How can Cloud Computing Improve our Education?

142016, 104833, 092912, 107857, 107186, 103740, 147406, 099089

12th December 2017

Module Code: MTH3035
Advisor: Dr Barrie Cooper

Abstract

We are seeking to investigate how cloud computing resources can be used to improve the quality of education at the University of Exeter. The cloud computing resources that we investigated were: Microsoft Teams, GitLab and Azure Lab Services.

To understand the University's needs we ran a survey with both CEMPS students and staff members. We also looked into the services themselves and how they operate. Once we understood the process of using these platforms we trialled them with a focus group of CEMPS students. In order to give a well rounded recommendation we also researched the costs of these services and compared this to the University's present outlays.

We found that there is some dissatisfaction with the present methods of teaching programming within CEMPS courses. Students found the benefits of cloud computing to be favorable. The staff on the other hand felt that implementing these resources would not affect their teaching.

Overall, we would recommend the University implement Microsoft Teams institution-wide. Azure Lab Services would be best implemented in concentrated settings. Finally, we would not recommend GitLab for use within mathematics modules but would endorse its use within computer science.

Contents

List of Figures

1 Introduction

1.1 Background

In today's world, computer programming and coding skills are essential for most STEM subjects, but with limited resources, it is not always possible to give every student access to a computer, especially for extended periods of time. As students progress through the university stages, they may need to use the required software for long running simulations which could require multiple hours, or even days. This means that the already restricted number of usable computers is decreased further, as other students are prevented from not using these computers while simulations are running.

The University aims to use cloud computing to provide students with the ability to access University computers from their own personal laptop or PC. This suggests that research into aspects of the cloud will be necessary for success of this project, including a definition of cloud computing and virtual machines, with investigation of particular resources on the market.

We define cloud computing following the resources provided by Microsoft[1].

> *"cloud computing is the delivery of computing services – including servers, storage, databases, networking, software, analytics and intelligence – over the Internet."*

From detailed research, we can identify potential impacts of cloud computing implementation, such as data security, mobility, accessibility, disaster recovery, collaboration, costs and increased training requirements. For example, providing cloud resources could increase accessibility to the University computers, and provide better methods at teaching coding, as the professor or teacher can set work on their virtual machine, for other students to access and complete remotely. However, acquiring these resources could be expensive, which is an important consequence as it may not be in the budget that the University allocates to student spending.

Another Microsoft produced resource[2] defines a virtual machine as:

> *"a computer file, typically called an image, that behaves like an actual computer."*

Therefore, we can describe a virtual machine to be computer emulation that, similar to a physical computer, runs an operating system and applications, providing the functionality of a physical computer from a server somewhere around the world. Within an education setting, the professor can install the specialised software, such as MATLAB or RStudio, so that students can access these programs remotely without having to install anything, only needing access to the internet. Also, with a virtual assistant, you can get instant feedback on whether your code works as intended and advice on how to improve it.

Many services are available which may prove useful in the teaching of certain elements of the mathematics syllabus at the University of Exeter, namely to streamline practical lab sessions and provide lab services outside of usual hours or session times. The University is in partnership with Microsoft, therefore we have focused on the following services: GitLab and Azure Lab Services, as they are easier to acquire. We aim to give a comprehensive overview of what these services are and if these would benefit the University and its students.

1.2 Cloud Computing Services

GitLab is "a complete DevOps platform, delivered as a single application"[3]. DevOps describes "a set of practices that automates the processes between software development and IT teams"[4]. Alternatively, we can define GitLab as a version management and continuous integration service utilising Git as its back-end. Git is a program that tracks changes made to files. Once installed, Git can be initialized on a project to create a Git repository, this repository tracks all changes made to files in your project, building a history over time. GitLab offers individual, educa-

[1] Microsoft Azure, *What is cloud computing?* Accessed on: 11th December 2019. URL: `https://azure.microsoft.com/en-gb/overview/what-is-cloud-computing/`.

[2] Microsoft, *What is a Virtual Machine.* Accessed on: 11th December 2019. URL: `https://azure.microsoft.com/en-gb/overview/what-is-a-virtual-machine/`.

[3] GitLab, *What is GitLab.* Accessed on: 11th December 2019. URL: `https://about.gitlab.com/what-is-gitlab/`.

[4] Atliassian, *What is DevOps.* Accessed on: 11th December 2019. URL: `https://www.atlassian.com/devops`.

tional, and industrial licensing options. The University of Exeter's implementation of GitLab is a locally hosted GitLab server on domain `https://www.git.exeter.ac.uk`. Although, from our perspective, this is not currently used or even widely known by students of the University.

Continuous Integration (CI) is a development practice that requires developers to integrate code into a shared repository several times a day[5]. Each check-in is then verified by an automated build, allowing teams to detect problems early. The continuous integration/development services are primarily handled by passing all code to a runner. A runner is a program, typically run on a dedicated server or instanced machine, which executes a number of tests on the code it receives. The typical form of such tests is to ensure compatibility with existing code, quality of code design, code structure, adherence to coding guidelines, commenting guidelines and more.

Another key tool for accessing cloud computing within education is Azure Lab Services, a paid resource designed by Microsoft that provides resources used in setting up pre-configured virtual machines that are accessible on any computer connected to the internet. This is particularly useful in creating classroom environments where users can interact with software separate from their physical machine, supporting scenarios such as group training, hackathons (team solving), hands on labs (workshops) and demo/test environments. In addition, Lab Services provides shared files, shared resources, data storage, backup and access to all created virtual machines from one place.

Azure Lab Services can cost from £0.16 to £3.26 per hour (per user)[6] and the difference in virtual machines ranges from 2 cores with 4GB RAM to 12 cores with 112GB RAM. Consequently, the more cores and storage you require for your machine, the higher the cost becomes. Accessing a more advanced virtual machine will allow you to perform more tasks simultaneously, which is particularly beneficial for students that require extensive code and multiple long-running simulations, as each core will be performing its own calculations.

1.3 Applications within the University of Exeter

We have been asked by the University to determine if cloud computing would be a useful resource within the CEMPS (College of Engineering, Mathematics and Physical Sciences) departments. Furthermore, we have also been asked whether we are able to determine if the cloud computing platforms under investigation would have a positive impact on mathematical education within the University. To achieve this we must take into account staff and student opinions on the different services and the cost to implement them.

We believe it is also important to find out which aspects of the current programming tuition need improvement and whether the benefits of cloud computing would be to our advantage in these areas.

The following is a quote from our research brief:

> *"Cloud computing offers some potential solutions to improve the student experience."*

Students deserve access to the best technology, as tuition fees tripled in 2012[7] universities must now find a way

> *"... to transform the way higher education content and activities are delivered, so that students can perceive as values for such a fee rise."*[8]

Students should have access to the best resources so that they feel they are getting value for money. However, with the student population increasing by %21 from 2014/5[9], we can estimate that the number of students is rising at a faster rate than building renovations and technology upgrades. Therefore, it is common for all the computers on

[5] Atliassian, *What is Continuous Integration?* Accessed on: 11th December 2019. URL: `https://www.atlassian.com/continuous-delivery/continuous-integration`.

[6] Microsoft Azure, *Azure Lab Services Pricing.* Accessed on: 11th December 2019. URL: `https://azure.microsoft.com/en-gb/pricing/details/lab-services/`.

[7] BBC Sean Coughlan, *Students face tuition fees rising to £9,000.* Accessed on: 11th December 2019. 2010. URL: `https://www.bbc.co.uk/news/education-11677862`.

[8] Victor Chang and Gary Wills, *A University of Greenwich Case Study of Cloud Computing – Education as a Service.* E-Logistics and E-Supply Chain Management: Applications for Evolving Business. IGI Global., 2013.

[9] topuniversities.com. Accessed on: 11th December 2019. 2012. URL: `https://www.topuniversities.com/universities/universiti-sains-malaysia-usm`.

campus to be in use, due to the limited resources. There is also the added problem of only select computers having the required software installed. Both we and the University feel it is vital to solve these problems.

1.4 Aims and Objectives

Within our project, we aimed to:

- Improve student accessibility to computing resources
- Research how cloud computing can improve student learning
- Research how continuous integration can improve student learning
- Increase student employability with relevant cloud computing skills

More specifically, our objectives were:

- To determine if, in general, the current system is a) well known, b) working as well as it can be and c) can it be improved.
- To ascertain the difference in opinion (and need) of staff and students of different year groups.
- To set up virtual machines, trial capabilities with ourselves and others.
- To provide actionable data for interested parties and their consideration of future implementation.

To achieve our goals we have assessed the tools available to us and obtained students and staff perspectives on the potential implementation of cloud computing. In particular, we have looked into whether using a virtual machine to teaching and assess coding is a viable and cost effective method for the University.

1.5 Other Literature

Case studies have informed our understanding of possible applications of cloud computing in education. One example of cloud computing applications in higher education is a 2013 case study at the University of Greenwich, evaluating the effect of cloud computing as a teaching aid. This is an example of education as a service application of cloud computing (EaaS)[10]. This case has limited generalisability for our project as it used Business School students as the focus of the study. It is also addressed how teaching staff may have to be trained in newly introduced technologies - finding that there was a high teacher satisfaction outcomes from workshops dedicated to explaining the technology to teachers. This study uses a useful evaluation concept of cloud computing applications: the hexagon model. The hexagon model identifies 6 criteria objectives for success and rates how well each project fulfils these objectives. Hexagon models can be useful to "indicate a business or a project's strengths and weaknesses visually for decision-makers"[8]. An example of a Hexagon model can be seen in Figure 1[8] evaluating the application of cloud computing at the University of Greenwich.

We also were informed by a case study from the University Sains Malaysia (USM). USM developed its own private cloud. The researchers found their cloud to have a high availability of computing resources at both peak and off-peak times[11]. These findings relate to the problem of unavailable computing resources at peak times at our University. Findings from this example may be less reliable than a domestic university. However, as the University of Exeter has a similar student population to USM (23,613[12] 24,237[9] respectively) the two institutes may have similar requirements.

1.6 Report Layout

Our report will begin with a description of our methodology and timeline. We created a critical path analysis to ensure that we kept to time.

[8] Victor Chang and Gary Wills, *A University of Greenwich Case Study of Cloud Computing – Education as a Service.* E-Logistics and E-Supply Chain Management: Applications for Evolving Business. IGI Global., 2013.

[9] topuniversities.com. Accessed on: 11th December 2019. 2012. URL: `https://www.topuniversities.com/universities/universiti-sains-malaysia-usm`.

[10] Nayan B. Ruparelia, "Cloud computing". In: (2016).

[11] Al-Rousan Thamer and Abu Al Ese Hasan, "Impact of Cloud Computing on Educational Institutions: A Case Study". In: (2015).

[12] University of Exeter, *Facts and figures.* Accessed on: 11th December 2019. URL: `https://www.exeter.ac.uk/about/facts/facts/#a3`.

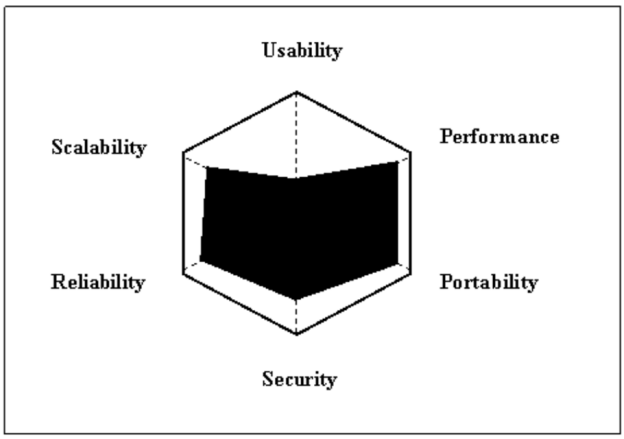

Figure 1: Hexagon model for IT service at University of Greenwich

We have split our findings into 5 subsections:

- ◇ Initially we researched what cloud computing is and the different services available to us.
- ◇ We sent out an online survey to all CEMPS students and promoted the survey in other CEMPS lectures.
- ◇ In addition we sent out a similar staff survey however, this did not return as many responses as we hoped. We then emailed specific staff members who we knew taught computer labs to try and increase the number of responses to no avail.
- ◇ After closing the responses, we created problem sheets accessible on a virtual machine and trialled this in a focus group where we received verbal feedback from the participants.
- ◇ We also looked into cost analysis so we could propose to the University the best cloud computing service and show whether it would be viable to implement.

We will conclude our report so the reader can understand what the next steps are for the University and whether they want to use virtual machines themselves.

2 Methodology

2.1 Our Methodology

To attain our first and second objectives we chose to compile two surveys, using Google Forms. One to collect the opinions of CEMPS students and the other for that of the CEMPS staff. To keep to our timeline we released these surveys within a week of starting our project, including a trial period. The goal of our survey was to ascertain the difference in opinion of staff and students of different year groups, so that we could provide actionable data for interested parties and their consideration of future implementation of cloud computing.

2.1.1 Survey

The survey was released on 14th October 2019 and was open until 18th October 2019. The survey was promoted via email; our project advisor Barrie Cooper was able to email our survey to all mathematics staff and students. Unfortunately we did not have permission to send this email to the rest of CEMPS. We also promoted the survey in various lectures, specifically targeting lectures of programming based modules, across stages and disciplines.

Social media was also used to advertise the student survey. We got in touch with the admins of the following University of Exeter society Facebook pages: Exeter Engineering Society, MathSoc Exeter, PHYSOC - Exeter Physics Society and University of Exeter Computing Society. We also shared the survey on our own social medias and encouraged friends in the CEMPS disciplines to

respond.

In total the survey received 309 responses. 200 of which were received within 24 hours and 50 in the first hour.

We then conducted our analysis of the data gained from the survey. First we filtered out inappropriate and blank responses, following this the data was turned into an excel document to be usable in R and then plotted jitter plots, count plots, and bar charts from the data, we chose these as the data was discrete.

We analysed our data depending on the density of data points, overall finding a fairly neutral response to computer labs, but were able to spot areas that could be improved. We also were able to gauge an understanding on how students might react to a cloud computing system, and suggest areas we might want to further explore.

2.1.2 Azure Lab Services

We began our investigation into Azure Lab Services by obtaining an active licence from the University of Exeter, following communication from the IT staff. We then began to set up a framework for classroom activities on a virtual machine hosted on Azure's cloud. For this we used a guide provided by Microsoft[13]. In addition to this we created a set of coding tests to be ran on MATLAB, designed to familiarise our focus group with the virtual machine environment. These tests were simple, one of which asked students to write code that would identify if a given number was prime.

2.1.3 GitLab

As a result of GitLab's CD runner architecture scaling it to a class size of 60 or more becomes very impractical, for example in conversation with Barrie Cooper he detailed a fourth year module he presently runs which uses GitLab's CI/CD pipeline. For smaller groups, however, e.g. postgraduate masters and 4th year modules for integrated masters programes, it could become more reasonable to implement and would - for those projects, which are naturally of a larger size and scope - be very informative. One of the primary applications we were to investigate, however, was GitLab's usefulness for teaching programming from the very beginning. In this capacity it would be beneficial, providing real-time feedback on the quality and accuracy of initial coding assignments. Additionally it would provide feedback to students completing the assignments out of lab sessions, whether they are catching up, having missed the session, or for finalising work they started during the sessions. In each of these situations the student would benefit from continuous feedback on their work whilst they don't have access to the teaching staff that would be present in the lab session. As a consequence of this system the teaching staff shall likely receive fewer 'simple' inquiries, as such matters should be dealt with by the automated system, thus the teaching staff can spend more time focusing on more nuanced inquiries and providing a better service in general.

2.1.4 Focus Group

Concurrently with the survey we ran a focus group to students, this received 3 total responses. The focus group was run in a computer lab on 13th November 2019, with the aim of generating a rich amount of qualitative data on student opinions on Azure Lab Services. We trialled the focus group beforehand to check it would run smoothly, including testing the virtual machine and confirm our interview questions were effective. The participants were briefed on how to remotely access the virtual machine, following this they then completed the previously devised coding tests. After being given an hour to complete the tests, we interviewed the participants with the aim of finding, if following their experience in the focus group, they believed there would be benefits to increasing the use of cloud computing in the teaching of coding. This group interview was recorded, with participants' permission, and transcribed.

The transcription took four different people a few days to listen and write up the 20 minute interview. We then discussed our findings later on in this report. From the transcription of this interview, students were able to give their opinion on the current coding teaching, as well as coding using virtual machines themselves.

[13] Microsoft Azure, *Tutorial: Set up a classroom lab*. Accessed on: 11th December 2019. Oct. 2019. URL: `https://docs.microsoft.com/en-us/azure/lab-services/classroom-labs/tutorial-setup-classroom-lab`.

2.1.5 Cost Analysis

The method for cost effectiveness (CE) analysis was informed by Henry M. Levin's[14] outline of the topic. We start by identifying ingredients that are required for our intervention. The same ingredients identification should be carried out for facilities, equipment, and other program inputs. Values must then be placed on the inputs. If exact values are unable to be identified, shadow prices can be used as an alternation. Shadow prices are the estimated value of a resource based on the value of a similar alternative. Combining all of these cost values would give us the total cost of an intervention. Then a cost per student can be calculated. A desirable statistic for analysis would be the improvement seen per unit of cost. This would give an evaluation of the effectiveness of different programs in ratio to the resources required for them. For this kind of analysis we must have data on benefits or improvements caused by our interventions.

2.1.6 Our Recommendation

Finally we have compiled the results of our explorations into a proposal for implementation of cloud computing resources at the University of Exeter.

2.2 Alternative Approaches

2.2.1 Survey

We could have augmented the promotion of our student survey using scannable QR codes displayed on a large screen at the front of a lecture theatre or on posters around Harrison building. There are many examples of free QR code generators online. This would likely increase the number of survey participants, resulting in a larger sample of student opinions at the University of Exeter.

We created our survey using the online platform Google Forms. When creating our survey we failed to implement limitations to force participants to give a response. A more robust design would have required participants to respond to each question before progressing so we would have a complete data set for each participant.

2.2.2 Cloud Computing Application Investigation

As an observational study we could have produced a cohort study, which "identifies a group of people and follows them over a period of time to see how their exposures affect their outcomes"[15]. This would attempt to show some difference in achievement of students with cloud computing assistance compared to a group without the intervention. In the University of Greenwich case study they observed two cohorts studying the same topic with different educational methods. One group had cloud computing assistance and one did not. In this example, the cloud computing assisted students were taught using supply chain simulations hosted on the cloud. Conversely, the other group of students were taught only using theory and case studies. There was an improvement in student satisfaction noted from the cloud computing assisted teaching.

The cohort study could have used the learning aid of a testing suite for student's code using continuous integration. We could have measured variables such as student satisfaction or participants' performance. We would then analyse how these statistics differ for the two groups of participants. Having an experiment structured like this would be capable of producing quantitative data. This data can then be studied with methods such as hypothesis testing, giving us evidence to prove a particular hypothesis. This could be a a very good practice to vary the types of analysis we perform, particularly as throughout this project we often received qualitative data. By limiting our studies to communicated responses, we can only analyse perceived impacts rather than actual measurable improvement.

Another alternative approach we could have considered may be exploring the cloud services already supplied by the University. The Exeter Virtual Learning Environment gives students access to course files remotely at all times - this is a cloud computing application. We could have surveyed student opinions or evaluated information on student usage or reliability of the platform.

Group project work is included in most degrees at our University. Cooperation between students using cloud computing could improve project out-

[14] Henry M. Levin, "Waiting for Godot: Cost-Effectiveness Analysis in Education". In: (2001).

[15] NHS, *Health news glossary.* Accessed on: 11th December 2019. URL: `https://www.nhs.uk/news/health-news-glossary/`.

comes. Thus, finding out if students could be supported by cloud computing technology during group project work would be an important area of research.

2.2.3 Focus Group

The focus group did not have a large sample size of participants. This may have led to the participants holding back through shyness or being talked over. A redesigned approach may have fewer members of our group leading the session with a clear goal of listening to the participants' experiences and feedback. This improvement was easy to recognise when transcribing the audio, we recorded at the end of the session. We, as the session runners, spoke more often than the focus group participant. This could prevent valuable feedback for participants from being obtained. Furthermore, we could have held multiple of these small focus groups and surveyed or interviewed the participants online, in order to receive sufficient feedback.

2.3 Skills Development

2.3.1 Teamwork

This was achieved by working collaboratively as a group to achieve the goal of a presentation and clear report. Throughout the project we ensured we all worked efficiently as a team in a number of ways such as clear communication, using our own individual skills effectively so each part of the project could be completed to the best of the groups ability and giving constructive feedback to each other. Teamwork is a cooperative process that allows ordinary people to achieve extraordinary results. Such synergy is only possible when all team members know what their roles are, compliment each other's skills, and are committed to team success.[16]

2.3.2 Communication

We believe that the main idea behind effective communication leading to excellent teamwork is the ability to get your point across clearly, and truly understand what other people want to tell you. The form of communication can be in person, via email, instant messages, or on the phone; the exchange of information must be effective and clear. During this project we achieved this by using a number of platforms to communicate before settling on Microsoft Teams as this was something we were asked to trial. We set up a Facebook group to organise group meeting events so we could see the location, time and who was attending. We also used Facebook messenger for instant access texts to keep everyone updated when we had changed files on our Google Drive. The Google Drive remotely held all our files and presentations and everyone could access and edit this. Although the use of all three platforms worked, Facebook messenger mixed up our social life with our university work. When we were asked to trial Teams it meant all our work stayed in one place and our communication definitely improved which was crucial during the end of the project when we were collaborating our final ideas together. Also communication with members of staff such as our advisor Barrie Cooper are important to gather more information on the task that we may not ave thought of. Moreover, the non-verbal aspects of communication are just as important. Great teams nurture a culture of openness and mutual trust. Everyone must feel safe enough to speak their mind.

2.3.3 Conflict resolution

Conflict is part and parcel of any team effort. What matters most is how adept we were at dealing with issues as they arise. Within our group we rarely had conflicts; we believe this is because we all worked cohesively as a group and kept each other informed if we had any problems with our delegated task. Any disagreements we had were often very minor and were resolved straight away by making a group decision.

2.3.4 Rapport-building, Listening, Respectfulness and Tolerance

Participating in a project with eight group members requires managing inter-group relationships. When we first met each other we introduced ourselves and discussed our strengths and weaknesses so we could use this to our benefit during our project. We set out some ground rules to reduce any conflicts. These were to keep everyone in the

[16] Maciej Duszyński, *Teamwork Skills: Definition, Examples, Best for Your Resume.* Accessed on: 11th December 2019. URL: `https://zety.com/blog/teamwork-skills`.

loop at all parts of our project and stick to regular meeting times so we make good progress. It was important to really listen to everyone throughout the project but especially at the start so we could build up trust and respect. Rapport and the ability to listen go hand in hand, one can't exist without the other. This is because you can only build rapport if you're listening to other people's voices. Being respectful towards other people does not mean you have necessarily agree with them. It is about not taking anyone for granted, and listening to them actively. Tolerance and respectfulness go hand in hand. We were all open-minded and eager to learn. This made working together much easier as we could get on with the work whilst enjoying doing it.

2.3.5 Decision-making

Making decisions can often be straightforward when everyone agrees on the course of action. However, that may not be the case when opinions start to differ and we need to make an unpopular decision. Most of our decisions were unanimously agreed on which made for quick progress. Before making a decision, we discussed different ideas with each other and combined these to produce, what we thought, was the best one. Sometimes changes were made to these decisions at a later date but again they were unanimously agreed on. The main point we took away from reflecting on our decision-making was that it was useful we all saw the same main goal and stuck to it not letting ourselves get sidetracked.

2.3.6 Problem-solving

Problem-solving skills are fundamental for each and every team member. The ability to look at an issue from multiple angles and allocate time and effort on the basis of individual team member's skills drive the entire team's performance and success. Our project heavily depended on successful problem solving. This was due to some issues we encountered during our data collection. Originally our survey was meant to be emailed out to all CEMPS students but unfortunately both us and our project advisor were unable to do this. To solve this, we made the decision to go into lectures to promote the survey and get students to answer it there and then as it only took a few minutes. After overcoming this obstacle our project moved on as expected. We reached another hurdle when trying to recruit people for our focus group as we only had one participant from the survey who was interested. We attempted to resolve this by asking our friends and course-mates to participate. Unfortunately due schedule conflicts only 3 people could participate but we still received valid feedback. The final unforeseen issue we faced was the strike action at our University. We were unaware that our lecture building would be occupied and out of use and our advisor was striking so we could not contact him with our draft report for feedback; this in turn meant our progress was stalled.

2.3.7 Organisational and planning skills

Our involvement in Microsoft Teams ensured we were organised and had good planning. When creating an event, each member received an email and calendar notification which they could accept so they could be further notified on the day an hour before. The use of overleaf allowed everyone to access the report simultaneously and see the updates as they were being made. This meant that even if we were all working on individual parts we could see the progress others were making. At the start of the project, we created a critical path analysis so we could see when parts of our project needed completing. Due to the extended deadline, we were given longer to submit out report so we had more time to finesse the quality of the writing.

2.3.8 Reliability

A team works because more can be achieved than each individual on their own. When working together as a team we realised we depended on the others as much as they depended on us. Each member showed their reliability by sticking to deadlines and clearly communicating to overcome the obstacles we faced.

3 Findings

3.1 An Overview

The following section of this report presents the results and analysis of our findings after adhering to our created methodology. As expressed by

an online article[17], cloud computing has multiple key advantages. Although these are described specifically for the workplace environment, these can be extended to education within mathematics. The source can be summarised as:

- IT problems: It is possible that many students can face numerous IT related problems during their learning. In various cases, with cloud computing, it is possible for staff to enter into a students 'area' (in which their data is stored) to find a potential solution for issues that may occur. Alternatively, students would have to contact the staff and then manually provide access to their data. This also gives the University the ability to outsource when wanting to update their services, which is beneficial when using a resources from large company such as Microsoft, as it will be more reliable.

- Safety and security: Microsoft hold more resources than the University, so it is likely that their impact on safety and security is much larger.

- Economically viable: With the rising numbers of enrolled students, an introduction of cloud computing could be a cost-effective solution, allowing the University to provide virtual computers as an alternative to more physical computers.

- More connected: With cloud computing students can be connected with applications that speed up and compile the communication process.

- Flexibility, functionality and Efficiency: One example is that cloud computing allows for file sharing. A virtual solution also enables quick responses to internal demands. Therefore, if user demand increases (more students enrolled into the University), cloud services can also be increased to meet the demand, and then be easily decreased if demand drops. Therefore eliminating the problem of over-provisioning or IT systems overload.

- More disaster resistant: Losing important data can be a huge issue for both students and staff, but with the availability of cloud services it is now much more convenient to prevent data from being lost. If a fire was to occur at the University, then data stored in the cloud would not be lost as it is stored in a different safe location.

- Greater competitiveness: The article states that:

  > *"74% of businesses feel like cloud computing has given them a competitive advantage."*

  Since firms are feeling the benefits of cloud computing implementation, it is important for students to have experience with it, so that when applying for a job they can make use of that knowledge.

- Big data management: cloud computing makes it simpler for both students and staff to handle big data, which is a large volume of data that can be unstructured or structured[18]. Whether this is for examinable work or managing the University's data, being able to use online resources to store and manage large quantities of information is pivotal in speeding up analysis and organisation over traditional storage methods. Thus, the cloud provides the necessary tools to sort through lots of unstructured data quickly and easily.

Comparatively, cloud computing could result in various disadvantages within an educational environment that are not related its price. For example, the University's own student website ELE, which is an outsourced resource portal provided to the students and staff, faced technical issues on the start of the 2019 academic year. This could suggest unreliability from outsourcing programs from other locations. Security is also an issue as universities must follow The General Data Protection Regulations (GDPR), which is an EU law focused on the security of personal data. An article from ZDNet[19] describes the law, saying:

[17] J-T-Ripton, *8 Ways Cloud Computing can Increase Productivity and Profits*. Accessed on: 11th December 2019. URL: https://www.business.com/articles/8-ways-cloud-computing-can-increase-productivity/.

[18] sas.com, *Big Data*. Accessed on: 11th December 2019. URL: https://www.sas.com/en_gb/insights/big-data/what-is-big-data.html.

[19] ZDNet, *What is GDPR?*. Accessed on: 11th December 2019. URL: https://www.zdnet.com/article/gdpr-an-executive-guide-to-what-you-need-to-know/.

> *"GDPR ultimately places legal obligations on a processor to maintain records of personal data and how it is processed, providing a much higher level of legal liability should the organisation be breached."*

This suggests that using programs outside of the EU may not be authorised by the University, as they may not follow these regulations, putting students personal data at risk.

In summary, we have compiled our survey results following our methodology to establish the student perspectives and demands of cloud computing implementation into education within mathematics. We have also presented our further findings into the accessible cloud resources, GitLab and Azure Lab Services. Although not in our project plan, we were given access to Microsoft Teams, which was used it as an important part of our findings. We have also performed a cost analysis on the programs under investigation in order to assess the impact on resource provision for the University.

3.2 GitLab

We have found that GitLab has many potential uses including, but not limited to, teaching basic programming, supporting postgraduate research/more complicated projects, and streamlining group programming projects.

3.2.1 Basic Programming

In many first year modules students are required to program in various languages, primarily MATLAB[20] and R[21], one area of interest for us was how Continuous Integration (CI) and Continuous Development (CD) practices could be implemented to assist in that learning process. One can imagine the obvious advantages of learning to program with continual feedback on the quality and accuracy of your code, additionally many students may feel their questions or problems are simple or 'stupid questions' and therefore might not develop at the rate they would otherwise be able to, but if they were to receive 'simple' feedback from the automated system they would catch such minor errors and build their confidence - leading to better quality programs and programmers as well as lessening the burden on the teaching staff such that they can focus on more difficult and challenging questions and bugs.

3.2.2 Postgraduate Research and Complicated Projects

Many postgraduate research projects require some quantity of programming, those projects tend to be of a larger scale and more complicated than those discussed before. For such projects it becomes important to have a solid version management system such that any changes can be reverted, in the event of some issue or other change, here the Git backbone of GitLab comes into play. So GitLab is, at least, as useful as Git itself in this instance, however there are other considerations for such a project such as that in such a system it becomes much more difficult to fully appreciate the impact of code alterations on the program as a whole, which one could determine with greater accuracy through GitLab's CI tools by writing integration tests. Additionally I was able to talk with students presently engaged in a postgraduate module (MTHM008) ran by Dr Barrie Cooper[22], these students expressed the service was useful, but had been unreliable in the past - similarly Dr Cooper reported the virtual machine had crashed several times and completely corrupted the virtual machine once. Additionally these students reported the system was difficult to get used to but after some experience it stopped being a barrier to development and started to assist in development; all this indicates GitLab could be useful for complicated projects.

3.2.3 Group Programming Projects

One can conceive of the usefulness of GitLab in a group working environment. Indeed it offers all the standard benefits of Git in managing who

[20] Prof. John Thuburn (Coordinator), *MTH1003: Mathematical Modelling Specification.* Accessed on: 9th December 2019. 2019. URL: http://udb2.emps.ex.ac.uk/api/index.php/databases/teaching/modules/modulecode/MTH1003/pdffile?year=2019.

[21] Prof. Peter Challenor (Coordinator), *MTH1004: Probability, Statistics and Data Specification.* Accessed on: 9th December 2019. 2019. URL: http://udb2.emps.ex.ac.uk/api/index.php/databases/teaching/modules/modulecode/MTH1004/pdffile?year=2019.

[22] Dr Barrie Cooper, *Health news glossary.* Accessed on: 11th December 2019. URL: http://udb2.emps.ex.ac.uk/api/index.php/databases/teaching/modules/modulecode/MTHM008/pdffile?year=2019.

makes changes to what and being able to track all said changes. Furthermore it offers the ability to ensure that code you are working on properly interacts with the code written by others, about which you may not have as intimate a knowledge as you may your own code, this would be handled by generic and specific integration testing which could largely be automated by the GitLab CI/CD pipeline.

3.3 Survey Responses: CEMPS Students

As you can see below we have had responses from a good spread of students across CEMPS subjects.

According to the University of Exeter website, the current distribution of students in CEMPS departments are as follows:[23]

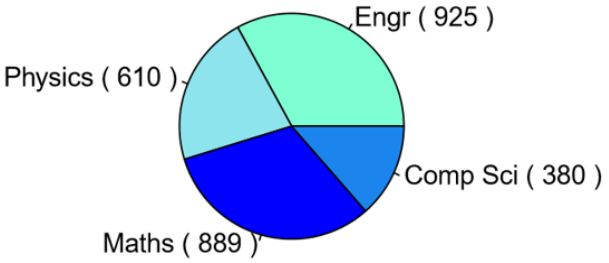

Figure 2: Proportion of CEMPS students: Degrees

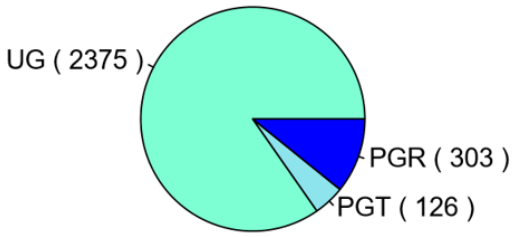

Figure 3: Proportion of CEMPS students: Stages

As mathematics students ourselves we were able to reach more maths students than any of the other courses, this is majorly due to our initial email only going out to mathematics students. We tried to overcome this by visiting lectures of a variety of degrees, including

Prior to sending out the survey, we evaluated what issues we might have so we could try to reduce these. This included, people giving silly answers (we filtered through the data to remove these responses) and not getting enough responses (we went into lectures to promote the survey). After closing the survey with a substantial amount of responses we found that some participants had answered the start of the survey then skipped through to the end. In hindsight, to prevent this we should have marked each question as mandatory so this could have been prevented, but as we had such a large number of sensible responses, this was not a huge problem to our analysis.

From our survey we were able to collect 309 observations across 25 variables which left us with a very wide pool of data. However, this data was not yet perfect and ready to visualise, it still needed to be tidied up. We needed to remove blank data points (where participants failed to answer) and change N/A entries to 0, as RStudio finds it difficult to recognise these points. We also needed to decide whether or not to remove small pools of data that might not be able to show any trends in the data. We chose to remove the single Data Science student as we felt it could not be representative of the entire course, moreover, we felt it could skew other plots where the data from said participant was included. We chose to include Natural Sciences students, despite there only being 3 participants, this is because it can be suggested that 3 data points can be enough to indicate a change[24]. Including these participants also means that we would have a broader range of degrees to observe.

Now that our data is all tidied we are able to create graphs. It is important to note that our data is all discrete, this limits our options of types of graphs that we can use. For 2 variables we are able to use GeomJitter and GeomCount, both of which we have used to visualise our data. For 1 variable, we are only able to use GeomBar, which shows us the frequency of our variable.

[23] University of Exeter, *Facts and figures: Detailed information about our student population since 2014/2015*. Accessed on: 11th December 2019. 2019. URL: https://www.exeter.ac.uk/about/facts/facts/#a3.

[24] William Christopher Long, *What is the number of observations needed to detect change of trends from time series data?* Accessed on: 11th December 2019. 2016. URL: https://www.researchgate.net/post/What_is_the_number_of_observations_needed_to_detect_change_of_trends_from_time_series_data.

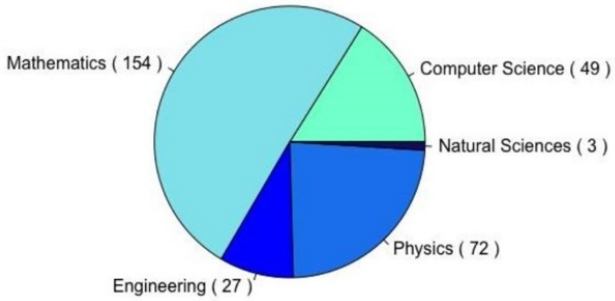

Figure 4: Proportion of student responses: Degrees

We chose to visualise the different degrees our participants undertook and how many were in each degree in Figure 4. To make the data clearer we also included the number of participants in each of the labels as the lack of clarity[25] can be the downfall of many pie charts. It is clear that mathematics had the greatest density of responses with 154 participants being from that discipline. The second greatest number response came from Physics with 72 participants which is over half the number of participants who were from maths. As a project relates cloud computing to mathematics particularly, we were glad to have such a large response from Maths students. Having responses from different degrees can help us understand whether there is a differing understanding of the teaching of computing at Exeter.

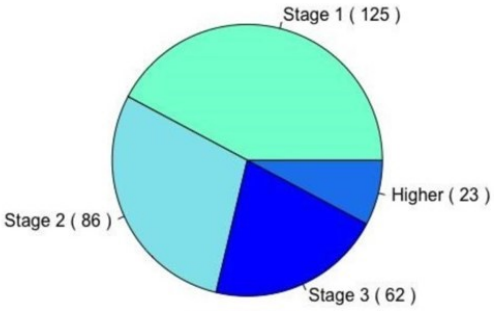

Figure 5: Proportion of student responses: Stages

We also chose to visualise the different stages of teaching that participants are currently in, as a pie chart, this can be seen in Figure 5. From this data it was clear that the greatest volume of participants were on stage one of their University degree. The strong majority of our participants are undertaking their undergraduate degree with 23 participants being in a higher form of education (Masters, PHD, etc.) As we have quite a wide spread of data for each of the stages, this should give us a good idea how each stage has experienced computing at university.

Next we have another grid.arrange, seen in Figure 6, which shows the frequency of different ratings relating to various parts of computer labs. We were hoping to gain a better understanding of the opinions of students in relation to the computer labs at the University. We already looked at the rating of the computer labs on our first Jitter plot.

For the rating of computer lab sheets we received a very average response with a lot of ratings of 4 compared to any of the other graphs, but a very low number of 5's. This might suggest that while many students aremostly satisfied with the problem sheets, that there are many who still feel that the can be improved. For confidence in their code the response was a lot more spread, the most frequent response being 4, that they were mostly confident. It also has the highest frequency of 5's compared to the other graphs. This might suggest that this is not a strong issue with the Computer Labs at this time. For Understanding, we received a mostly neutral response with no obvious skew to either side of the data, perhaps suggesting that students are unsure of what they do or do not understand. Finally for Ability to debug code the data appears to be skewed to a more negative response, with the greatest frequency of 1's given than any other plot. This shows that debugging code is likely a prevalent issue that we might want to look into to improve on the current system.

Figure 7 is a jitter plot that maps student ratings of the computer labs against the different degrees that the students undertook, we also used the colour of the points to determine what stage each of the participants are at. From the plot we can see that the greatest density of ratings are at 3 and 4, suggesting that overall most of the students are somewhat satisfied by their teaching of computing. Looking at the different stages it can be seen that a large number of students in Stage 1 rated the labs as 3 or less, this might imply that the teaching at Stage 1 is not adequate, as many students do not enjoy them. However, it might be suggested that as we took this survey quite early into the term that students had not had enough time to properly get into the lab sessions.

[25] Yan Holtz, *The issue with pie charts.* Accessed on: 11th December 2019. 2018. URL: `https://www.data-to-viz.com/caveat/pie.html`.

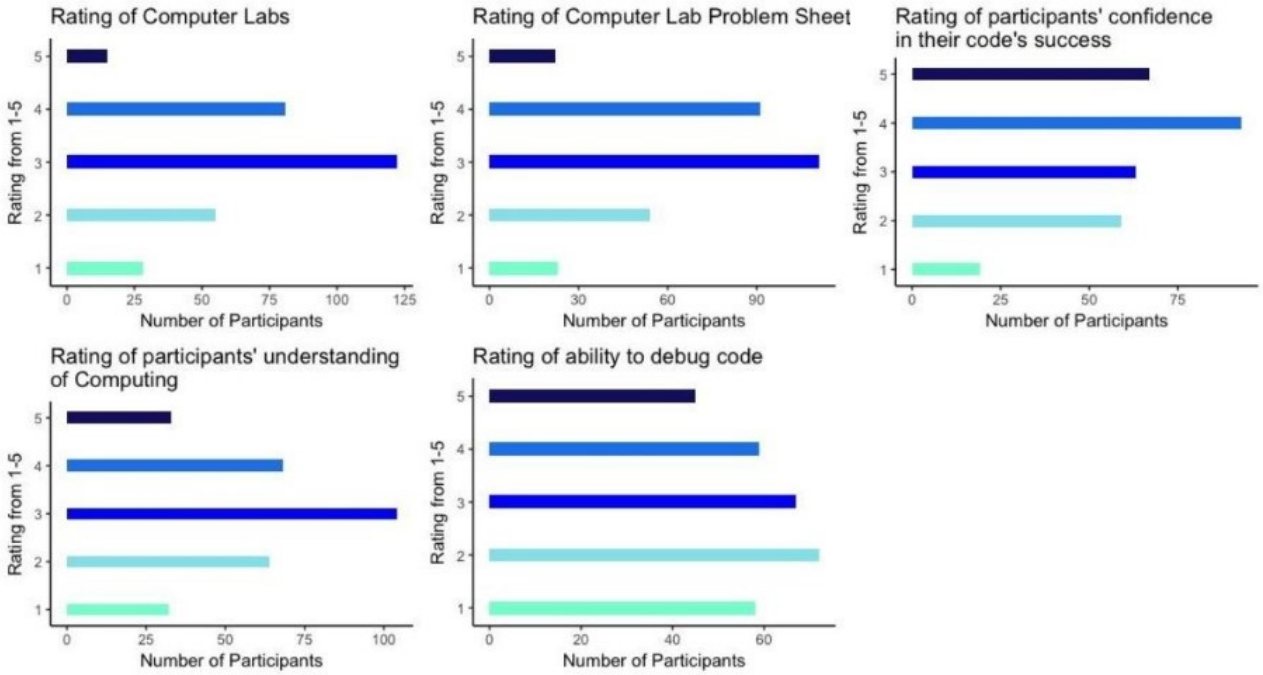

Figure 6: Rating of current computer labs

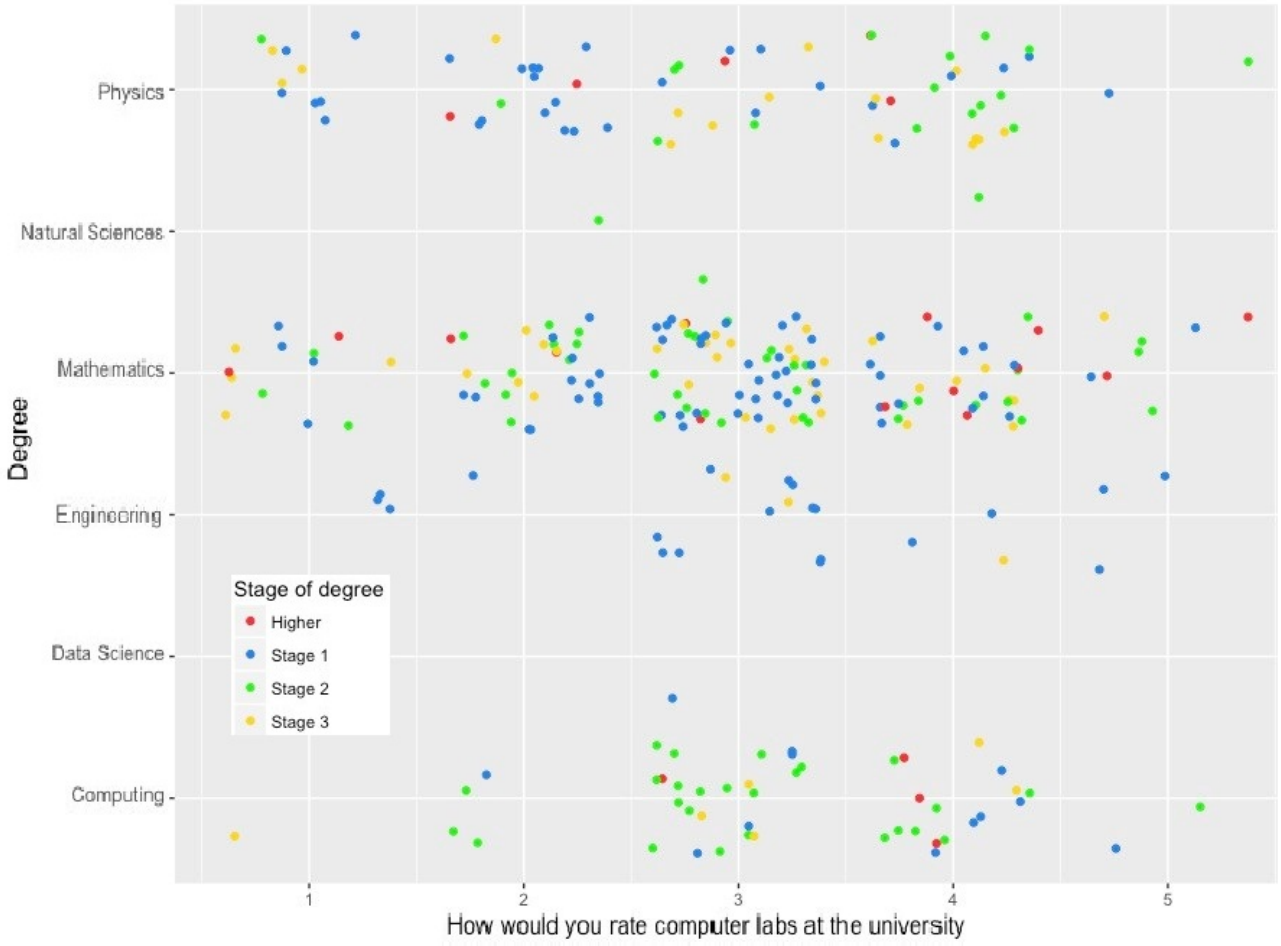

Figure 7: Stage and Degree jitter plot

Alternatively it might be that after 1st year students who did not enjoy or understand labs decided to avoid any modules that might contain this, so higher years appear to enjoy them more. There also seems to be a greater number of physics and mathematics students rating the labs as 1, whereas computing students have overall voted higher. It could be inferred that perhaps computing students are taught in a different manner, so they have a greater enjoyment, or that they are more inclined to understand computing as it is the basis of their entire discipline. Overall, it would appear that the majority students had an average to above average experience in computer labs, but that the system could clearly be improved.

Our next graph, Figure 8, is another grid.arrange of Bar charts looking at the different experiences that the participants had had in computing. The different programs that we looked at included Python, R, MATLAB, Latex, and others. The programme that students had the most experience in was MATLAB, and the programme with the least experience is C++. From these graphs it would appear that the most used programmes were Python, R, MATLAB, and Latex, but a lot of participants did not have experience in computing. Although, we can't be sure of any overlaps in the choices made in this section of our survey.

Our next jitter, Figure 9, looks at the different Degrees, the Stages that they are at in their degree and the colour of the points indicate their experience with MATLAB. We chose to put more of a focus on MATLAB just so that our research did not become confusing, especially as MATLAB is one of the programmes that is taught in mathematics. Our graph showed that the majority of those who are experienced in MATLAB can be found in mathematics, further suggesting that this reduction in focus was correct for our project.

Figure 10 is a GeomCount which makes the data points bigger in size for a greater frequency. We used this to create a graph showing Degree types against experience with cloud computing. The greatest point is no experience in cloud computing in mathematics, and it appears that "No" is the most frequent response by participants, with those who have heard of it but have never used it. It would also seem that most computing students have heard of cloud computing and are more likely to have tried it, suggesting computing might have more exposure to it. Natural Sciences seems to have the least knowledge of cloud computing, however, we might be inclined to ignore these responses as they are unlikely to be representative of the whole course. Overall, it appears that cloud computing is well known amongst the students we surveyed, and those that have used it enjoy using it, or would like to use it more.

Figure 11 is a jitter plot of the those who have had experience with cloud computing and the different ways that our participants have used it. We also used colour to make it clear what level of experience each of our participants has had with cloud computing. From the plot it can be seen that Google Cloud, GitLab, and Azure Lab Services are the most popular type of cloud computing that have been used. Looking at those who have used cloud computing but did not like it, Google Cloud is the main outlet with 4 of the 6 participants selecting that option. This might be something we would like to consider asking any participants that we get in our Focus Group, so we might be able to understand the problems with this. This graph shows us what programmes are available now and what we might want to explore further, possibly focusing on Azure Labs and GitLab, and assess their usability.

Figure 12 is grid.arrange of the various benefits of cloud computing. In the graphs we have looked at the benefits of: a virtual assistant, disaster recovery, flexibility, having a portal with access to all the information you might require during your coding, and the ability to collaborate with other people on a project. We used the bar chart to plot the frequency of ratings of each of these benefits; this type of rating is know as a Likert scale[26] which we used to gain a better understanding of the opinions of our participants. This type of rating also appropriately allows for participants to give a more neutral choice, which 1-10 scales struggle to do. It also helps to remove the possibility of a false positive skew which a 1-10 scale can sometimes give, as it has been seen that people tend to choose the number 7 on a 1-10 scale more than any other number[27]. What we were able to see is a very positive response in the possible benefits of

[26] Achilleas Kostoulas, *On Likert scales, ordinal data and mean values.* Accessed on: 11th December 2019. 2013. URL: https://achilleaskostoulas.com/2013/02/13/on-likert-scales-ordinal-data-and-mean-values/.

[27] Alex Bellos, *Why odd numbers are dodgy, evens are good, and 7 is everyone's favourite.* Accessed on: 11th December 2019. 2014. URL: https://www.theguardian.com/science/2014/apr/13/favourite-number-survey-psychology.

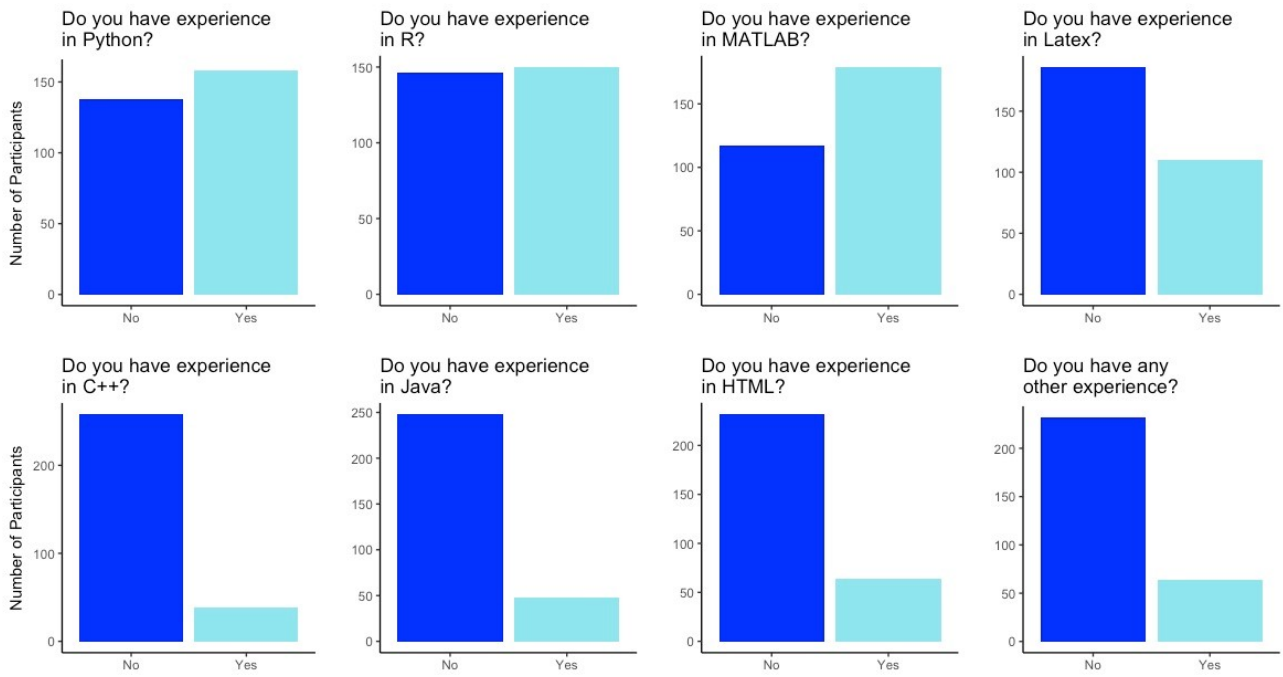

Figure 8: Programming experience bar charts

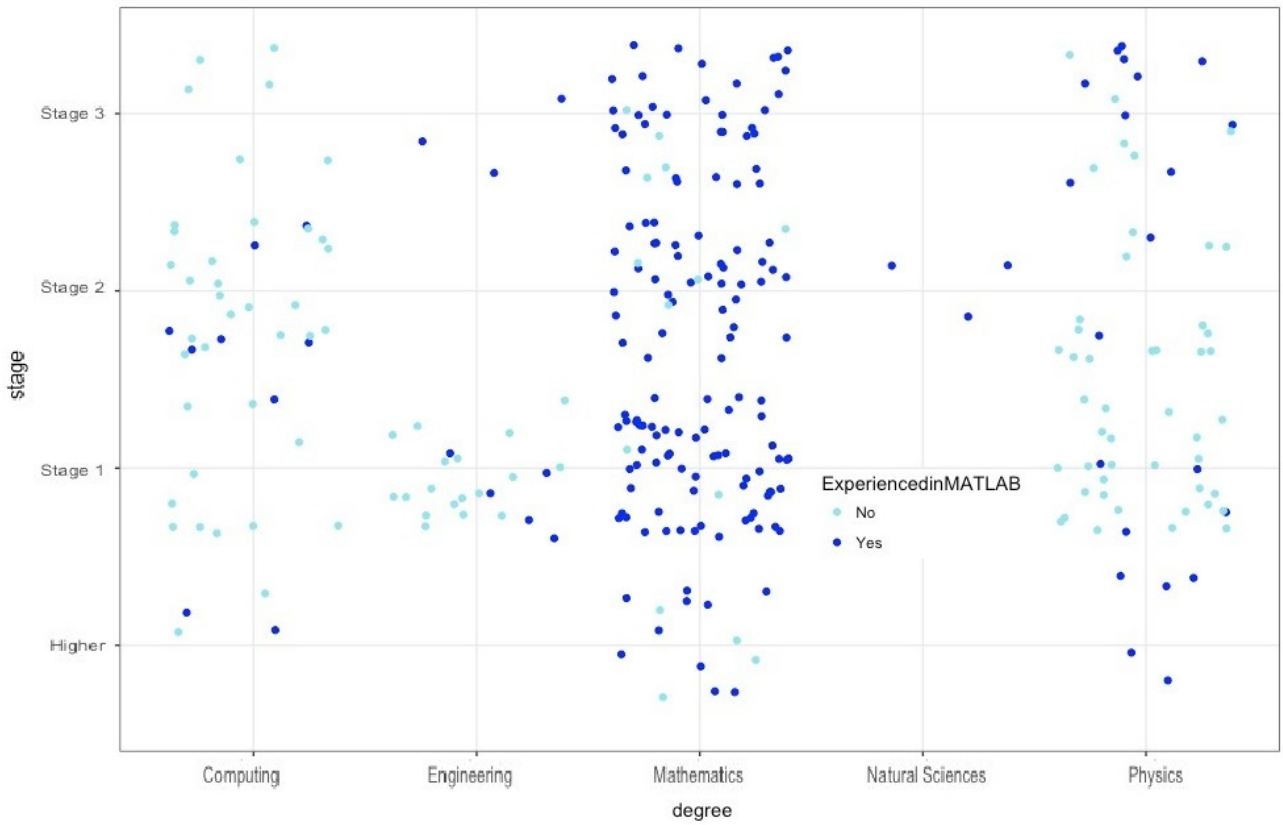

Figure 9: Experience with MATLAB

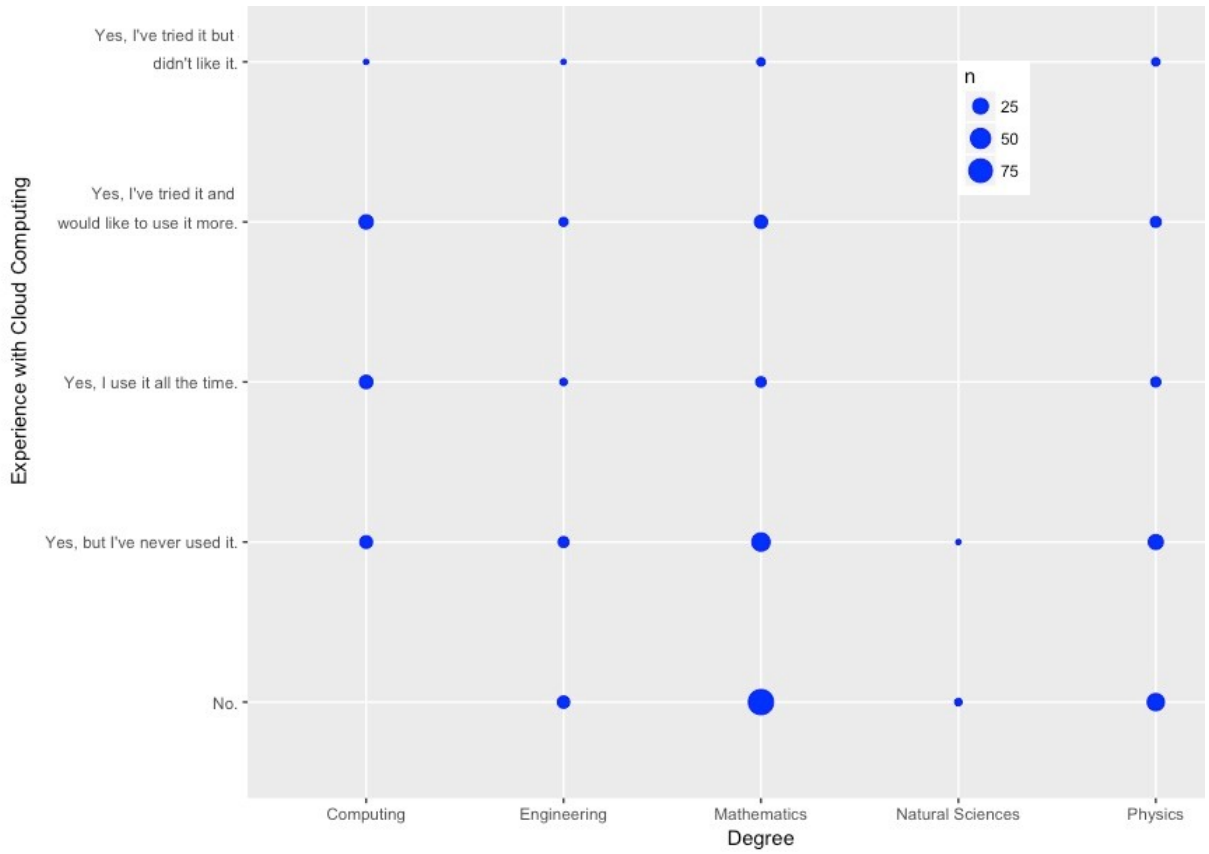

Figure 10: Experience with cloud computing count

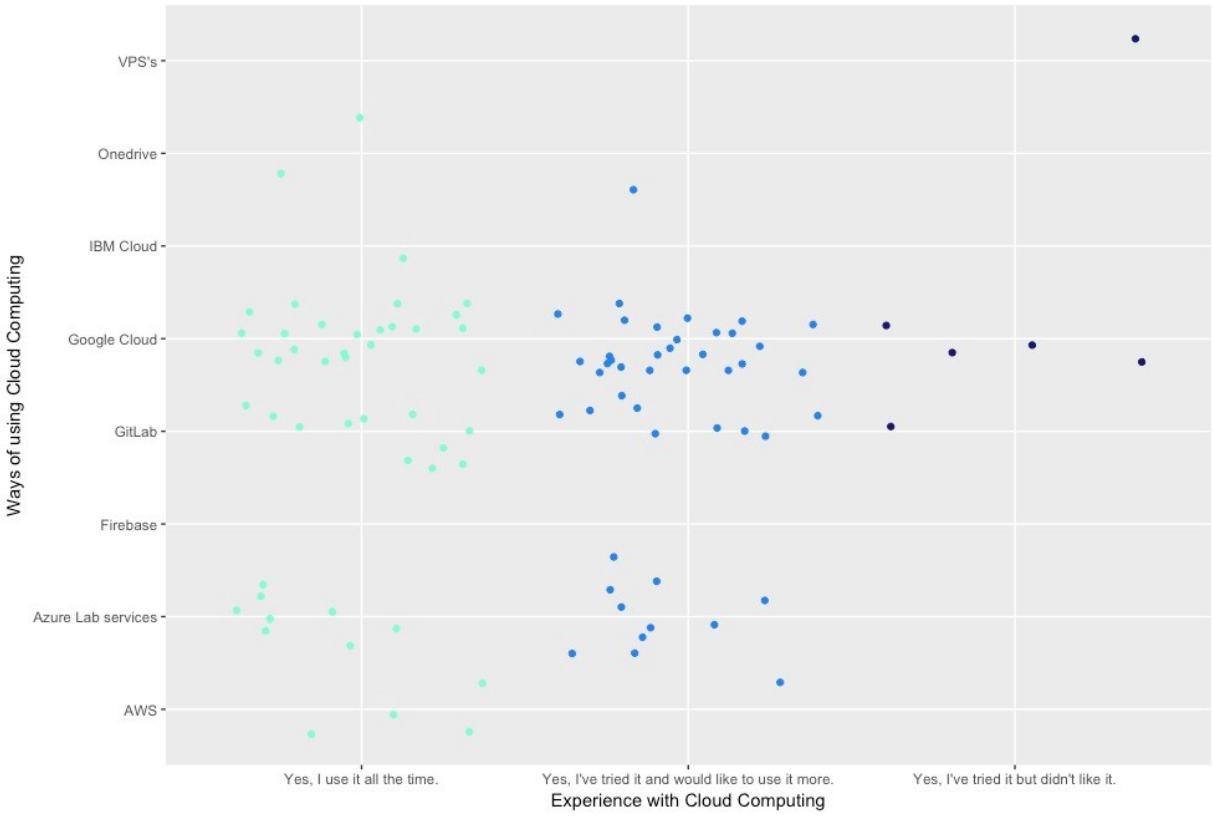

Figure 11: Cloud computing services, have you tried them?

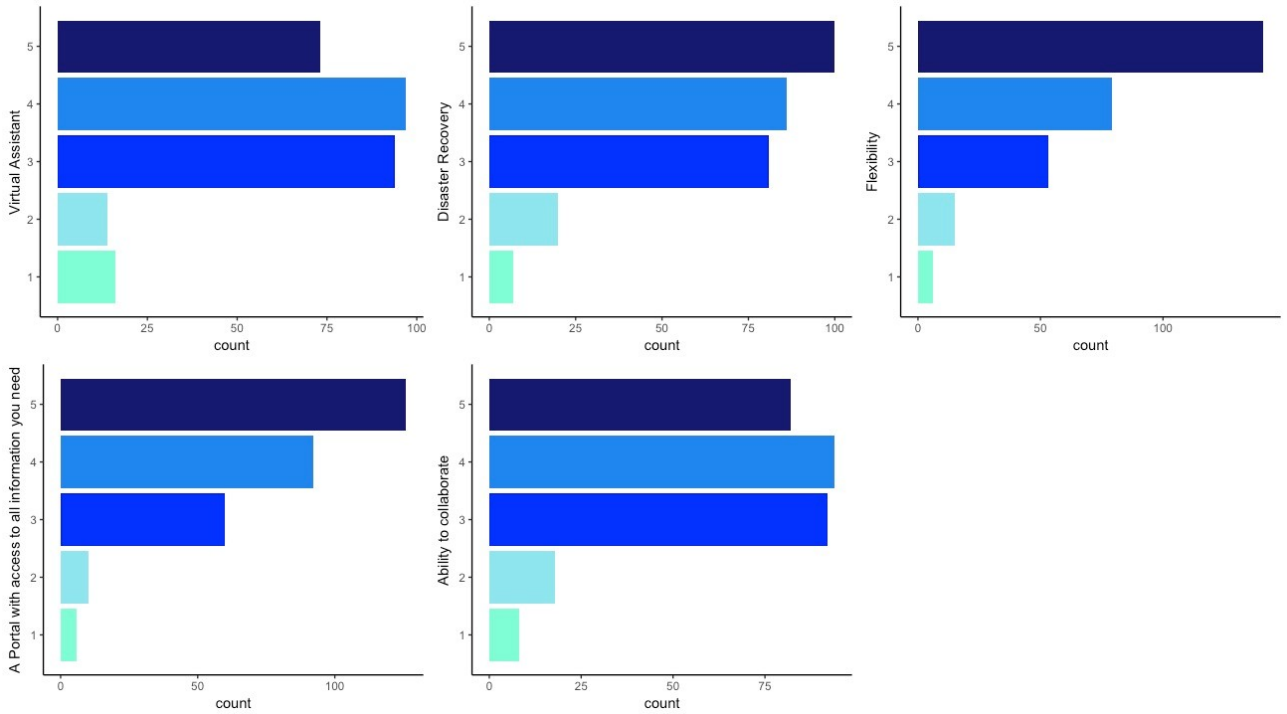

Figure 12: Benefit of cloud computing Bar chart

cloud computing. With Flexibility being the most popular benefit, which we may identify as being an issue with the current system. If people are unable to download the necessary software onto their own personal computers they might struggle to complete their work. Surprisingly an ability to collaborate was not as popular as the other benefits have been suggesting that people are already fairly happy with the way they collaborate on group projects. The lack of negative response however is very promising, as it might suggest that this is something that could really benefit the University and would be appreciated by students.

Overall, from our data have been able to ascertain a more solid direction for our research. We have decided to use MATLAB in our virtual machine for our focus group. We have also determined that using cloud computing would be useful to the University, as opinions of the benefits of cloud computing have been very positive.

3.4 CEMPS Staff: Opinions

In order to provide the University with a comprehensive report and the best recommendation possible, we felt it necessary to also have the opinion of CEMPS staff, most importantly those involved in the teaching of programming. Our first attempt to procure staff opinions was a survey, this was very similar to the student survey.

3.4.1 Survey Responses: CEMPS Staff

Our staff survey was emailed out at the same time as the student one; this survey had very little success compared to its counterpart. The survey was left open for a second week after the student one was closed, but we still only received 17 responses.

There are a total of 285[28] staff in the CEMPS department. If we neglect staff members from non-programming fields, this decreases to 236. Unfortunately this is still not an accurate count of the number of staff involved in the education of programming; not all members of a department will be professors of a programming based module. Nevertheless, we suspect that 17 people is not a good representation, using a sample size calculator with respect to our quantitative data, this number of responses compared to a population of 236 at 90% confidence level gives a 19% margin of er-

[28] University of Exeter, *Academic Staff*. Accessed on: 11th December 2019. URL: `http://emps.exeter.ac.uk/staff/academic/`.

[29] Christopher Martin, *The Quantitative Research Sample Size Calculator*. Accessed on: 11th December 2019. Aug. 2019. URL: `https://blog.flexmr.net/sample-size-calculator`.

ror[29]. Knowing this we have omitted the quantitative data when composing our recommendation. However, we will include some of this data here for your perusal.

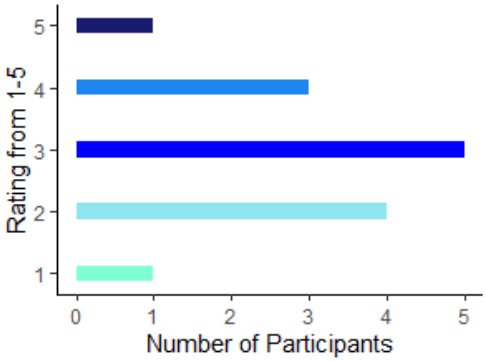

Figure 13: CEMPS staff give their opinion of the current computer lab sessions. From 1 – "Very unsatisfied" to 5 – "Very satisfied"

Figure 13 shows the distribution of responses to the questions "How satisfied are you with the way programming is currently taught in computer lab sessions?". The graph is slightly positively skewed, indicating there are marginally more negative reviews. This demonstrates the need for computer labs to be improved. We will go on to show how this can be done. We have also been able to include the data from the question

> *"How beneficial do you feel each of the following would be to the way you teach?"*

where "the following" refers to the 5 benefits of cloud computing that, though our preliminary research, we found to be the most direct benefits to the University.

- A virtual assistant to analyse and highlight failures.
- Disaster recovery - automatic uploads of your code to a secure location.
- The flexibility to work from anywhere, from any machine.
- A portal where all coding programs and exercise sheets are accessible.
- Shared file space and collaborative working.

Each of these benefits were rated from 1 to 5, where the ratings were as follows:

1. No impact on my teaching
2. Little to no benefits
3. Some benefits
4. Noticeable impact
5. Really helpful, very impactful

This data can be seen in Figure 14 below. Overall all 5 were positively skewed, i.e. in general the staff did not consider cloud computing to be a benefit to their teaching. It is difficult to discern, from this data, if there is a most impactful benefit.

This is all the quantitative data from the survey we can include. The remaining questions were about the participants' previous use of cloud computing resources and how they rate the Universities current use of cloud computing. We were not able to include data from this section of the survey as only 2 of the 17 respondents (12.6%) answered. This was because all other participants had not previously used any form of cloud computing.

The staff survey was successful in part as we were able to obtain some very good qualitative data; 17 responses was enough for the written answers provided to sufficiently describe the phenomenon of interest.

> *For phenomenological studies, Creswell (1998) recommends 5 – 25 and Morse (1994) suggests at least six.*[30]

When asking how the current teaching programme could be improved, we had responses such as: Multiple respondents mentioned the "Elimination of MATLAB". Many students come to the University having never learnt any programming languages before. "People who have not coded before often find learning e.g. MATLAB difficult." It was suggested that students should learn "free, open source languages like Python" first, once you have mastered Python it is much easier to learn a "proprietary language" such as MATLAB. The following 3 points were also made

- "Better machines would help, especially with modern graphic cards."

[30] Statisticssolutions.com, *Qualitative Sample Size*. Accessed on: 11th December 2019. URL: `https://www.statisticssolutions.com/qualitative-sample-size/`.

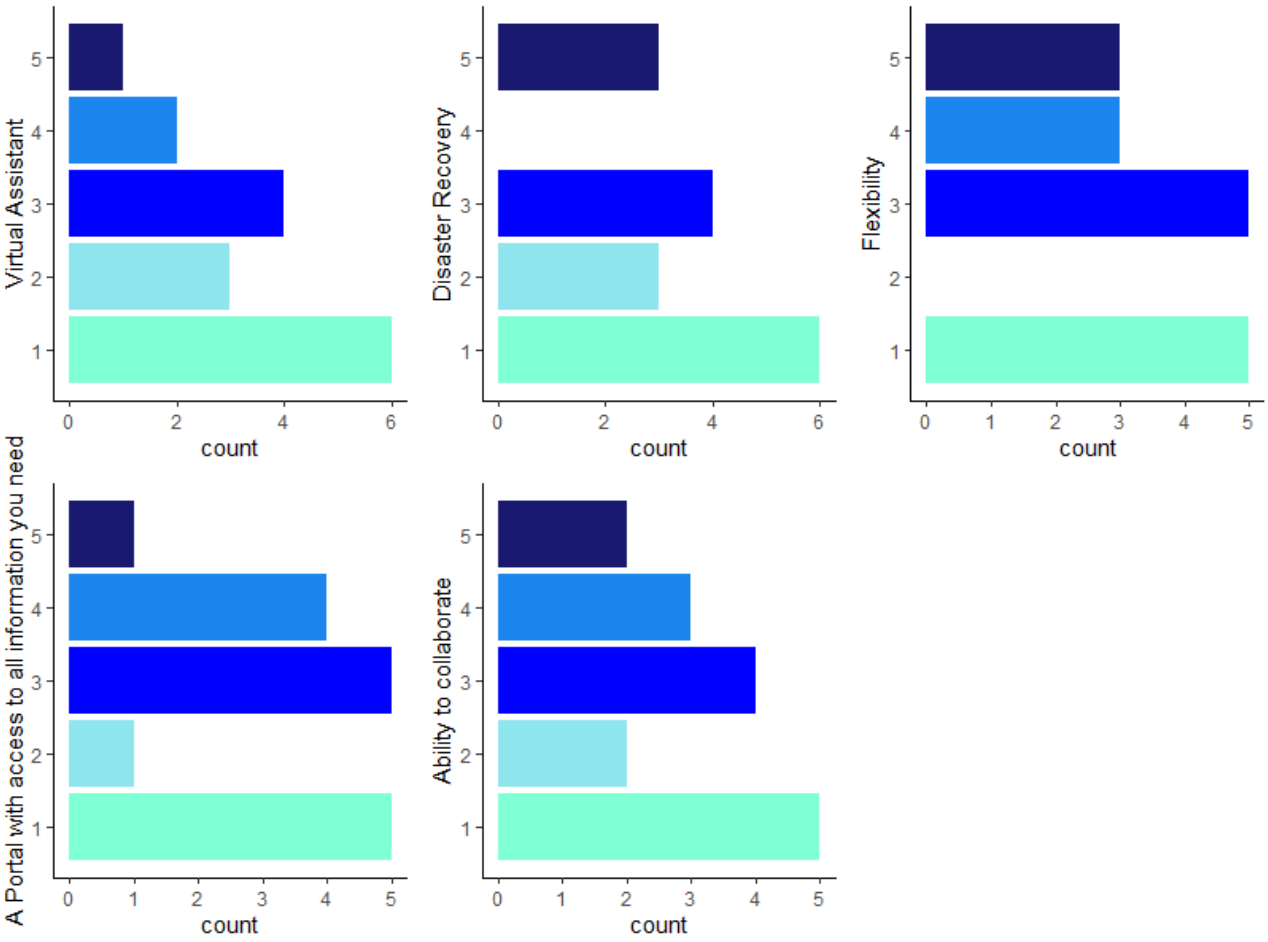

Figure 14: Staff rate the benefits of cloud computing. 1 - No impact on my teaching to 5 - Really helpful, very impactful

- "Make sure all the PCs have up to date Python 3 (e.g, with Anaconda) as a matter of course."
- "The computers are rather slow, surprisingly so because it isn't the hardware. Every summer everything is reinstalled even if it was working. I know this means the software is up to date but it often gets broken in the installation"

These points can all be fixed with the use of virtual machines. By simply logging on to the virtual machine you have immediate access to all the relevant, full updated, software you require. This can be done from anywhere with an internet connection. When asked if "there any other uses of cloud computing that you know of and think would improve your experience?" one response was as follows:

> *"Knowing that the latest versions of software are available, without installation, from University computers and students personal machines"*

This is, again, in support of cloud computing. In response to the same question someone also mentioned that "Benefits in cloud computing mainly come later after students understand the very basics.". While many aspects of cloud computing, such as solving the problems of long running simulations, will not be used until a students later years the majority will be of use from the get go.

3.4.2 Staff Interview

In an attempt to get a wider range of responses from the staff we sent out an email asking for times to meet for an interview. To ensure that we directed our questions at the right people we found all the CEMPS lectures that teach in the computer labs. If they were unavailable for an in-

terview we attached a questionnaire for them to fill out instead.

The questionnaire consisted of an introduction paragraph detailing our 5 benefits of cloud computing, as seen in 3.4.1, and 3 open ended questions.

Unfortunately, in comparison to the survey, we had even less success with this approach. We received one response, in which they apologised that they did not have time for an interview. Fortunately, their attached questionnaire was aptly completed:

What aspects of cloud computing do you think would be most beneficial to your teaching? And your students' learning?

> *"Most of the above benefits are also available without cloud computing, though they may require a bit more discipline or good practice from the user. Tools (such as CODY) to help students learn and provide immediate feedback may be the most useful."*

Do you feel improvements need to be made to the tuition of programming in CEMPS? Please let us know the best and worst aspects.

> *"All of the above mentioned benefits are nice, but none of them addresses the real challenge of teaching programming, which is to get students over the initial conceptual hurdles. Also I think students are often put off when code does not work first time and they do not feel confident about debugging."*

Have you heard of cloud computing? If so, have you used it within your teaching? Please expand on what platform(s) you have experience with, your opinion off the platform and whether it would be beneficial at the University.

> *"I have used an online version of Octave for lab classes when we had problems running MATLAB locally. It was adequate as an emergency measure, but not as good as running MATLAB locally."*

It can be seen that CEMPS staff do not believe that cloud computing will be an advantage to their teaching. They have stated that the problems with the current programming education is more to do with the programming languages taught and the lack of experience students enter with, then with the computing resources. Although cloud computing may not have a direct effect on staff members, I predict that if the students benefit from these resources then their understanding will develop at a faster rate, which will effect tuition.

3.5 Azure Lab Services

As previously described, Azure Lab Services is a virtual machine manager which can be utilised for teaching, testing and individual or collaborative group work. Consequently, the service can be a useful tool for university lecturers aiming to teach students about coding, as it can be set up with downloaded applications such as Python. When given access to a virtual machine, students are able to do whatever they want without worry of breaking the physical computer. The virtual machine can also be reset by an admin as well as deleted completely.

The service also has benefits when performing long running simulations, as you are able to exit the virtual machine whilst having it running. In relation to our project brief, students who commonly have to test code would have to stay on the same computer throughout the day due to how long it takes to run. Therefore, as the University resources are limited, many of the physical computers are being used. Virtual machines provide a good solution to this because a user can begin their simulation, exit the virtual machine and then re-enter when their simulation is complete. This means that the student does not need to be on the computer during its performance, allowing someone else to utilise it.

Azure functions by having the user on their physical computer communicate with the online service, which will then interact and receive data from Microsoft's storage manager, as represented by Figure 15.

A benefit of Microsoft holding the storage over the University is that it is much more cost effective. One reason for this is that the University is not required to own space for their own servers.

Following our methodology, we have successfully used the application provided by the Univer-

Figure 15: The stages of accessing Azure Lab Services

sity's IT staff to set up our own virtual machines, where we then asked several students to trial run the service as part of the focus group section.

3.5.1 Focus Group: A Definition

A focus group allows opinions and feedback to be given by potential users of a product[31]. In this instance, we want to obtain student perspectives on the implementation of virtual machines into the University of Exeter. This type of research is common in commercial markets as it provides a useful insight into a particular product before it is released. Thus, allowing any important changes to be made where it can then be re-trailed or officially launched. Ideally, we wanted 6 to 10 people present in our focus group; we had 3 participants who were not part of this project, with 8 of us who were.

3.5.2 Our Focus Group

Prior to our focus group we had prepared 2 short mock problem sheets. Once the participants had logged onto the virtual machine, coded using MATLAB and logged back off we asked them a few questions of their experience.

We first wanted to know if the participants felt confident with the definition of cloud computing and the response we received was that they "had a better understanding, but not enough". We went over the main concepts again by explaining what they had just done in the task of the focus group. We had remotely accessed the hardware over a network connection (the internet). During the set up of the virtual machine, we selected servers in southwest England.

We explained how it could be beneficial for this to be implemented in the University. In summary, we described how current students (particularly third years and masters students) who often perform long running simulations set up their computer in the University and leave it running throughout the day with a note, hoping another student does not turn the computer off. Using a virtual machine prevents the risk of losing work or someone logging you off and it can be accessed at home (or anywhere) to check its progress.

The participants understood our topic and we wanted to ask them if they had used any cloud computing software - they were not aware the programmes they had used were encompassed in cloud computing so we prompted them with a few they may have used. This included Google Drive, One Drive and iCloud. All of them had used at least one of these programmes and we informed them that these programmes allowed them to have automatic backup, autosave and remote access. The University system of Recap Recordings is also an example of cloud computing software as it can be accessed anywhere and anytime. All of the participants had used this, saying that they were

> *"interested to see what other cloud computing programmes we could be introduced to."*

We told them about our experience with Microsoft Teams that we had been asked to trial during our project. This software allows all your files, messages and feedback in one place. Our participants said

> *"if there were notifications similar to messenger it would be a very good platform to use as it keeps your work separate from your social media."*

The participants informed us that they often struggled with communication during group work as they spilt up the work into sections and only

[31] experienceux.co.uk, *What are focus groups?* Accessed on: 11th December 2019. URL: `https://www.experienceux.co.uk/faqs/what-are-focus-groups/`.

came together at the end. Therefore, if something had gone wrong there was very little time to fix it. With Microsoft Teams you can see who is online, and what changes they are making in real time so communication is strong throughout the project. They believed this to be very beneficial.

This was the first time most of the participants had used virtual machines, we found out that they were willing to continue using them, especially as it meant they would not have to download programmes onto their own devices. When asked if they would prefer to use virtual machines in the future or not one participant said

> *"Virtual machines because all of the programmes actually work on them, half the computers in Harrison don't actually have MATLAB on them, so it's not great for trying to do coursework."*

The participants mentioned some of the computers at University did not have MATLAB on them so it was not easy trying to complete coursework there and the lab lectures for trying out problem sheets which have MATLAB downloaded were too short to understand the work so it made understanding the coursework very difficult. Furthermore, one student believed that the lab sessions were too short.

> *"I think the labs are never long enough to really do anything in"*

All the participants agreed that labs would be more beneficial if they were longer, and if coding knowledge was already present.

We moved onto discussing the idea of having a virtual assistant on the virtual machines. At a basic level, it would run code for a coursework question to check the code was producing the result expected, being efficient or telling the user straight away where the error in the code was. They seemed interested in this so it is definitely something we can consider putting more research into.

From the staff survey feedback, lots of lecturers did not like MATLAB, our focus group participants had never worked on alternatives to MATLAB, thus the University could consider using a new programming software that is more highly rated amongst users. This could solve problems with not having the relevant programmes downloaded on University computers. In addition, we can hypothesise from our own experiences that MATLAB does not have as much online help compared to other programming software such as python. Therefore assisting students who often struggle with coding as they can find help online to solve issues themselves.

Overall, the focus group was a very useful way of getting the users feedback. They understood the core definition of cloud computing and were eager to try out the software it offered. They thought the virtual assistant would be especially useful so we can look into costs for this and virtual machines for the University.

3.5.3 Limitations of Azure

From the experience we had with creating our own labs combined with the findings from the focus group, we identified some notable limitations of Azure Lab Services.

During the focus group, we discussed how the virtual machine was like when using it, where one participant replied:

> *"I did see some slowdown compared to when I normally use a computer"*

It is common for virtual machines to feel latency, which is the delay before a transfer of data begins[32], due to the distance in which the data must travel. However, as referenced from our survey results, some staff also feel like the physical computers within the University can often be slow. Therefore, although there may be a noticeable difference in speed, the impact may be reduced if the current computers are deemed non-optimal.

After the focus group was complete, most of the virtual machines that were activated were not turned off. It was clear that all of us, although informed, had forgotten to stop running the virtual machine to prevent additional costs to the University. Thus from our experience, we believe that it is extremely easy to keep the virtual machine running by mistake. Fortunately, there was a 2 hour limit set on each machine which prevented wasted resources.

In addition to setting the quota, students can see how much time remaining they have left on

[32] Oxford Lexico, *Definition of Latency.* Accessed on: 11th December 2019. URL: `https://www.lexico.com/en/definition/latency`.

their virtual machine, which could be counterproductive in the case of stress related issues where students feel pressured by the limited time they have left. However, it could also be seen as motivation to get as much work done as possible in the time allocated. It is likely that more student feedback would be required to provide a strong answer in this area.

Price is also an important factor when a University or firm is deciding on new software, as this service is not free. During the cost analysis section, we have discussed the potential cost of Azure Lab Services onto the University. If the overall cost for it is deemed too high, then the University is consequently limited in obtaining its benefits.

3.6 Microsoft Teams

Microsoft Teams is a paid software aimed at collaborative work environments by improving communication methods. The service provides instant messaging, live call hosting, file sharing and event management/creation all in one application. This can be accessed via a web browser, on a downloaded computer app or on a mobile phone app. Users can also interact with other Microsoft Services[33], such as OneNote, OneDrive and Office 365.

Within the University of Exeter, some staff are familiar with Microsoft Teams, such as the University's IT team, who use it to manage meetings and discuss current events. James Bingham, who provided us with these cloud resources is one user, and has allowed us to trial it ourselves. We used this opportunity to finish the rest of our project with this form of cloud computing.

The diagram shown in Figure 16 demonstrates the connectivity path and highlights the tools available to users, from file sharing to messaging. Figure 16 indicates that messaging can be done in one-on-one chats or in groups and channels. Admins can also be assigned so that lecturers or module leaders can monitor and assess the work being done by students. This is particularly useful if course related issues arise as a students can have a quick response, as an alternative to emails.

Figure 16 also addresses the use of O365 Information Protection Tools, which is built in cloud security, preventing data loss and unauthorised access to emails. This relates to a key benefit stated in the overview section (safety and security), providing an example of how using cloud computing can be a safer than alternative computing. Furthermore, an online article[34] breaks down the security of Microsoft Teams further, providing a quote from Microsoft:

> *"Teams is built on the Office 365 hyper-scale, enterprise-grade cloud, delivering the advanced security and compliance capabilities our customers expect."*

This assures the security of information stored by Microsoft's clients. Similarly, the University of Exeter issued a statement[35], announcing that "it is not possible to set out an exhaustive list of all the ways in which your personal data may be processed by the University". However, they do inform us that the University "takes it duties and responsibilities under the legislation extremely seriously and will only keep your data for as long as necessary". Therefore, although we know that both Microsoft and the University of Exeter take data security seriously, we are only able to theorise that Microsoft use more reliable resources to protect information due to university policies.

Within mathematics, Microsoft Teams is a potentially useful tool that can enable convenient collaboration when drafting solutions or managing large projects with multiple file transfers. If this enables students to become more productive, then learning for students can be improved as they will be provided assistance with their work more frequently.

3.6.1 Our Experience

All eight students in this project were able to successfully trial run this software, and by using Mi-

[33] Microsoft, *Top Features of Microsoft Teams.* Accessed on: 11th December 2019. URL: https://techcommunity.microsoft.com/t5/Microsoft-Teams-Blog/Top-Features-of-Microsoft-Teams-amp-Information-Protection-in/ba-p/63046.

[34] Ruth Christensen, *Microsoft Teams - How Secure is it Really?* Accessed on: 11th December 2019. May 2019. URL: https://www.brainstorminc.com/blog/microsoft-teams-how-secure-is-it-really/.

[35] The University of Exeter, *Information for current students.* Accessed on: 11th December 2019. URL: https://www.exeter.ac.uk/privacy/students/#BE4RZ4A0bRGpe7Wl.99.

[36] Microsoft, *Microsoft Teams University Students.* Accessed on: 11th December 2019. URL: https://education.microsoft.com/courses-and-resources/resources/microsoft-teams-university-students.

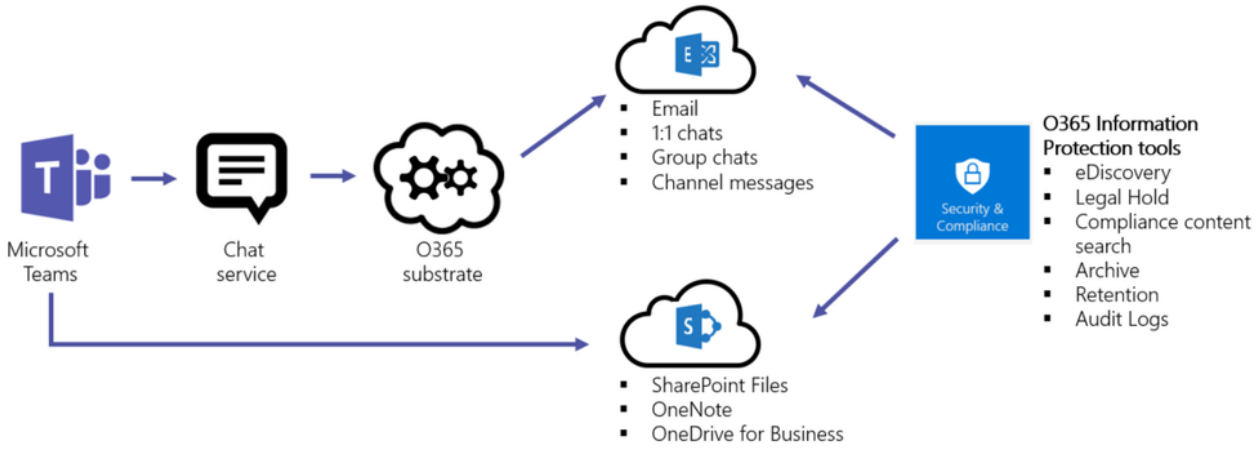

Figure 16: A Breakdown of the Teams Service

crosoft's official sources[36], we were able to utilise it for the remaining time given to us. Previously, we had been using Facebook's Messenger service for communication, Google Drive for file sharing and a Facebook page for event management. We unanimously agreed that Microsoft Teams was the preferred service with a response from one user commenting:

> *"Collaborating with Microsoft Teams is so much easier as it's like having multiple applications combined into one."*

Another response stating:

> *"After getting used to it, I found that having all group work in one place kept everything organised."*

Due to the size of our group, quantitative data for our experience of Microsoft Teams would have been impractical. Instead, we have noted some components of the software that were particularly useful. Firstly, being able to create message channels to communicate with specific people or groups kept discussions organised and prevented an overload of messages into a single channel. Secondly, file sharing was easy and particularly practical as it extended the benefits of Google Drive alongside the messaging tool. Lastly, the event manager was a simple but effective tool that overshadowed our use of the Facebook page originally used to schedule events.

It is evident for us students that the compilation of different data transfer methods is superior to using individual alternative methods. Organisation is also a key factor when studying mathematics because there is commonly large amounts of data being worked with. Hence, it is easy to become overwhelmed by analysing large amounts of unstructured data. Keeping all files within labelled folders that are only accessible to an assigned group, creates a manageable structure that helps prevent human errors.

3.6.2 Uses Outside of Exeter

A case study from the University of Plymouth[37] details some judgements on the service from a supervisor working with a group of final year students. The report goes into some impactful benefits of the system:

- Message archive that "allows easy access to previous comments that were made".
- "The opportunity to collaborate on documents directly".
- Having a "central file pool for all files".

Also provided were student testimonials, all of which praised the service, suggesting a clear demand for future use. There were also some downsides to the system, most directly was the notifi-

[37] University of Plymouth, *Case study: Using Microsoft Teams for final year dissertation supervision*. Accessed on: 11th December 2019. URL: `https://www.plymouth.ac.uk/about-us/teaching-and-learning/digital-education/case-study-using-microsoft-teams-for-final-year-dissertation-supervision`.

cations that would not appear when the app was closed. However, the author responds with acknowledgment of a resolution. The author also seems to indicate that there was learning involved and a small amount of time before getting familiar to Teams.

> *"Another example of the need to get used to the way Teams works is to remember to 'reply' to a student post as opposed to start a new conversation."*

This suggests some training may have to be provided if this service was to be offered on a large scale into the University.

In December 2019, the University of Edinburgh advised the use of Microsoft Teams for both students and staff, providing resources on how begin utilising it[38]. The notice also informs students that an alternative service, Skype, will be closing down during 2021.

> *"If you use Skype for Business Online to chat with colleagues or schedule online meetings, you should know that Microsoft announced its retirement, scheduled for 31st July 2021."*

Additionally, the University suggests that Microsoft Teams is a more effective alternative to Skype, encouraging staff and students to begin using it now.

> *"Information Services Group will be planning for this transition much sooner but we encourage you to start using Teams now, it extends the features of Skype for Business you will already be familiar with for much better collaborations."*

Similarly, the University of Reading have begun the use of Microsoft Teams for Staff[39], where they have provided an explanation and resources for their staff about launching the service.

3.7 Cost Analysis

3.7.1 Methodology

The University of Exeter has 3377[12] student enrolled in the College of Engineering, Mathematics and Physical Sciences, totaled over the Exeter and Cornwall campuses.

A cost effectiveness analysis could consider student satisfaction as a benefit when calculating an implementation's effectiveness relative to resource use. The true benefit of this could be intangible monetarily. Implementing cloud computing resources as a substitute to physical onsite hardware may lead to savings on capital investment at the University. IT services could lower the requirements of the onsite computer services by transitioning activities with higher requirements to a cloud computing service.

Using the pricing data from Microsoft's online resources[6] we have looked into the potential costs that could be placed onto the University when using Azure Lab Services. The source provides a simple calculation for cost of running a virtual lab- this is shown in Figure 17.

We could consider a class of 40 students participating in 10 hours of labs per week using the small lab size of 20 lab units would cost £256 per week. However, class sizes can vary from 20 to 350[40]. Therefore, the estimated value for virtual machine implementation into classrooms can range from £128-£2,240. It is important to address that because of the University's collaboration with Microsoft, the price for this could be smaller, but this is unlikely.

Another scenario would be giving higher year (second, third and masters CEMPS) students access to cloud services. These students are required to run long simulations as part of their degree. This would give these students flexible access to computing resources. A class of 200 students could be allocated 10 hours per month to a large virtual machine with a quota of 84 lab units per hour. At a rate of £0.008 per lab unit per

[6] Microsoft Azure, *Azure Lab Services Pricing.* Accessed on: 11th December 2019. URL: https://azure.microsoft.com/en-gb/pricing/details/lab-services/.

[12] University of Exeter, *Facts and figures.* Accessed on: 11th December 2019. URL: https://www.exeter.ac.uk/about/facts/facts/#a3.

[38] The University of Edinburgh, *Teams.* Accessed on: 11th December 2019. Dec. 2019. URL: https://www.ed.ac.uk/information-services/computing/comms-and-collab/office365/teams.

[39] The University of Reading, *Microsoft Teams.* Accessed on: 11th December 2019. URL: https://www.reading.ac.uk/internal/its/windows10/ms-teams.aspx.

[40] University of Exeter, *Module Information.* Accessed on: 11th December 2019. URL: https://business-school.exeter.ac.uk/study/international/modules/.

hour this would come to £1344 per month maximum spend. This would be a maximum spend as students would not be required to use all of their allocation.

An important feature of Azure Lab Services is the ability to limit the hours used on each virtual machine. Therefore, students can not cause undesired expenses for the University by overusing the service or accidentally leaving it running. In addition, the University is only charged for the actual hours of use and not the time in which the virtual lab was available to use.

Virtual machines in Azure Labs have a scaling cost per hour based on the computational power selected from their options. The values we have considered for our example £0.16 per hour for a small capacity machine and £0.672 per hour for a large capacity machine.

The cost of implementing Microsoft Teams at the University would have no additional acquisition cost as confirmed by the IT Business Liaison. From communication with James Bingham:

> *"The cost of Teams is a part of the University licence that we pay for"*
>
> *"There is also another cost around user adoption and training."*

3.7.2 Cost Analysis - Background

An effective cost analysis will allow decision makers to compare "effectiveness relative to resource use"[14] of possible cloud computing interventions.

Henry M. Levin has a research driven approach with over 30 years of experience. His literature suggests that "educational research does not provide an unambiguous estimate of effects" or "differences in effect sizes that are so small that they lack practical significance". Meaning that it is important to look for opportunities to show a significant statistical improvement or reduction in cost.

Garber and Phelps (1997)[41] explored principles underlying the CE analysis technique and discussed the implications for the evaluation of the medical field.

Garber and Phelps suggest that for their purposes an appropriate way to think about CE analysis being that it "describes intervention in terms of the ratio of the incremental costs per unit of incremental health effect (I.e marginal cost/ marginal health effect)".

This source goes into detail about consideration of factors to be included in a CE analysis of a medical program. This source is useful in our application as the logic and approach to the problem Is consistent for CE analysis in different fields. This source considers whether long term effects should be included, this is an appropriate question to pose for education as well. This source showed examples of cost-effectiveness analysis applied to the medical field. It has complex methodology to look for optimal ratios in regard to lifetime medical expenditure.

3.7.3 Other Considerations for Cost Analysis

Cost of refreshing capital resources to keep up with demands for students could be compared with alternative cloud computing implementations.

Marginal cost of providing computer access to one more unit of students for the University may be less for cloud computing infrastructure than capital on site computer investment, or simply not possible for space restrictions[42].

Overall our consideration would be limited to the short-term cost of a cloud computing implementation and the immediate effect the variable of cloud computing intervention has on student satisfaction or student performance in a cohort study.

3.8 Limitations

In this section we have identified the limitations of our findings and sources, to assess if they are reliable and accurate.

Figure 17: Cost calculation for Azure Labs

[14] Henry M. Levin, "Waiting for Godot: Cost-Effectiveness Analysis in Education". In: (2001).

[41] Alan M. Garber and Charles E. Phelps, "Economic foundations of cost-effectiveness analysis". In: *Journal of Health Economics* 16 (1997), pp. 1–31.

[42] M. Woodhall, *Economics of Education*. Ed. by GEORGE PSACHAROPOULOS. Pergamon, 1987, pp. 393–399.

The article featured in the overview section was informal, however the author is a business, marketing and technology writer. Within the article there was a data taken from Harvard Business Review Analytic Services with a link to their report, but the link was invalid.

The survey results aimed at the University staff had few replies, thus suggesting weak evidence to reflect the rest of the staff's views. Moreover, the survey results aimed at students had many replies, but contained many answers that were deemed inappropriate at had to be deleted. There was also a time constraint involved, where we had little time to perfect the survey and prevent inappropriate answers. For example, we could have implemented a feature where students had to answer each question, as we often found blank responses.

A large number of the sources used as part of our findings for Microsoft Teams and Azure Lab Services were from Microsoft, suggesting high reliability and accuracy. This is because Microsoft's business is dependant on the accuracy of the services they provide, so inaccuracies would be heavily scrutinised.

As our focus group was such a small number, it may not be reflective of the whole population of students. In addition, one of the participants does not code and rarely has group coursework set, so their views may not reflect the average mathematics student.

4 Conclusions

Overall, cloud computing as a concept has many benefits, most importantly allowing students to access software, that for some would only be available on university computers. The current system at the University of Exeter has many issues, such as difficulty in running long-running simulations and a lack of computer systems to use. In our report we have aimed to identify the ways in which cloud computing could be beneficial and solve these issues that have been presented. Furthermore, we have not only tried to identify whether this would help the current system, but also whether this would be affordable to the University, and therefore could be a justifiable solution to this ongoing issue.

4.1 Aims and Objectives

Improve student accessibility to computing resources

We were unable to directly affect the accessibility of the computing resources, however, we have provided an alternative solution that could solve the problems that we have presented. We have also been in communication with James Bingham, who is a member of the IT staff at the University of Exeter, and he has helped us to realise the capabilities of the University, as well as introducing us to Microsoft Teams. Therefore, we can only estimate that our research could help improve student accessibility in the future.

Research how cloud computing can improve student learning

From our research we were able to identify various benefits of cloud computing, including: a Virtual Assistant that can troubleshoot errors, disaster recovery in a scenario where data might be lost, more flexibility that allows the user to access their data from anywhere on internet numerous devices, a self-contained portal to access any information you might require, and finally an ability to improve communication and collaboration, so students are able to work more effectively within group projects.

Research how Continuous Integration can improve student learning

We achieved this aim, identifying that Continuous Integration can allow students to check the effectiveness of their code and how it could be improved. Therefore, students will save time by not being required to error check their own work allowing, them to focus on their learning.

Increase student employability with relevant cloud computing skills

Throughout our education we have been made aware of the impact that computing skills can have on increasing employability. We have also researched the ways in which cloud computing can improve the teaching and understanding of coding, therefore this could help to improve students' skills within programming. Although we were unable to directly impact student employability with our research, we have been able to show that the use of the Cloud will allow students to keep up to date with employer's increasing use of computer technology, therefore increasing employability.

More specifically, our objectives were:

To determine if, in general, the current

system is a) well known, b) working as well as it can be and c) can it be improved.

Through our survey we found that many people had not heard of cloud computing and that it was accessible via the University. Other students who had heard of it were mainly familiar with Google Cloud, and they also did not realise that the University gave out 1 terabyte of storage for every university student. We also took a poll on the opinions of the current computer labs, and we identified that while many students were satisfied with the system, we felt there were many who were struggling, so we could not reasonably say that the system did not need improving.

To ascertain the difference in opinion (and need) of staff and students of different year groups.

We sent out two surveys, one for students and one for staff, we did this so as to identify if there were many major issues that staff might acknowledge that students may not. We were keen to see if there was any major conflict in the opinions of staff and student, we hoped that keeping our survey anonymous would help to bring more honest opinions. Overall, we found that both staff and students identified issues with the current system, with some staff voicing strong opinions against the use of MATLAB. We also asked students to select their stage of education so that we were also able to see if different stages struggled or succeeded in different areas. We found that more students struggled in earlier years, which suggests that teaching at the lower levels in not sufficient in supporting students. As most of our data came from stage 1 students, and the size of classes decrease across the years, this might suggest that students who struggle in coding, later avoid taking programming heavy modules.

To set up virtual machines, trial capabilities with ourselves and others.

We were able to set up a virtual machine and recruit participants for a focus group, in which we gave them access to the virtual machine and asked them to complete a short problem sheet that we had created. As a team we also partook in the focus group testing, with varying levels of understanding of coding. We felt this was a partially successful trial increased our understanding of the Cloud, and the opportunities that it offers.

To provide actionable data for interested parties and their consideration of future implementation. Alongside our research on the impacts of cloud computing, we were able to provide a cost analysis and offered recommendations as to what we feel should be implemented. Communication with James Bingham suggests that our investigation provides some actionable data, as he values our own experience on the resources we trialled. In addition, our survey responses offer some insight into the views that the current CEMPS students and staff within the University hold on learning.

4.2 Our Recommendation

4.2.1 GitLab

We do not believe GitLab should be adopted by the University for the mathematics course. The primary reasons for this recommendation are that it would need to be introduced in stage 1, potentially taking up valuable time in early computer labs setting the system up, additionally the nature of the scalability of Gitlab would require the students to individually provide the token of their project and their username which is a GDPR protected item. This makes the handling of such data a liability. Additionally as the system seems unstable for a group size of 4, it would likely be incredibly unstable for a group the size of a first year computer lab (30+). However, we would recommend GitLab be introduced to the computer science curriculum. Our reasons for this are because Git itself is a regularly used tool in industry and the projects undertaken by computer science students are frequently of a level of complexity where continuous integration would provide valuable insight and be invaluable for the development of such projects. Additionally as all computer science students will be programming such projects throughout their time at university introducing it early would be beneficial.

4.2.2 Azure Lab Services

We believe that Azure Lab Services would be best implemented in concentrated settings, such as small groups of students in stage 4. We believe this particularly because of the cost that increases as more students are introduced to the system. Our focus group informed us that Azure's benefits will not reach every student, such as those studying modules with limited or no coding. With our

own experience we can estimate that training will be necessary in order for members of staff to be able to set up computer labs. Therefore, only requiring a small number of staff to use this system will reduce training costs.

4.2.3 Microsoft Teams

We would recommend Microsoft Teams and its implementation for all students involved in collaborative projects. In comparison to its alternatives (Skype business, discord, facebook messenger, google drive), Teams offers various more tools in a single, self-contained app. Once we had gained access to this service, it remained as the sole method of communication. Moreover, the cost of Teams is part of the Microsoft licence already paid by the University. Therefore, there would be no additional cost in software acquisition. Although there may be pressure on the IT department who would have to take responsibility for troubleshooting student issues, we believe that with students desires to access better collaborate methods this is an opportunity to solve particular limitations. Finally, with other universities beginning the implementation of Teams, it could be useful for the University of Exeter to follow, as more students will carry on their experiences onto future career paths.

4.3 Further Research

Before implementing our recommendation, we would suggest researching further into the following topics:

- Trialling virtual labs in Azure Labs with larger numbers for a more realistic classroom environment. This would help identify more views on cloud services and their current learning methods.
- Survey more participants for a larger pool of data. There may be other tools available for this which could be more effective. In addition, it may be useful to perform statistical analyses on larger groups of data, such as hypothesis tests, in order to prove a particular change in student learning.
- Exploring other cloud computing services may be useful to the University. However, as Exeter is partnered with Microsoft, it is unlikely that this will be necessary.
- Increase the number of students using Microsoft Teams and report their activity. The IT team can view who uses it with the activity report function offered[43]. With this information, the University can understand which students this service impacts by their total usage.

[43] Microsoft, *Microsoft Teams user activity report*. Accessed on: 11th December 2019. 2019. URL: `https://docs.microsoft.com/en-us/microsoftteams/teams-analytics-and-reports/user-activity-report`.

References

[1] Microsoft Azure. *What is cloud computing?* Accessed on: 11th December 2019. URL: https://azure.microsoft.com/en-gb/overview/what-is-cloud-computing/.

[2] Microsoft. *What is a Virtual Machine*. Accessed on: 11th December 2019. URL: https://azure.microsoft.com/en-gb/overview/what-is-a-virtual-machine/.

[3] GitLab. *What is GitLab*. Accessed on: 11th December 2019. URL: https://about.gitlab.com/what-is-gitlab/.

[4] Atliassian. *What is DevOps*. Accessed on: 11th December 2019. URL: https://www.atlassian.com/devops.

[5] Atliassian. *What is Continuous Integration?* Accessed on: 11th December 2019. URL: https://www.atlassian.com/continuous-delivery/continuous-integration.

[6] Microsoft Azure. *Azure Lab Services Pricing*. Accessed on: 11th December 2019. URL: https://azure.microsoft.com/en-gb/pricing/details/lab-services/.

[7] BBC Sean Coughlan. *Students face tuition fees rising to £9,000*. Accessed on: 11th December 2019. 2010. URL: https://www.bbc.co.uk/news/education-11677862.

[8] Victor Chang and Gary Wills. *A University of Greenwich Case Study of Cloud Computing – Education as a Service*. E-Logistics and E-Supply Chain Management: Applications for Evolving Business. IGI Global., 2013.

[9] topuniversities.com. Accessed on: 11th December 2019. 2012. URL: https://www.topuniversities.com/universities/universiti-sains-malaysia-usm.

[10] Nayan B. Ruparelia. "Cloud computing". In: (2016).

[11] Al-Rousan Thamer and Abu Al Ese Hasan. "Impact of Cloud Computing on Educational Institutions: A Case Study". In: (2015).

[12] University of Exeter. *Facts and figures*. Accessed on: 11th December 2019. URL: https://www.exeter.ac.uk/about/facts/facts/#a3.

[13] Microsoft Azure. *Tutorial: Set up a classroom lab*. Accessed on: 11th December 2019. Oct. 2019. URL: https://docs.microsoft.com/en-us/azure/lab-services/classroom-labs/tutorial-setup-classroom-lab.

[14] Henry M. Levin. "Waiting for Godot: Cost-Effectiveness Analysis in Education". In: (2001).

[15] NHS. *Health news glossary*. Accessed on: 11th December 2019. URL: https://www.nhs.uk/news/health-news-glossary/.

[16] Maciej Duszyński. *Teamwork Skills: Definition, Examples, Best for Your Resume*. Accessed on: 11th December 2019. URL: https://zety.com/blog/teamwork-skills.

[17] J-T-Ripton. *8 Ways Cloud Computing can Increase Productivity and Profits*. Accessed on: 11th December 2019. URL: https://www.business.com/articles/8-ways-cloud-computing-can-increase-productivity/.

[18] sas.com. *Big Data*. Accessed on: 11th December 2019. URL: https://www.sas.com/en_gb/insights/big-data/what-is-big-data.html.

[19] ZDNet. *What is GDPR?* Accessed on: 11th December 2019. URL: https://www.zdnet.com/article/gdpr-an-executive-guide-to-what-you-need-to-know/.

[20] Prof. John Thuburn (Coordinator). *MTH1003: Mathematical Modelling Specification*. Accessed on: 9th December 2019. 2019. URL: http://udb2.emps.ex.ac.uk/api/index.php/databases/teaching/modules/modulecode/MTH1003/pdffile?year=2019.

[21] Prof. Peter Challenor (Coordinator). *MTH1004: Probability, Statistics and Data Specification*. Accessed on: 9th December 2019. 2019. URL: http://udb2.emps.ex.ac.uk/api/index.php/databases/teaching/modules/modulecode/MTH1004/pdffile?year=2019.

[22] Dr Barrie Cooper. *Health news glossary*. Accessed on: 11th December 2019. URL: http://udb2.emps.ex.ac.uk/api/index.php/databases/teaching/modules/modulecode/MTHM008/pdffile?year=2019.

[23] University of Exeter. *Facts and figures: Detailed information about our student population since 2014/2015*. Accessed on: 11th December 2019. 2019. URL: https://www.exeter.ac.uk/about/facts/facts/#a3.

[24] William Christopher Long. *What is the number of observations needed to detect change of trends from time series data?* Accessed on: 11th December 2019. 2016. URL: https://www.researchgate.net/post/What_is_the_number_of_observations_needed_to_detect_change_of_trends_from_time_series_data.

[25] Yan Holtz. *The issue with pie charts*. Accessed on: 11th December 2019. 2018. URL: https://www.data-to-viz.com/caveat/pie.html.

[26] Achilleas Kostoulas. *On Likert scales, ordinal data and mean values*. Accessed on: 11th December 2019. 2013. URL: https://achilleaskostoulas.com/2013/02/13/on-likert-scales-ordinal-data-and-mean-values/.

[27] Alex Bellos. *Why odd numbers are dodgy, evens are good, and 7 is everyone's favourite*. Accessed on: 11th December 2019. 2014. URL: https://www.theguardian.com/science/2014/apr/13/favourite-number-survey-psychology.

[28] University of Exeter. *Academic Staff*. Accessed on: 11th December 2019. URL: http://emps.exeter.ac.uk/staff/academic/.

[29] Christopher Martin. *The Quantitative Research Sample Size Calculator*. Accessed on: 11th December 2019. Aug. 2019. URL: https://blog.flexmr.net/sample-size-calculator.

[30] Statisticssolutions.com. *Qualitative Sample Size*. Accessed on: 11th December 2019. URL: https://www.statisticssolutions.com/qualitative-sample-size/.

[31] experienceux.co.uk. *What are focus groups?* Accessed on: 11th December 2019. URL: https://www.experienceux.co.uk/faqs/what-are-focus-groups/.

[32] Oxford Lexico. *Definition of Latency*. Accessed on: 11th December 2019. URL: https://www.lexico.com/en/definition/latency.

[33] Microsoft. *Top Features of Microsoft Teams*. Accessed on: 11th December 2019. URL: https://techcommunity.microsoft.com/t5/Microsoft-Teams-Blog/Top-Features-of-Microsoft-Teams-amp-Information-Protection-in/ba-p/63046.

[34] Ruth Christensen. *Microsoft Teams - How Secure is it Really?* Accessed on: 11th December 2019. May 2019. URL: https://www.brainstorminc.com/blog/microsoft-teams-how-secure-is-it-really/.

[35] The University of Exeter. *Information for current students*. Accessed on: 11th December 2019. URL: https://www.exeter.ac.uk/privacy/students/#BE4RZ4A0bRGpe7Wl.99.

[36] Microsoft. *Microsoft Teams University Students*. Accessed on: 11th December 2019. URL: https://education.microsoft.com/courses-and-resources/resources/microsoft-teams-university-students.

[37] University of Plymouth. *Case study: Using Microsoft Teams for final year dissertation supervision*. Accessed on: 11th December 2019. URL: https://www.plymouth.ac.uk/about-us/teaching-and-learning/digital-education/case-study-using-microsoft-teams-for-final-year-dissertation-supervision.

[38] The University of Edinburgh. *Teams*. Accessed on: 11th December 2019. Dec. 2019. URL: https://www.ed.ac.uk/information-services/computing/comms-and-collab/office365/teams.

[39] The University of Reading. *Microsoft Teams*. Accessed on: 11th December 2019. URL: https://www.reading.ac.uk/internal/its/windows10/ms-teams.aspx.

[40] University of Exeter. *Module Information*. Accessed on: 11th December 2019. URL: https://business-school.exeter.ac.uk/study/international/modules/.

[41] Alan M. Garber and Charles E. Phelps. "Economic foundations of cost-effectiveness analysis". In: *Journal of Health Economics* 16 (1997), pp. 1–31.

[42] M. Woodhall. *Economics of Education*. Ed. by GEORGE PSACHAROPOULOS. Pergamon, 1987, pp. 393–399.

[43] Microsoft. *Microsoft Teams user activity report*. Accessed on: 11th December 2019. 2019. URL: https://docs.microsoft.com/en-us/microsoftteams/teams-analytics-and-reports/user-activity-report.