topic they wished to study, and they rated highly both the tutor assistance and having a space to work.

They reported that "*The support sessions provided the tutors with an opportunity to practise interacting with students on a regular basis. The experience seemed to boost the tutors' confidence in their ability to deal with students and their misconceptions*" (Donlon and Ní Fhloinn, 2016, p. 52). Slightly more than two-thirds of tutor respondents indicated that they volunteered to gain teaching experience and reported better awareness of the school curriculum and improved content knowledge. Furthermore, while tutors were unable to prepare for the variety of questions they receive, and most initially found this daunting, it was overall a positive experience, with tutors working with each other and students experiencing tutors working as a team while problem solving.

Some Irish HEIs provide forms of mathematics outreach to schools in disadvantaged areas. For example, Technological University Dublin (TU Dublin), Tallaght Campus, offer the Mathematics Volunteer Programme (MVP) for fifth-year students from local secondary schools (O'Sullivan et al., 2023). TU Dublin student-tutors work with school students to support the development of their mathematical skills as they work on their homework or revision questions. Students reported feeling more confident with mathematics and were very positive about the atmosphere and usefulness of the service. At University College Cork (UCC), university students can volunteer to provide homework clubs and extra revision sessions for secondary school students in examination years (University College Cork, 2016). Similarly, University College Dublin (UCD) provide extra-curricular mathematics workshops, under the Maths Sparks initiative. While the UCC support is curriculum based, Maths Sparks is aimed at promoting a love of mathematics and they report "…*increases in pupils' self-confidence, in their mathematical ability and in their enjoyment of the subject.*" (Ní Shúilleabháin et al., 2020, p. 17).

Outside of Ireland, we acknowledge that there is little literature which gives a sense of the extent of such MLS provision in HE, but it might be relevant for the reader to consider other initiatives such as the *Advanced Mathematics Support Programme* (https://amsp.org.uk/) in England, the *Further Mathematics Support Programme Wales* (https://furthermaths.wales/students/studentcs/) and *The Brilliant Club* (https://thebrilliantclub.org/) across the UK. Further afield, there are studies which consider the effectiveness of such supports at local level. For example, in Pennsylvania, an afterschool mathematics programme was introduced in partnership with the local university from which suitable tutors were recruited. School students deemed at risk attended one day per week for 90 minutes over 20 weeks. Students worked on homework, skills reinforcement tasks and participated in educational games. Similar to DCU and MU, some of the tutors were recruited from elementary education majors and, therefore, through their teacher training were "*motivated, and [they] believe, provide better quality experiences for children than tutors without such training.*" (Baker et al., 2006, p. 290). The authors report, for the school students who attend, "…*an increase in achievement, a positive change in attitude toward mathematics, increased participation in math class, and higher rates of students completing* *their homework in a timely manner*." (Baker et al., 2006, p. 290). The tutors also commented on the benefits of being afforded the opportunity to put their teaching methodologies into practice.

4. Methodology

Qualitative studies, in the form of surveys, are common in the evaluation of MSC services (see, for example, Lawson et al., 2019). For our annual evaluation, we issue two anonymous optional paper-based surveys; one for students and one for tutors. In this paper, while we include a brief summary of student feedback, the main focus is on the tutor survey. This has an initial statement making respondents aware of its optional nature and that any feedback they provide may be used for research. There are seven questions, one Likert, two 'yes/no' with the option to provide further information, and four open response questions.

All survey responses were entered into Microsoft Excel. Each respondent was assigned a unique code. Separately, the authors identified themes which emerged from analysis of the open responses (Braun and Clarke, 2006). Any discrepancies that arose during the coding process were discussed and resolved.

5. Results

5.1 Tutor Survey

Feedback from tutors, over ten years of data, was very positive. For example, when asked to rate the usefulness of the experience, all respondents (n=78) picked 'very useful' (57) or 'useful' (21). 75 of 77 selected yes when asked 'Do you think you can use any of your teaching experiences in the MSC to help your future second level teaching?'. The two no's indicated that they were not continuing in education. From the coding of the open responses, four main themes emerged: insight, confidence, improved subject and pedagogical knowledge, and rewarding experience.

Tutors identified opportunities for gaining insight into student difficulties. For example, "*Insightful, helped me to see where students were struggling and diagnose misconceptions and bring them back to the classroom*" (R38), and "*Definitely when I started here, I didn't really understand the big issues students were having. Now I can see how the students are having issues with certain aspects and I can bring this to the classroom, understanding the main areas of difficulty*" (R18). Some referred to the learning they gained from conversations with students in the MSC's informal setting, e.g. "*Hadn't realised how much I had learned until I sat down to do my education portfolio. There were things I learned here that I never would have learned from being out in a school, because sometimes you needed to sit down with students and chat about one on one which is not possible in a school environment*" (R13).

Tutors referred to confidence, and how their experience in the MSC helped copper-fasten their self-efficacy as a teacher, e.g. "*The experience has helped me become more comfortable working with students and has given me great confidence in my teaching ability*" (R39). Unlike a regular secondary school lesson, tutors have no idea in advance what questions they will be asked. This forces them to think on their feet and mature in ways to handle this appropriately, "*Helping in the MSC defines your way of thinking as a teacher and juggling many different levels of maths as you move around helps you come up with more creative methods of teaching*" (R30).

Tutors also highlighted their improved subject and pedagogical knowledge. For example, the challenge of facing forgotten topics: "*When I first started tutoring, I was very nervous as it had been two years since I'd actually completed secondary school maths so I felt I wouldn't have been able to even attempt the questions myself but thankfully I was and felt this experience helped develop my knowledge of*

Junior and Leaving Cert syllabus" (R20). Others found the experience "*Challenging at times when presented with concepts I hadn't looked at since secondary school, but helpful to try different ways of explaining things and to see where students have problems*" (R50). Respondents also recognised the development of valuable teaching skills, e.g. "*…it helps you to become more patient. It helps you think of alternative ways describing how to do maths problems. It makes you better at explaining things*" (R36), and "*This experience has been enriching in all aspects of my teaching-content knowledge, explaining maths content, unveiling student misconceptions, building relationships, and working as a team.*" (R73).

Finally, tutors identified the rewarding experience of tutoring in the MSC. For example, "*Brilliant experience - helping for 3 years, especially if you want to teach. It's great to see the student progressing throughout the material and grasping the topics*" (R17), and "*Very valuable experience which I really enjoyed. Even when I have had a long day/ am tired it feels great to be able to help students with maths that they are finding very difficult. As a student I would have loved this service just to be able to ask questions I was afraid to ask in class*" (R68).

Recall that, aside from a brief training session at the start of term, these tutors receive no further MSC specific training. When asked, 16 (of 73) indicated that they did need further specific training, with many suggesting revision of various topics on the secondary curriculum. From those who selected 'No', the majority referred to learning on the job. For example, "*No, I think it's better to approach it in your own way and then learn as you go along … It's an active learning discovery process and I think it's a better way*" (R25). Several were of the view that "*… the brief introduction given was sufficient. Through placement and education lectures [we were] well equipped to help students*" (R52).

5.2 Student Feedback

We collected 381 surveys from students over ten years. In brief, students were extremely positive about the service (see Table 1).

Table 1. Rating of the MSC

How would you rate the MSC? (n=374)				
Very useful	Useful	Neutral	Not useful	Not at all useful
180	167	24	3	0

Students reported that they attended the services due to difficulties with mathematics and to use it as a place to study. They were very appreciative of the tutors, the flexibility of the service and the positive, friendly atmosphere where students feel safe to ask questions. Most students reported that attending resulted in improved confidence in their mathematical ability, about half indicated that it changed (for the better) their attitude towards mathematics as a subject, and almost two thirds suggested that the MSC changed their study habits for the better. Students were asked whether they were considering attending MU (263 of 363 said yes) and if the MSC had an influence on this (174 of 349 said yes). 162 students provided a positive response to both questions, citing the friendly atmosphere and their experience of MU facilities.

6. Discussion and Conclusion

It appears that only positive outcomes and opportunities arise from the provision of drop-in support by student teachers at HEIs to secondary students. When initially established, our hope was to replicate the benefits of MLS for undergraduates (Mac an Bhaird et al., 2009; Lawson et al., 2019) with secondary students. While we have only briefly summarised their feedback in this paper, secondary students who avail of our support, or MLS initiatives provided by other HEIs (e.g. Donlon and Ní Fhloinn, 2016; O'Sullivan et al., 2023) seem very positive about their experience. We are currently investigating how to proceed with research on the secondary student experience of such supports in HE and are considering Valsiner's (Blanton et al., 2005) extension of zone theory to link any findings with existing literature on both student learning and on teacher training.

A second benefit of this support, the main focus of our paper, has been the positive impact on the student teachers (tutors), a benefit which is also evidenced in other studies (e.g. Donlon and Ní Fhloinn, 2016; Baker et al., 2006). In general, tutors found the experience to be extremely rewarding. They gained insight into the difficulties that secondary students experience and this, along with their increased knowledge of mathematical topics, resulted in increased confidence in their self-efficacy as teachers. MU Department of Education, where these tutors complete their teacher training, strongly encourage students to volunteer for this service. To further investigate the impact that this experience has on the tutors' own teaching practice, the first author and a colleague from the MU Department of Education have conducted a series of interviews with former volunteer tutors who are now teaching in secondary schools across Ireland. Analysis of this data is currently being completed using the Knowledge Quartet, a framework which can be used for the analysis and development of mathematics teaching (Rowland et al., 2005).

From our perspective, the third benefit of this service is positive advertisement of the MSC at MU. For example, local newspapers have published articles celebrating our achievements and parent associations have posted on social media endorsing our service and sharing their children's positive experiences. Senior Management also acknowledge the exposure that the service creates for MU and are, anecdotally, more receptive to MSC resource requests. They know, for example, that the service facilitates regular student visits to campus and that this appears to lead to student recruitment. MU has also used the service on a national stage with Campus Engage (https://www.campusengage.ie/) as an example of best practice in terms of community outreach.

From our perspective, there are no downsides to offering this support. Following presentations on different aspects of this service at the 2022 and 2023 CETL-MSOR conferences, we have been made aware that some HEIs in Ireland and the UK are now implementing this model of student support.

7. Acknowledgements

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SHORT UPDATE

What role does Skill Centre based consultancy serve in mathematics and statistics teaching communities of practice?

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Abstract

Mathematics and Statistics Teaching (MAST) is a staff facing service set up by the University of Bath Mathematics Resource Centre in September 2021. The service was created to collaborate with academics involved in mathematics and statistics teaching in their academic departments. In September 2023, MAST ended its pilot phase and entered a new growth phase fine-tuning existing structures and practices. During the pilot phase, MAST worked with academics consulting on enriching their programme of study and/or teaching practices. Specifically, the key principle that guides MAST is engaging in long-term sustainable collaborations with academic departments. As a means to address the key principle, we explore the potential of building communities of practice and supporting a wider network across the range of disciplines who encounter similar objectives. Facilitating a wider community of practice could be challenging, especially considering the tight schedule of the academics involved. We discuss our plans to cultivate communities of practice within departments and how we are working towards meeting our goal of establishing best practice and collecting evidence to support a wider community.

Keywords: mathematics and statistics teaching support, teaching collaborations, communities of practice, consultancy.

1. Introduction of the landscape

In 2007, the Mathematics Resources Centre (MRC) at The University of Bath was established. In 2008, the primary service Mathematics and Statistics Help (MASH) expanded and the Statistics Advisory Service (SAS) was initiated. In the years since, MASH and SAS interacted with students with mathematical or statistical questions often in the regular, on campus, drop in. Sometimes ‘floods’ occurred, where a large number of students came with the same questions within one cohort. The MRC would evaluate the significance of the issue in terms of whether it was likely to affect the learning experience of the specific cohort at large. If the issue was deemed significant, the MRC staff would approach the academic department in question to discuss the difficulty.

MASH and SAS – as primarily student-facing services – could provide limited support to academic departments. Historically, academic departments asked MRC staff to teach some mathematics or statistics content for their department (i.e., service teaching), as a solution to the issue. However, limited capacity meant that the MRC staff could not offer service teaching to all departments. During this operational phase, despite some historical MRC service teaching being present across the university, the University Executive Board confirmed that service teaching was not in the MRC mandate. Subsequently, the MRC did not enter into any new service teaching arrangements and all prior arrangements were phased out. The future for the MRC would involve the support of teaching collaborations, rather than teaching the units themselves.

In 2021, The Mathematics and Statistics Teaching (MAST) service was set up to take on a consultative role for academics (i.e., teaching/research staff within academic departments). MAST was developed as a staff facing support to academics at The University of Bath who deliver mathematical and statistical content to students within their departments. MAST was established to work alongside the complementary services in the MRC.

The aims of the service are for the MAST team to work with academics and departments to support or enrich existing practice, research and develop new teaching methods within a current module or course, support the creation of new units, and to develop contextualised teaching and learning resources.

During the pilot phase, the MAST offer was based on the team's personal skills and expertise and was not structured in a way that could be sustainable if a team member with a particular expertise left or if the team diverged. The initial services were instigated to enable quick wins that could be delivered in a timely way by the small two-person team. The two people in the team are both trained teachers and are employed as teaching fellows by the MRC on part time contracts. The first author and team member is a lecturer in the maths department in addition to their role in the MRC and has a breadth of experience teaching mathematics in secondary schools in England and abroad. The second author and team member has a PhD in Mathematics Education and pedagogic research expertise. The team's initial objectives were to be supportive to academics while building a series of case studies. The case studies could be used to explore what works and identify a network of potential MAST collaborators with the intention of building a sustainable model.

The growth of the MAST service, in this second phase, focuses on how we aim to operationalise our key principle to engage in long-term sustainable collaboration with academic departments. This growth is underpinned by the idea of utilising and developing communities of practice (CoPs). To take you through our reasoning for this claim, we are first going to briefly highlight the main aspects of CoPs from a theoretical perspective in the following section.

2. Communities of Practice

CoPs are "*groups of people who share a concern, a set of problems, or a passion about a topic, and who deepen their knowledge and expertise in this area by interacting on an ongoing basis*" (Wenger, McDermott and Snyder, 2002, p.4). The main idea behind the conceptualisation of CoPs is that learning is a matter of belonging as well as intellectual processes (Lave and Wenger, 1991; Wenger, 1998; Wenger, McDermott and Snyder, 2002). CoPs emerge in organisations as social learning systems (Lave and Wenger, 1991; Wenger, 1998; Wenger, McDermott and Snyder, 2002). In Higher Education, CoPs has been operationalised as a model for engaging staff and organising professional development opportunities (Hunter-Jones et al., 2009; Moore, Elfving-Hwang and Garnett, 2009; Kilpert et al., 2022).

According to Wenger, McDermott and Snyder (2002), the structure of CoPs can be thought of in terms of three key elements: community, domain and practice. The element of community is considered key for learning in this context. Communities can provide a sense of belonging and trust, encourage interactions and willingness to share and challenge ideas, ask questions, and listen to others. The boundaries of the topic and what activities are considered relevant for a CoP are determined by the subject of shared interest or what is called the domain. The domain creates a shared understanding and an identity for the members of the CoP and it can be the source of inspiration for the members. Finally, the third element of CoPs is their practice. Practice is the set of shared knowledge, ideas and information; shared stories and a common language along with the tools and resources that guides the community's engagement with its domain. When these three elements function well together make a social structure – a CoP – that can develop and share knowledge, thus facilitating learning (Wenger, McDermott and Snyder, 2002).

3. The rationale that led to the current structure of the service

Initially MAST did not have CoPs in mind as a way forward for the development of the service. However, as the collaborations developed, elements of CoPs emerged. The idea of developing CoPs as a means to achieve long term sustainable collaborations with academics and their departments was the product of reflection and self-study during the pilot phase. Self-study is a well-conceptualized methodology grounded in theory and justified by moral, ethical, and political values, making it a trustworthy approach to improving practice (LaBoskey, 2004). Schön (1983) highlights the dynamic nature of practical professional knowledge and emphasises that "*reflection-in-action*" holds transformative value in professional development. In this case, the professional development needed is the knowledge of how to develop a course of action for the MAST service in a way that does not depend on individual goals, skills and priorities. Studying our actions during the pilot phase of the service, we aim to abstract the features that would make the service sustainable. To do so, we use documentation such as our initial action plan, meeting notes, and feedback from collaborators. This methodology allows us to proceed with integrity and confidence, leading to an improvement of the service. Sharing our reflections with the CETL-MSOR community acts as a guard against self-justification.

Reflecting on our activities as a consulting service, we have identified the three elements of CoPs – community, domain and practice – in MAST collaborations. In the following sections we present our reflective accounts through examples from collaborative activities during the pilot phase and challenges we encountered. In Section 3.1, we highlight the three elements in our activity of facilitating workshops for student teaching staff. In Section 3.2, we outline how the three elements emerge in collaborations to review the delivery of mathematical and statistical content in various academic departments. In Section 3.3, we reflect on challenges we encountered along the way which inform our future actions.

3.1 A reflective account of workshops

The MRC had experience of delivering workshops on teaching mathematics and statistics to groups of new student teaching staff who deliver mathematics or statistical-based tutorials and seminars in a department delivering substantial quantities of such tutorials and seminars. These staff will hereafter be referred to as 'tutors'. MAST was approached to expand this offer to provide ongoing support to tutors as they became more experienced. Thematic areas such as interaction and engagement during tutorials or marking and feedback were selected in collaboration with the tutors and the academic coordinator.

We began by consulting with tutors, gathering their opinion on their preferred areas for development to support them in transforming their aspirations into teaching practices. We developed the theme's centred around our own ideas and the tutor responses, identifying an overlapping domain of shared interest and key issues.

We designed the workshops to provide a protected, safe, structured opportunity to share good practice, exchange ideas and learn from each other. The aspect of community emerged as a central pillar to build mutual trust and engagement. The role of the MAST staff was as facilitators, to help tutors set realistic goals to enrich their teaching by providing starting points and concrete activities to develop shared practice. This involved engaging in the conversations and sharing our teaching experiences, introducing tutors to ideas, tools, and resources that they could adopt and build their shared repertoire.

At the time of the pilot, we did not have a framework in mind guiding our collaborations. Thus, the three elements we identified are not necessarily fine-tuned to encourage the development of a CoP In the meantime, our collaboration grew beyond just offering workshops and we established a virtual area on

Microsoft Teams where tutors could communicate and share. We hope this could be a step towards forming an online CoP and provide the opportunity for tutors to continue their development together after this initial input from MAST. This potential online CoP has some prepared resources (curated by the MAST team) that tutors can use directly or as stimuli to create or adapt their own, before sharing back to the community.

Our role is central in the initial stages of this type of collaboration. Reflecting on the emergence of a CoP, we note the requirement of a consultancy, such as MAST, to step back at an appropriate time. This allows the participants, in this case the tutors, ownership over the CoP's future direction. We would still hope to continue as active members of the CoP by sharing news, events, ideas, new tools. However, the tutor's agency will be enhanced when adding their own resources and through their participation and discussion.

3.2 A reflective account of supporting the development of new materials and courses

Other pilot phase activities included reviewing and developing the delivery of mathematical and statistical content with academic departments. Our aim was to collaborate with departmental staff and together identify good practice, priorities, and areas for improvement (e.g., potential knowledge gaps or diverse needs of students) to be addressed.

Products of these activities are the collaboratively designed contextualised resources (e.g., Numbas questions, lecture notes) to aid students transition to mathematics within their discipline of study. First, the idea of developing contextualised Numbas questions as tools for supporting students learning was proposed during our initial collaboration to develop a unit for non-specialists in a department of the Faculty of Humanities and Social Sciences. MASH had an established, positive history, trialling and using Numbas questions (Southwood, McGovern and Hand, 2022) before the MAST service was created. Up until that point in time, MASH was leading the development and use of Numbas resources across the university. However, during this first collaboration the development of Numbas questions became a shared *practice* beyond the MRC and is a corner stone for our collaborations with academic departments. The collective engagement with the development of the questions means that we share expertise, responsibility and knowledge throughout the creative process.

During our collaborations, new Numbas questions are created, and old ones are adapted and shared across different departments with similar needs. The repertoire of shared resources and tools expands to encompass the priorities and ideas developed in each collaboration, as well as new technologies and tools acquired by the university (e.g., Notable for statistics assessments). The role of the academics is crucial, as experts of their subject they provide insight into ways of knowing in their discipline, applications of mathematics and specialists' vocabulary. MAST provides expertise related to students' mathematics education backgrounds, teaching, and learning approaches as well as technical support with teaching tools. In that sense, the development of contextualised resources, such as Numbas questions, can be thought as part of a shared practice during the collaborations.

The modus operandi of the collaborations calls for regular meetings, clear objectives and expectations. During the meetings we exchange ideas, plan, develop and assess our progress. This practice is common across our collaborations and works well with mutual engagement from all parties. For example, one of our collaborations was centred around the development and delivery of the mathematical content in a first-year skills unit for an academic department within the Science Faculty. This collaboration was operationalised under the clear boundaries of a *domain*. The objectives of our collaboration were established during the initial meeting based on the needs, as communicated by the department, and the expertise of MAST staff. The process of reviewing the current content and developing new teaching and assessment materials was a group effort that required mutual engagement of staff in various positions (e.g., the Director of Teaching, the academic who convenes the unit and administrative staff supporting the delivery) creating a small group with a shared interest of improving the delivery of the unit. During our meetings and email correspondence, the group members would share their ideas, concerns and insight associated with their respective role and the group would carefully listen and discuss them, indicating that the group shared qualities of a small *community*.

The above account covers a number of examples that illustrate how the elements of CoPs arose when reflecting on our varied activities during the pilot phase. However, the identified elements of *community, practice* and *domain* do not provide sufficient evidence to suggest the emergence of well-functioning CoPs.

3.3 Reflecting on the challenges

Despite the overall positive uptake of the service, we have often faced challenges when trying to approach new collaborators. These challenges should be acknowledged and addressed to develop a sustainable course of action, fostering the growth of mathematics teaching practices and developing CoPs.

During the pilot, varying levels of academic involvement and interest have impacted how the MAST service functioned. For example, the development of workshops for student teaching staff would not have been possible without the interest of the academic with responsibility for tutoring. Their promotion and enthusiasm for the development of the tutors was crucial for steering the development of the *community* and identifying its *domain*. In this case we had positive outcomes but in other potential collaboration the schedules, workload and responsibilities of the link academic has impeded, and in some cases halted, the progress of a collaboration. Another challenge is related to the staffing for mathematics teaching which is transient across academic departments and impacting the stability of the potential *community*. Often those who have been allocated to teach the mathematics and statistics sections of courses in a discipline are new or only allocated the teaching for a year. On the other hand, we have also had discussions with staff members who have taught the mathematics and statistics for a long time but sharing their practice with others was not a priority for them at the time. Finally, the MAST service currently operates with two members of staff in part-time roles. Therefore, MAST collaborations required clear distribution of responsibilities within a specific timeframe.

4. Discussion of the developed structure

The reflective accounts presented in the previous section highlight elements of community, domain, and practice that emerged in MAST collaborations during the pilot phase. Abstracting these three elements of our collaborations helps in refining the structure of the service and developing a practice-based and theory-informed course of action. When liaising with academic departments, we realised that there are already various *communities* which could encourage the development of mathematics and statistics teaching and our consultancy has a role in refining the structure and facilitate the *domain* of those communities. In our interactions with academics, we have worked to bring colleagues with shared issues closer together, take part in discussion and use our expert knowledge and skills when needed, to develop shared knowledge and a *shared practice*.

This means we have all three elements: *community*, *domain* and *practice* required to develop CoPs. When the three elements function well together, the CoP is a construct that encourages individuals to form alliances which facilitate learning through the development and sharing of knowledge (Wenger, McDermott and Snyder, 2002). In earlier collaborations, the elements were not necessarily fine-tuned to encourage the development of CoPs. However, we are working on establishing strategies that would allow the elements' co-function grounded on the practice-based literature.

CoP structures emerge in organisations to achieve specific aims and phase out when their aims are achieved or otherwise mitigated (Wenger, 1998). Using this 'ecological' metaphor, the scope of MAST collaborations could be to facilitate professional growth within a CoP when and as the need arises. In relation to the key principle of engaging in sustainable collaborations, framing the MAST collaborations around the idea of building CoPs could help us set boundaries and clear responsibilities for the parties involved. Whilst the timeframe of the collaboration depends on the specific aims and engagement.

Finally, comparing the domains across our engagement with different departments, we have identified that a common area of interest across different departments is to address the mathematical and statistical needs of uneven cohorts due to the various admissions roots. Thus, it might be possible to bring small communities from different departments together and work on common issues. Cultivating a wider community of practice can be challenging, especially, considering the tight schedule of the academics involved. To alleviate the challenge, we are currently working towards building and maintaining communities of practice within departments, branching out to multiple departments whenever possible.

5. Conclusion

In the initial stages of an alliance with a new academic or department we have learned to factor in academic time commitments to ensure we understand the potential scope of the partnership. In the 2-year extension of the service, the MAST team will concentrate on developing mechanisms to support the functions of existing and new CoPs. To this aim, we are reviewing the practice-based literature on CoPs for reports on how to systematically overcome the identified challenges. We are testing different recommendations and approaches, and collecting evidence for evaluation.

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