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Effective Online Assessment Methods for Maths Education and Student Access

By

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Executive Summary

The development and integration of digital assessment has been underway in the past decade and was considered a natural progression that is expected from the technological revolution. The complex language of mathematics and how it is taught and communicated has been one of the reasons why there are hesitancy in its integration. However, the pandemic accelerated the adaptation of the software before students and teachers were ready, and many students from disadvantaged backgrounds were left behind as a result.

The aim of the report is to make recommendations for both secondary and higher education in terms of digital assessment formats, content, and approach that will enhance learning of mathematics, with a particular focus on students from groups that are disadvantaged or under-represented in higher education. This is done in three parts: a literature review, an evaluation, and making recommendations. First, a literature review is conducted on the benefits to digital assessments and how different barriers to participation to higher education can hinder these benefits. Thus, the review gives context to digital assessment formats, content, and approach that will enhance learning, and how students can be unfairly disadvantaged due to social disadvantages and disabilities. Secondly, an evaluation is conducted on the digital assessment tools currently available on the market, with focus on accessibility and assessment formats based on the information gathered in the literature review. Finally, recommendations are made to educators on the key considerations and information to seek out before making a decision on adopting a tool for mathematics digital assessment.

There are many benefits to switching to digital assessments in Mathematics, Drijvers (2019) identified 8 arguments for integrating technology into testing which is explored further in the report, such as the benefits of embedded and extracted analysis. The 8 arguments are:

1. The opportunity to integrate other “rich items” (Drijvers, 2019, p.47) such as simulations and animations.
2. Using every day technology to assess skills that are applicable in contemporary settings.
3. Outsourcing basic procedural work, such as the allowance of a calculator in an exam, can allow time for higher order thinking skills.

4. Ability to deliver the exam in different places at the same time.
5. Ease of test production using a database of questions, can more easily control the difficulty of a test.
6. Generation of automatic feedback.
7. Automated scoring can save time and give increased reassurance of consistency.
8. Adaptation of difficulty during the test can measure students' skills more efficiently. (Drijvers, 2019)

It is found that further innovation is needed to allow for all students to benefit from mathematics digital assessments. Technologies that allows visually impaired people to access written documents are often not designed to also deal with mathematics. From interviews with students and staff that supports them, the students still face challenges even with assistive technologies because the format of the class, notes or textbooks are not adaptable to their technologies. Many people who uses sign language to communicate considers the written language of their country as a second language, therefore sign-language videos accompanying questions and answers of assessments is a good accommodation for them. But it is not considered a priority even in official guidance in the UK. Students who are neurodivergent, which includes students with ADHD, dyslexia, dyspraxia, and autism, also benefits from tests accommodations and assistive technologies. For example, minimising sound effects, animations and bright colours can minimise sensory overload; allowing space to make tree diagrams for parts of working can help students with lower than average short-term memory; sans serif fonts, using coloured overlays to reduce glare, breaking up paragraphs into bullet points, and different colour lines are all good accommodations for dyslexic students but can help other neurodivergent students. The lack of these accommodations in digital assessment products will reduce the effectiveness of the benefits, causing unfair disadvantages to those students.

There are many social characteristics that are associated with lower participation in higher education, or lower attainment in secondary and higher education. The characteristics may include socio-economic backgrounds, postcodes, age and race. It is important to look at how each characteristic is affected individually and examine their intersection with each other as well as physical disabilities and neurodiversity. Pupils from poorer backgrounds can face many barriers in digital assessments, such as inadequate or lack of appropriate devices and no means to acquire one, inadequate or unreliable internet connection, lack of quiet study spaces where they would not be disturbed or interrupted. Unconscious biases can also lead to pupils missing out on support that they require and otherwise would have gotten, this means that some pupils may not get the reasonable adjustments that they need, or software or hardware provisions they require to perform well.

A shortlist of criteria is produced to access the accessibility of some software that are common in secondary and undergraduate Mathematics assessments and a list of potential features that would enhance learning is also produced. The products on the market for mathematics digital assessment is varied in terms of their features, price and accessibility.

The products aimed at higher education include: TopHat, Numbas, Stack, Möbius, Gradescope, and Inspera. Numbas and Stack are free and open source, of which Numbas has clearer accessibility documentations for its product specifically whereas Stack's is linked to Moodle, the LMS it is linked to. However, Stack has a more powerful reasoning by equivalence feature, which the step-by-step reasoning by equivalence is under development in 2021, in which Stack will check if each iteration is mathematically equivalent to the previous one, and if the first line is equivalent to the set question. This step-by-step reasoning by equivalence feature is not available in the other paid products either, although Numbas, TopHat, and Möbius offers reasoning by equivalence for students' answers. But it was noted that TopHat uses a third-party widget for its maths questions which may not be accessible.

The products aimed at secondary education include: Nearpod, Showbie, Socrative, MyMaths, Pixl Maths App, and Mathspace. Nearpod and Socrative are aimed at formative assessments during lessons, whereas the others are focused on formative assessments outside lessons. Mathspace and Nearpod has the most comprehensive resources for accessibility for its products out of the six. Nearpod is clear about what answer formats are available for each activity and what support media is available in each activity on their website. Whereas Mathspace has comprehensive notes on how to use its accessibility mode feature for its printable worksheets, and what browsers and screen readers this feature is compatible with.

From the literature review and evaluation of tools currently on the market, it can be concluded that there is no perfect tool for digital assessment that would enhance learning for everyone. A good tool is a tool that suits the needs of the pupils and teachers, this depends on many factors of circumstance. Key points to consider would include: the accessibility features of the tool, the hardware and internet connection needed to use it, and the assessment format that is used with the tool, the price, mode of assessment, medium of feedback, level of mathematics supported and LMS integration support. Finding information on the following can help with the key points: the educator's obligations, the students' accessibility needs, the students' hardware specifications and internet connection, the product's VPAT, the product company's support policy and its development.

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1 Introduction

1.1 Scope of Project

This project is about the various ways of implementing online formative and summative assessment for maths education in Key Stage 5 and undergraduate level, and possible ways to improve student access for these assessments so as to improve participation of groups that are under-represented in higher education. The study is focused on accessibility of students, so as to give an overview of considerations that teachers would take before choosing various digital tools for teaching or evaluating. However, the perspectives of teachers and academic institutions are also considered so as to be sympathetic to all parties and give more realistic recommendations.

1.2 Integration of Digital Assessment for Mathematics

The development and integration of digital assessment in both formative and summative context has been accelerated during the scramble to move education online during the Covid-19 pandemic. However, it should be noted that the move to digital formative assessment was already underway and was considered a natural progression that is expected from the technological revolution, despite apparent reluctance from teachers and slow system change (Dalby et Swan, 2019). It is suggested that, “for pedagogical change to be achieved, it seems that a better understanding of how technology contributes to effective learning processes is still required” (Dalby et Swan, 2019).

Teachers’ use of digital formative assessment analytics data is examined in a study by Admiraal et al. (2020), and teachers’ change in classroom instructions is noted to see how teachers can best use the technology, thus seeing routes for improvement in the software to enable teachers to get the information they needed for making decisions in the classroom. Teachers had regular meetings throughout the experiment and found it useful to experiment with different forms of feedback learning from each other. The study shows that pedagogical change is ongoing and need further research and development.

One of the challenges of moving mathematics assessment online is integrating its complex language. The peculiar and particular demands of the mathematical language poses a challenge in software designing when it comes to balancing user friendly interface and accuracy of product, such as the ink-to-math feature in OneNote compared to the equation typing in Microsoft Word: ink-to-Math is more convenient, but more likely to make errors; typing take much longer but is more reliable. Not to mention the different ways to express mathematics aside from numerical and symbolic equations, such as graphical representations of many dimensions and simulations. Due to this complexity, interfaces that allow many ways of expressing mathematics may become more reliant on the end-user having a certain level of digital skill and experience with the software itself. Therefore, “a careful inspection of the students’ familiarity with the digital techniques needed to answer the items is needed to make sure that validity is not threatened by the digital format of the test” (Drijvers, 2019).

The sophistication of technology is required for post-primary level because the learning outcomes of mathematics in secondary school and university level is often on problem solving skills which can be applied to real-life problems. The assessment of complex problem solving skills cannot be done through multiple choice or other close-ended questions because “appropriate problem-solving strategies are considered more important than correct outcomes of procedural work” (Drijvers, 2019). Therefore, only giving marks to the correct answer would not accomplish the learning outcomes. This means that autograded assessments would at least require equivalent answers should be recognised by the software, a feature commonly known as reasoning by equivalence (Drijvers, 2019); scoring of continuation of work after a mistake; even assess understandings or misconceptions through students’ working. All of these would require much more advanced technology compared to software that only offers fill-in-the-blank and multiple choice. Without these technological advances, or other innovative ways to design digital assessments, digital assessment for mathematics would not be able to measure the learning outcomes required.

The plethora of software available on the market to address assessment needs for mathematics shows that it is a demand that the market is eager to meet. However, the challenges of the complexity mathematical communication and need for effective and accessible communication between students and teachers through assessments has to be addressed to make sure that everyone can get the most out of this technology.

1.3 Impact of Covid-19 Pandemic on Disadvantaged Students

Whist the development of digital assessment was already ongoing, the pandemic accelerated the adaptation of the software before students and teachers were ready. As a result, many students from disadvantaged backgrounds were left behind, with inadequate support due to lack of reliable internet connections, insufficient hardware to run new demanding software required to access their education networks, or a quiet place to complete their coursework. The Sutton Trust (2021) found that the digital gap between private and most deprived state school has widen between March 2020 and January 2021. The most stark contrast would be the availability of a learning device, in a survey of 6,208 teachers in schools across England it is found that “while 32% of teachers in the most deprived schools report more than 1 in 5 lacking devices, this is just 5% at the most affluent state schools and even lower, 3%, at private schools” (Sutton Trust, 2021, p.1). The learning gap caused by learning loss in disadvantaged pupils are considered the largest for reading and mathematics, “the effect on disadvantaged pupils is equivalent to undoing a third of the progress made in the last decade on closing the gap in primary schools” (Department of Education, 2021, p.31) in Autumn term 2020/21.

Aside from the challenges posed by the lack of sufficient tools and environments, the increasing use of meta-data has been amplifying the unconscious biases against disadvantaged pupils. The Ofqual algorithm for GCSE and A-Levels in 2020 is also an example of students from disadvantaged backgrounds being treated unfairly. By factoring in the school’s performance in the last 3 years, “bright students from an underperforming school was likely to have their results downgraded through no fault of their own” (BBC, 2020), or similarly, a school or an individual student who has improved their overall performance would not have that improvement rewarded. Despite the reversal of the plan after widespread protest on the system, it still showed that when given the chance, the education system prioritises the consistency of the overall average grades to prevent inflation of grades, over the individuals who would lose out on opportunities they worked hard for. This is further dampening social mobility, in a system that already hinders it via the diversified system, which “has resulted in socio-economic segregation between types of schools” (Crenna-Jennings, 2018) where higher-performing schools admitting fewer and fewer disadvantaged pupils.

It is important that these findings are taken as lessons in future design decisions on any assessments or digital algorithms, such as software designers deciding how to use or present the data that is collected in digital formative assessments can affect teachers' decisions in the classroom. When unchecked, unconscious bias will transfer into human built tools and used to further justify the bias using a source that is perceived to be objective. This can cause students to be marked down unfairly, for example, "an analysis of school census data found that black and poor white British pupils were marked down in teacher assessment relative to their Key Stage result" (Crenna-Jennings, 2018, p.13). Furthermore, a possibility of programming unconscious negative bias into online proctoring software with facial recognition capability which will affect students' credibility on their summative assessments, online proctoring companies put in effort to "establish distinctions between the use of 'facial detection' as opposed to 'facial recognition' techniques" (Selwyn et al., 2021) in response and ensure people that "AI is sensitive to diversity and is trained to ensure zero discrimination" (Selwyn et al., 2021). The consideration of internet access and device availability and compatibility should also be taken into consideration. Research on the current digital assessment market to identify possible unconscious bias can be helpful when improving the digital assessment system, and inform educators and students on how to start reducing unconscious negative bias on under-represented groups in higher education.

1.4 Perceptive of Author

The present study is undertaken by an undergraduate student in the School of Civil Engineering at the University of Leeds. I hope that I can bring a student's perspective on the topic of digital formative and summative assessment. The research topic interests me because of my increasing interest in identifying potential gaps that would disadvantage different groups, prompted by the news columns being filled with how students from poorer backgrounds are being left behind by the system during the Covid-19 pandemic. Furthermore, the realisation of sound sensitivity affecting my academic performance did not come until the pandemic led to pre-recorded online lectures becoming the new normal. After reading the news about younger pupils returning to school with increased sensitivity to noise causing difficulty to concentrate made me think that perhaps innovation in online learning is the step that needs to be taken to ensure all students have the means to perform the best they can. I became aware that not all tools are equally helpful for all pupils from my personal experience with Kahoot in secondary school, the tool is anxiety inducing for me, an experience I did not share with anyone else I know. All of these experiences led me to look more into accessibility and social inequality during my spare time, thinking about disabilities, economic background, race, gender inequalities and their intersections. As an engineering student, I naturally am drawn to mathematics and the ways in which they are taught. During my first year at university, I was taught the same mathematical concepts in my IB Mathematics Higher Level course, but I found the concept very difficult to grasp during Year 12 and 13, then it all became very clear within 2 months at university. This is an example for me that the teaching method and tools used are very important when explaining mathematical concepts. These are the experiences that inspired me to want to take on the project in researching assessment formats, content, and approach that will enhance learning so as to improve the access to, preparation for, and experience of, students from disadvantaged or under-represented groups in higher education.

2 Aim

This project aims to make recommendations for both secondary and higher education in terms of digital assessment formats, content, and approach that will enhance learning, with a particular focus on students from groups that are disadvantaged or under-represented in higher education.

3 Objectives

1) Determine the benefits and challenges of digital assessments for Mathematics by carrying out a literature review.
2) Determine whether the barriers to participation of higher education can also be a barrier to performance on mathematical digital assessments by carrying review of the relevant literature.
3) Produce checklists for assessing the accessibility and learning enhancement of mathematical digital assessment tools.
4) Produce product summaries to communicate the supported formats, content, approach, and accessibility of mathematical digital assessment tools on the market currently.
5) Produce recommendations for educators of both secondary and higher education in terms of digital assessment product choices that would allow all students to benefit from digital assessments.

4 Literature Review

4.1 Benefits of Digital Assessments

4.1.1 Formative assessments

The benefits and challenges of digital assessments for Mathematics have similarities and differences for formative and summative assessments, which will be examined boardy separately although some aspects may still apply for the other assessment type. According to the Education Endowment Foundation (EEF), the content of formative and summative assessments are often the same while many refer to them as though they are completely different entities, the only difference is the way that the data is used (EEF, n.d.). Formative assessments are assessments used in a formative purpose, to develop the skill, the data collected in formative assessments are to aid teachers in assessing students' learning progress in order to tailor teaching to students' needs. These are usually conducted via in-class participation, interim quizzes, games and activities, and homework.

Digital formative assessments allowed students and teachers to have interactive feedback while learning and working from home during Covid-19 lockdowns. In the long term, reducing the need to travel can open up learning opportunities for people with mobility issues, or with other responsibilities that does not allow them to commute to school every day to still participate in class in the many ways digital formative assessments are used. Digital assessments can also be integrated into in-person teaching to allow teachers to get more detailed real-time feedback from students during lessons.

There are many benefits to switching to digital assessments in Mathematics, Drijvers (2019) identified 8 arguments for integrating technology into testing which can be explored further:

9. The opportunity to integrate other "rich items" (Drijvers, 2019, p.47) such as simulations and animations.
10. Using every day technology to assess skills that are applicable in contemporary settings.
11. Outsourcing basic procedural work, such as the allowance of a calculator in an exam, can allow time for higher order thinking skills.
12. Ability to deliver the exam in different places at the same time.

13. Ease of test production using a database of questions, can more easily control the difficulty of a test.
14. Generation of automatic feedback.
15. Automated scoring can save time and give increased reassurance of consistency.
16. Adaptation of difficulty during the test can measure students' skills more efficiently. (Drijvers, 2019)

Expanding on the forth argument, digital formative assessment can also be seamlessly integrated into Learning Management System (LMS) so that students can access all of their learning resources in one place without having to log into different systems during learning. This also reduces the possibility of losing paper copies of assignments, and reducing the carbon footprint related to printing.

From the sixth argument, digital formative assessments allows detailed relevant data to be collected automatically, which can help teachers to gain more insight into their students' learning than they would otherwise on a non-digital system, such as pen-and-paper homework and quizzes, or in-class interactions. The use of this data is usually called learning analytics, which can be defined as "the measurement, collection, analysis and reporting of data about learners and their contexts, for purposes of understanding and optimizing learning and the environments in which it occurs" (Siemens & Gasevic, 2012).

Different types of feedback can be given depending on the context of the assessment and the type of learning analytics collected, in digital assessments, these usually involve two types of learning analytics: embedded and extracted analytics (Admiraal et al., 2020, p.578).

Embedded analytics is "data that are used to inform the learner and/or to adapt tasks to the ability levels of students without teacher intervention" (Admiraal et al., 2020, p.578). When used for digital assessment, multiple choice or close-ended questions with embedded analytics make marking time significantly reduced, and students can get immediate feedback on their work. In these types of questions, automated feedback can be generated easily, and are usually in 3 types: knowledge of results – the correctness of the answer, knowledge of correct response – show the correct answer, elaborate feedback – give correct answer along with information or explanation about the answer (Van der Kleij et al., 2015). In the meta-study done by Van der Kleij et al. (2015), elaborate feedback is shown to be the most effective out of the three categories of feedback. Embedded analytics can allow the teachers' role to become less central to the students' learning, when the technology gives good quality feedback, adapt difficulty of questions based on students' response, and give sufficient extracted analysis to teachers to intervene if needed. This may pave the way giving pupils more opportunities to practise maths problems in the classroom, see error as a learning opportunity, and increased organisation of work, which are all things that schools with higher intake of disadvantaged pupils tend to lack (Crenna-Jennings, 2018).

Extracted analytics is "data that are presented for interpretation and provide teachers with information about learning process and outcomes, which they use to improve their classroom instruction" (Admiraal et al., 2020, p.578). In a study by Dalby and Swan (2019) the ways in which information from extracted analytics are used is explored, two ways of categorising the methods are: dividing into 5 key classroom activities where formative assessment takes place based on previous research by Swan and Burkhardt (2014), The 5 key classroom activities are as follows:

1. ***Building on students' prior knowledge**: Pre-lesson diagnostic assessment and class overviews are generated electronically and used in lesson planning.*
2. ***Identifying and responding to students' conceptual difficulties**: Sample student work is selected and displayed electronically by teachers to initiate class discussion and expose misconceptions.*
3. ***Using questioning**: Student work is displayed electronically by the teacher and students are questioned about their methods.*
4. ***Increasing student collaboration**: Students compare and discuss their work when displayed electronically for class discussion and also when working on individual iPads.*
5. ***Enabling students to become assessors**: Peer assessment takes place during class discussion and collaborative work using information provided electronically.* (Dalby and Swan, 2019, p.837)

The other way of exploring formative assessment is to examine "the interactions and strategies being employed" (Dalby and Swan, 2019, p.6) through mapping the interactions on a diagram based on a framework by Wiliam and Thompson (2007), which involves 4 stages of formative assessment: Ask, Answer, Analyse, Adapt, then separating student, teacher and technology to indicate who are doing work during that stage.

In the examples of using extracted analytics, the technology is often seen as a means of communication between student and teacher. The teacher is needed to initiate the formative assessment learning task, and the direction of progress determined by teachers' interpretation of misconceptions of the students and what feedback they decide to give the students. Teachers would use one student's work as an example to show the misconceptions that they think a lot of pupils in the class has. Sometimes, teachers would also pair up students based on their answers so that they can compare answers and give peer feedback. The teacher is very important in this exchange, it is found that "small changes in the type of verbal questioning or feedback -used by the teacher could affect how readily students gained understanding" (Dalby and Swan, 2019, p.843). Therefore, the quality of teaching is still affected mostly by the teachers. In the 2018 annual report for education in England from the Education Policy Institute, "evidence shows that the difference between being taught by a good versus bad teacher is equivalent to a whole year of learning for disadvantaged pupils" (Crenna-Jennings, 2018, p.13). Unfortunately, "disadvantaged pupils are more likely to experience lower quality teaching" (Crenna-Jennings, 2018, p.13) due to schools serving disadvantaged communities "are less likely to have a formal teaching qualification, have less experience, and are more likely to lack a degree in the relevant subject; these schools are also more likely to see a higher teacher turnover rate" (Crenna-Jennings, 2018, p.13).

Teaching using extracted analytics can still be a good teaching method, but it depends greatly on the quality of the teachers, on the other hand, embedded analytics depends more on the quality of the software to spot the mistake and give feedback, which is done by the programmer and author of the questions. Teachers can and often use both, embedded analytics as homework, and extracted analytics during live classes.

Another benefit of digital assessment not mentioned in Drijvers' (2019) 8 arguments is that the layout of the test can be customised by the student, or more functions can be put into the software than a pen-and-paper test allows. In a study by Siozos et al.

(2009), secondary and undergraduate students and teachers were interviewed in their respective groups on what layout and features they would like a digital assessment software to have, resulting in two draft applications from the design of secondary and undergraduate groups respectively. It was noted that secondary students' design are more focused on the needs of formative assessments, and the requirements from undergraduates favours summative assessments. In the design by secondary school students and teachers is shown in Figure 4.1 below, the design includes: (I1) the question list which allows the students to move between questions non-sequentially, and see the state of the question which can be answered, unanswered or uncertain ; (I2) time display and (I3) progress display which can be hidden ; (I4) the response area and scrapbook, where student can use a stylus to write or keyboard to type, the style of the ink and the background of the 'paper' can be customised, the notes in the scrapbook can be drag and dropped onto the response area, or the test can be configured so that the content of the scrapbook is also submitted ; (I5) is where the student can mark a question as uncertain so they can review it later ; (I6) tools that are

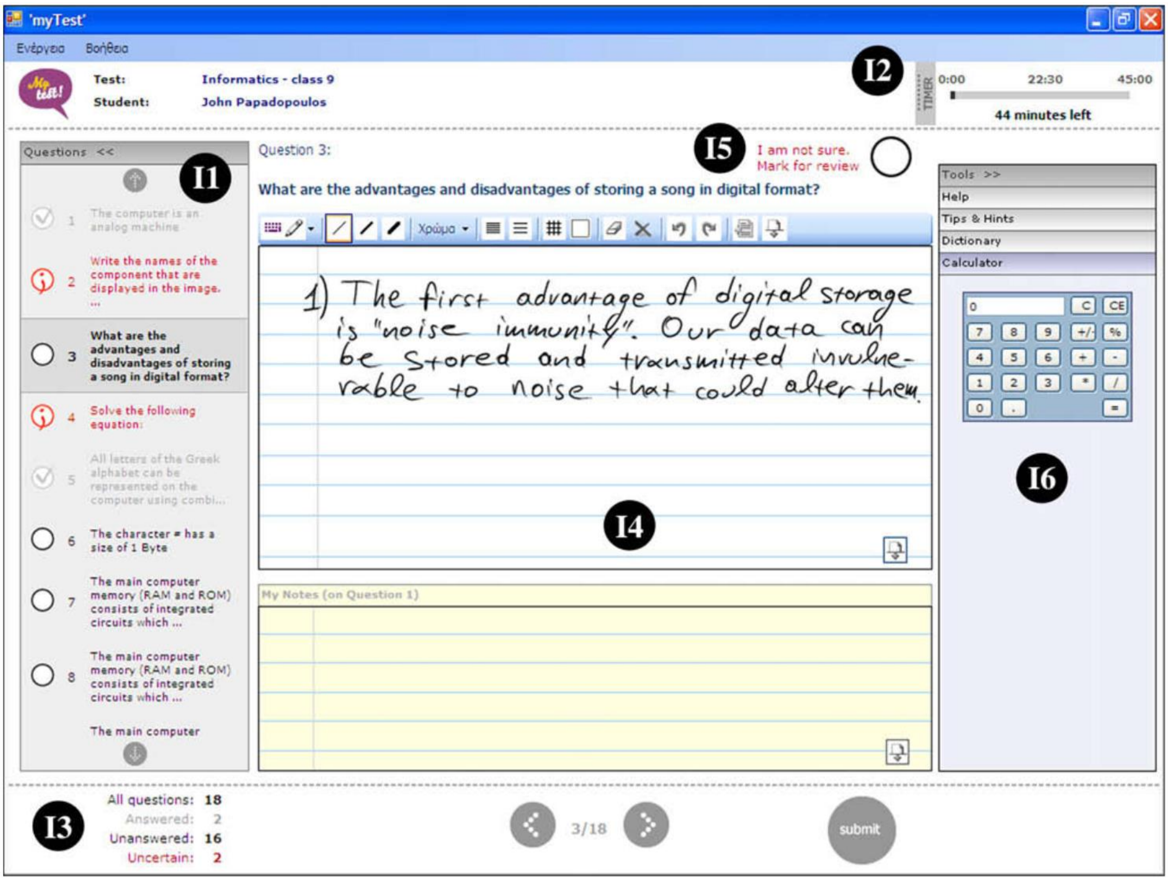
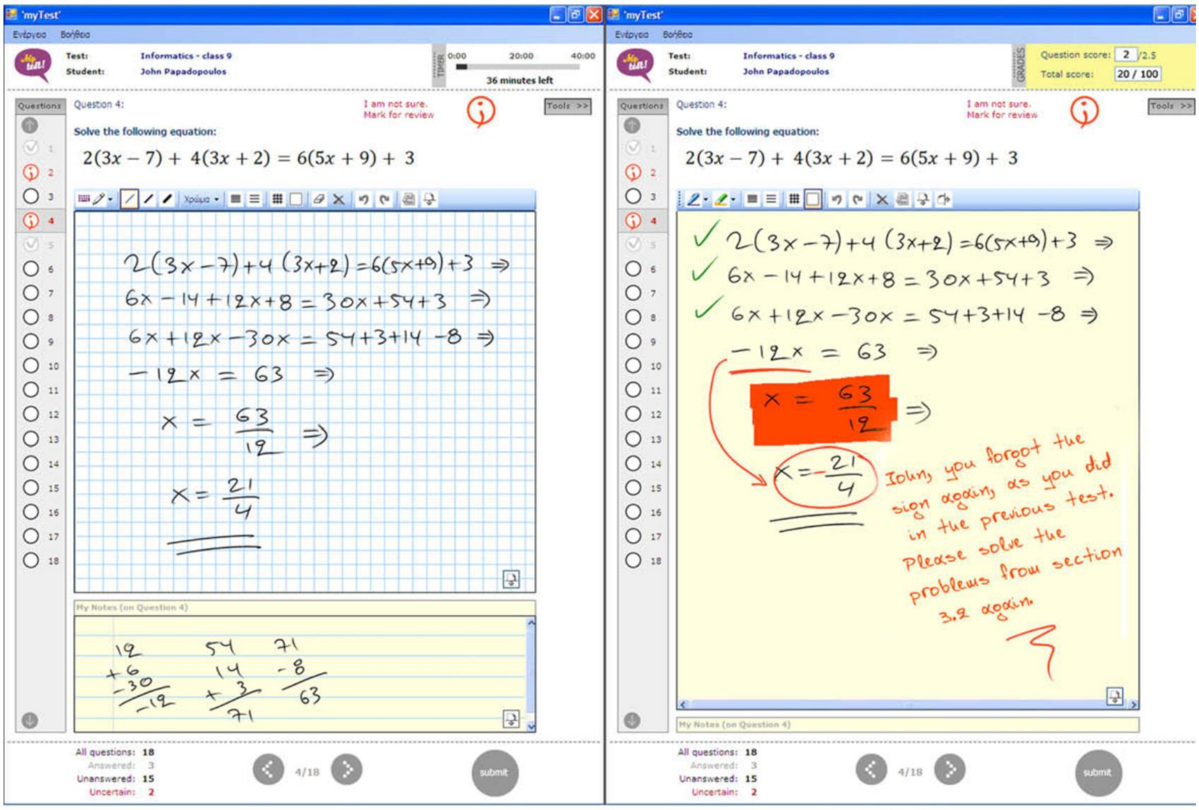


Figure 4.1 Main functional screen of the MyTest application. (Drijvers', 2019, p.815)

provided by the teacher, which can be customised for each test, or even hints or other useful media specific to the question (Drijvers', 2019). The application also supports both landscape and portrait mode and collapsible elements allows the response section to be bigger to allow for more room to response as shown in Figure 4.2(A). Manual response and inked graded automatically. This allows for flexibility in questions design and feedback, whereas the layout of this application shows the potential for a more intuitive and flexible layout to suit the needs of different students.



(A) (B)

Fig 4.2 The MyTest application in portrait layout: (A) student's (testing) view, (B) teacher's (grading) view (Drijvers', 2019, p.816)

This process of interview and design also shows the importance of input from all end-users when designing the digital assessment application, but it is noted in the report that students "have limited design skills and are incapable of knowing, experiencing and taking advantage of pedagogical approaches and pioneer technologies. Their contribution and their assessments, are guided by experience and intuition and can be simplistic and, at times, unoriginal" (Drijvers', 2019, p.819). Therefore, empirical measures such as observations would be better compared to "self reporting questionnaires" (Drijvers', 2019, p.819). From the current literature, digital formative assessment has many potential benefits, which teachers and students are working to integrate into their classrooms, whether it be online or in-person.

4.1.2 Summative Assessments

Summative assessments are used to evaluate students' learning at the end of teaching, the assessment is designed to test the students' success in achieving the desired learning outcomes of the programme. In traditional pen-and-paper summative assessments, students are invigilated in a controlled environment, usually the test is taken at the same time and at a fixed location for each group of students, some adjustments and accommodations are made for students with recognised special needs to mitigate the impact of it. Digital assessment provides opportunities and poses challenges for summative assessments, especially of the goal to make sure people have as equal chance as possible to achieve their best performance during the test.

Digital summative assessments provide opportunities of a more accessible test environment for all students. From the interview and design exercise by Siozos et al. (2009), the requests from undergraduate students had needs that are more specific to a strictly timed, and controlled test environment. This comes from suggesting more ways for users to be as much in control of the assessment process as possible, such as organise their time by customisable time reminders, emergency management such as reporting and solving technical problems, ability to customise layout configuration such as multiple options to view and navigate between questions, and different possibilities for contacting instructors during a test like private but publishable discussions Siozos et al., 2009). Having multiple, possibly redundant ways of doing one task is actually a good indication for accessible design as it recognises diverse abilities. "There are redundant or repetitive or duplicated ways to take part, but no one way is privileged over the others" (Dolmage, 2017, p.120). This is not possible in the pen-and-paper medium, and students who do not fit into the category that would find the test accessible to them have to apply in advance for different arrangements. In a well-designed digital assessment space, this should not need to be the case, which is part of the idea of Universal Design, which is "an acknowledgment that our design practices have long been biased" (Dolmage , 2017, p.117) and that we should always be moving forward to design spaces that would be accessible for all, rather than seeing those people as ‘other’ and make temporary changes for them without thinking that the original design is wrong for not considering them in the first place. The effectiveness of test accommodations and opinions on and Universal Design are further explored in the next section.

The 8 arguments for integrating technology into testing identified by Drijvers (2019) are still applicable in summative assessments, argument 4 in particular, ability to deliver the exam in different places at the same time, was much needed during the Covid-19 pandemic. This is a valuable opportunity to expand the possibility of future summative assessment, such as allowing students who are not as mobile to have the option to not travel. However, it also brought a challenge, which is the concern of ‘exam integrity’, in the traditional summative assessment, students are invigilated to prevent cheating, such as use of unauthorised materials, submitting someone else’s work as their own, or working collaboratively. When students are required to take their exams at home, many educational institutions turned to online proctoring companies in fear of compromising their institutional reputation. Selwyn et al. (2021) looked into publications of commercial providers, and interviewed university authorities, university staff and student groups to get their perspective in the rapid uptake of online proctoring technology, in particular, the switch from ‘live’ human proctors to artificial intelligence (AI) process. Automatic proctoring “includes the use of basic facial recognition software to match the photographed ID and student face. Thereafter, the test-taker’s identity can be continually verified during the examination process through biometric keystroke analysis and ‘automatic proctoring’ techniques, including the use of eye tracking, audio monitoring and facial detection to monitor for signs of engagement with unauthorised information sources” (Selwyn et al., 2021, pp.2-3). From the interviews, the online proctoring companies presented ‘auto-proctoring’ “as instantaneous, accurate, ‘scalable and dependable’” (Selwyn et al., 2021, p.7), and that it is a service for university authorities and does not interfere with exams. Universities generally do not want non-university technical staff to handle summative assessment technical assistance, however, “despite promising fully automated proctoring with ‘no human in the loop’, one major platform encouraged students to contact its ‘live agents’ to resolve technical issues during the exam” (Selwyn et al., 2021, p.10). These show that the technology itself was not yet ready to be used in high-stake summative assessments at a large scale, and definitely not as dependable or sophisticated as the companies advertised. However, universities were under pressure to "maintain the impression of having trustworthy assessment processes" (Selwyn et al., 2021, p.8), especially from accreditation bodies, and therefore feel that they had little choice but to take it up. Fortunately, considerable efforts have been made by some universities to ensure students are familiar with the software by holding workshops, running practise tests and Q&A events, and by the end, student activist angered by the lack of consultation and institutions' lack of trust in students have turned into apathy. Much like digitalisation of formative assessment, online proctoring of summative assessments are likely to become more common, which means that it is imperative that basic requirements are established to protect the interests of all parties. As with any technology used in education, consulting all end-users should be a minimum requirement of the uptake of any software such that students feel respected.

As mentioned in the introduction, social disadvantages and disabilities often hinder students' participation in higher education, and how these barriers may affect the benefits that students usually would gain from digital assessments should be explored. The following is a list of some of the barriers to participation to higher education that many students faces, some of their challenges, technologies available, and alternative arrangements currently suggested are outlined here below for an overview of each of them. Further resources are available for finding out more about how to improve access of mathematics for students, The Mathematics Resources Centre (MASH) is part of the University of Bath and it helps to improve access of mathematics for disabled students. Teaching and Learning Mathematics Online (TALMO) is founded in 2020 as a community of academics aiming to make help with technological and pedagogical aspects of moving teaching of mathematics online during the Covid-19 pandemic. Disability Rights UK has a factsheet which includes a list of general and impairment specific adjustments.

4.2 Effect of Barriers to Participation on Benefits of Digital Assessments

4.2.1 Visual Impairment and Blindness

Students with visual impairment and blindness have a more challenging time when it comes to learning mathematics. This is because technologies that allows visually impaired people to access written documents are often not designed to also deal with mathematics.

Cliffe and Rowlett (2012) edited the Good Practice on Inclusive Curricula in the Mathematical Sciences as part of a bigger project on mathematics accessibility at the University of Bath. It includes entries on assisting students with visual impairments, dyslexia, and on the autism spectrum, as well as more general experiences and techniques such as lessons learnt in the Open University, using software such as MathML and speech text, or techniques like mindmaps. Cliffe noted in the introduction to the guide that Maths, Stats and Operational Research (MSOR) "is cumulative in nature so concepts may take time to be fully assimilated and this has an impact on teaching and assessment design" (Cliffe, 2012), which is the major challenge of accessibility within Mathematics. The need to process the information 'in real-time' comes into conflict with the traditional lecture format which involves lecturers using the board to show the development of the concept, when full notes in appropriate formats are not made available prior to class, students may not be able to follow along with the rest of the class. This is particularly true for students who are visually impaired. As assistive technologies work best when the language is linear, compared to the "2 dimensional relative positioning of symbols, their relative sizes, etc., that codes meaning" (Cooper, 2012, p.40) in Maths, along with the need for manipulation of this symbolic language, it is different to subjects that uses only written English.

There are various assistive technologies students with visual impairments uses to aid studying mathematics. This includes but not limited to: Braille (tactile writing system) which can be printed centrally, or with a printer, or in a refreshable display, LaTex (a typesetting language that allows students to type or read mathematical notations in plain-text format) which usually needs to be requested from document owner so that it can be either used as it is or translated to be more condensed and accessible, ways of translating diagrams such as German film ("plastic substance which when placed on a rubber mat produces raised lines when drawn upon" (Williams and Irving, 2012)), Zyche (machines that produce embossed diagrams), Mathtrax (software that depicts graph by audio tones) (Williams and Irving, 2012). But from interviews with students and staff that supports them, the students still face challenges even with assistive technologies because the format of the class, notes or textbooks are not adaptable to their technologies.

Experiences of students with visual impairments and staff who support them are explored in a qualitative study by Rowlett and Rowlett (2012), support workers have experience with students who has a Braille resource ask them to read out the equations to get a sense of the layout and structure, and have found that it takes much longer for students to read Braille and makes it hard for them to keep up with the pace of the lecture. Two-dimensional Braille is also considered as an alternative to linear, which is designed for complex mathematical notations, but some students find that the mathematics is harder to manipulate in this system. Students find it difficult to do their own research on topics they are interested in because of the lack of easily accessible material available so that they can have the freedom to choose the material without making a big commitment, and some feel that not having accessible formats for textbooks has limited their grade.

The good practice guide from Cliffe and Rowlett (2012) does not cover summative assessments, but some general pointers can be derived from classroom environment and homework. One of the points often repeated is that lecturers should make reading lists and lecture notes as far in advance as possible because it gives the student and their support workers time to source and produce accessible versions of the text in advance (Rowlett and Rowlett, 2012). There should be consistency of format between formative and summative assessments and student's learning, so copying and manipulating mathematical equations to communicate with tutors and classmates should be part of the learning routine, incorporated into formative assessments in class (Cooper, 2012). It is important to work with students on a one-to-one basis as needs and preferences differs for each person. For example, preference for how to handle diagrams differ from student to student, some preferring description when it is a simple diagram, while others only uses description instead of tactile when it is complex (Rowlett and Rowlett, 2012). Soak (2012) also found that read aloud accommodation during summative tests improved student who are partially sighted or blind in their experiment with 10 pupils in a special school for students with visual impairments in South Korea.

Making mathematics accessible for people who are visually impaired is an ongoing project, the challenge revolves around accessible convertible formatting of exiting literature, the price, precision and accuracy of the software and hardware used to process materials into usable formats between sighted and non-sighted world, the consistency of the accessible formats, logistics of production of syllabus in advance, awareness of educators on producing accessible content.

4.2.2 Hearing Impairment and Deafness

Challenges faced by people who are deaf or have a hearing impairment are different to visually impaired people. Again, there are many technological advancements that can help people with hearing impairments during secondary and higher education.

Depending on the severity of the hearing impairment, students may have different technologies to aid their hearing, such as different types of hearing aids, hearing implants, and assistive listening devices (NHS, 2018). In these cases, many users of those devices would benefit from hearing (induction) loops, which helps the device users to “hear sounds more clearly by reducing the effect of background noise” (The Royal National Institute for Deaf People, n.d., p.3) by transmitting sounds from a microphone as a magnetic field which is picked up by the hearing aid. It is recommended that lecture halls are provided with a room loop so that a person sitting anywhere in that lecture hall can use the system. However, people who are deaf from birth or have developed severe hearing loss later in life would not benefit from these technologies and they can learn to communicate with other people in other ways such as sign language and lip-reading.

Many people may forget that English (or other major languages in their countries), whether it be written or spoken, is considered a second-language by many people who are deaf. This can affect student’s performance during an exam if they are only provided with a written copy and expected to write their answer in their second-language. Rojano-Caceres and Gonzalez-Contreras (2020) pointed out this problem for summative multiple-choice exams in Mexico where deaf students are not given any accommodations other than a sign language interpreter who is only allowed to translate the instruction from the examiner or invigilator. They have therefore designed a multimedia template based on the types of questions in that exam, so that it can be accessible for people who uses sign-languages. In this digital format, each question and the associated answers have a sign-language video accompanied, “in any case each element whether is question or answer must have associated a path to a multimedia and a context which can b text or figures” (Rojano-Caceres and Gonzalez-

Contreras, 2020, p.91). Resources for learning new British Sign Language (BSL) sign for maths and science specific terms are available from the Scottish Sensory Centre (SSC), but it is recommended that students can get a glossary of new terms along with the notes for the lessons in advance so they can prepare in advance for the new terms they must learn in order to keep up with the lesson. As mentioned in the section on formative assessments, teachers may pair students up for peer feedback after a formative assessment during class, it is important that the teacher is sensitive to the student's disability and give them adjustments so that they do not feel left out of the class, they must work with the student to identify the best adjustment. This can be having other students learn Sign Language, the teacher learning sign language to interpret, use captioning through digital services etc. which will likely be provided as an accessibility adjustment during normal class time as well.

4.2.3 Attention deficit hyperactivity disorder (ADHD)

People with Attention deficit hyperactivity disorder (ADHD) "can seem restless, may have trouble concentrating and may act on impulse" (NHS, 2018) and may have additional problems such as sleep and anxiety disorders (NHS, 2018). People with ADHD are often described as inattentive, hyperactive and impulsive (Troot, 2006) in neurotypical circles.

The concentration difficulties caused by ADHD can result in more frequent numerical and copying mistakes even though the student understands the mathematical concept fully. This mostly causes arguments of unfairness in summative assessments. Although a poor night of sleep can cause students to perform worse in mathematics regardless of ADHD status (Cusick et al, 2018), students with ADHD will still be more likely to be affected because of the tendency to get poorer sleep. Frequent wakings the previous night is associated with "significantly lower numerical operations and math fluency achievement scores and marginally lower working memory scores" (Cusick et al, 2018, p.75) for all students. This means that students with ADHD is disadvantaged in mathematical assessments under the same test condition with their non-ADHD peers when assumptions are made that they are working at their full capability when it is capped due to sleeplessness caused by ADHD. Although some symptoms of ADHD can be lowered by medication, some students opt not to take them due to side effects or not recommended it by their doctor. Therefore, test accommodation should be given to lower the chance the students are being unfairly disadvantaged, such as extended time, quiet room with less distraction, and allowance of breaks to move around. These accommodations would be more challenging for students under remotely proctored exams due to the concern for academic integrity and logistics.

The validity of extended time as a test accommodation is still argued between various studies on different disabilities, which is illustrated in Gregg and Nelson's (2012) meta-analysis, but ultimately it is the test organiser who decide what is a reasonable adjustment, so one argument for extended time accommodation for students with ADHD is as follows: A study was conducted on extended time accommodations for students with and without ADHD by Lewandowski et al. (2017), which compared 2 groups of 27 middle school students in the U.S., one group diagnosed with ADHD and the other group shows low on the ADHD symptoms rating scale and similar processing speeds for both groups. It was found that "although the ADHD group benefited from extended time, the control group benefited significantly more" (Lewandowski et al., 2007, p.23), and when the variable is number of questions completed, results were "showing that work output was relatively equated when the ADHD group received 50% more time than the control group" (Lewandowski et al., 2007, p.24) even though the control group still out-perform the ADHD group when the variable is the number of items correct in the same time interval. Therefore, extended-time accommodation should be one of the strategies to "reduces variability in irrelevant characteristics that affect test scores but are unrelated to the construct that the test is designed to measure" (Lewandowski et al., 2007, p.18).

In terms of digital formative assessments, as ADHD students have lower working or short-term memory, any class assessment or game tool that requires split screen (for example, the question on the screen at the front and students answer from their own device) would not be assessable for any student with lower short-term memory. This is not something experienced by people with ADHD exclusively, people with dyslexia and autism also struggles with this.

4.2.4 Dyslexia

Dyslexia is a “common learning difficulty that can cause problems with reading, writing and spelling” (NHS, 2018) and is also marked by lower than average short term memory (Trott, 2006). Dyslexia can result in poorer arithmetical skills, difficulties learning theorem, formulae or specialised vocabulary or symbols (Trott, 2006).

Maths students with dyslexia can also find copying from line to line or to different media troublesome cause messy work and make frequent mistakes, they may also find it difficult to associate symbol to word to theorem. These are not a measurement of their mathematical thinking and understanding so accommodations should be given so as to help students to read, copy and communicate the logic behind their work. Common accommodations for students with dyslexia include the use of sans serif fonts, using coloured overlays to reduce glare, breaking up paragraphs into bullet points, different colour lines, more frequent use of diagrams and mind-maps, use of card indexes or wall posters as memory-aids, and providing centimetre-square paper (Trott, 2006). Sometimes it would even be more beneficial for student to talk through the solution they provided with the teacher (Trott, 2012) so as to assess their mathematical understanding, perhaps in a formative assessment, to save teachers misinterpreting less well documented solutions and not understanding the student’s progress. Furthermore, questions that require recalling statements of definitions and theorems without proof are a test of rote recall and disadvantage dyslexic students as they find rote recalling difficult but is fully capable of develop the proof and understand it fully (Trott, 2012). It is recommended that all students are provided with the theorem and formulae needed for close-book summative assessments so that the test is not focused on memorising. Due to difficulty in associating symbol to word, rather than having multiple symbol for one word, symbols and notations should be consistent throughout the course to avoid confusion, or more memorising (Trott, 2012). In terms of feedback from formative assessments, having audio recording of the feedback may be more useful than a written paragraph (Trott, 2012) because some students find it difficult to read the feedback and thus negating the benefit of a summative assessment on learning.

During formative assessment activities in class, it would be best to avoid timed questions, or rewarding students who answer faster because it would cause stress and is unfair to the student while not beneficial to the overall group. Allowing time and space for students to do their own working out is important, especially to allow them to use a diagram to branch out different parts of their workings instead of stacking them so that they can see it all on one level as one step to prevent the need to split up information needed for the next step. This applies to both digital and non-digital assessments, but in particular digital assessments where screen space is limited and scrolling would not be ideal for dyslexic students because it would be difficult to use that information if scrolling is needed, it would be forgotten as soon as it disappears from view (Trott, 2012).

4.2.5 Dyspraxia

Dyspraxia is also called Developmental co-ordination disorder (DCD), which is a condition affecting physical coordination. People with dyspraxia may submit graphs and diagrams that are poorly defined (Trott, 2012) because they have difficulty in using tools for drawing like rulers and protractors. They may also find using a keyboard or mouse more difficult than other students, and have less tidy handwriting. Teachers should work with the student and their support worker to identify suitable test accommodations, as some may find one form of communication easier than others depending on their specific motor skills. In terms of digital assessments, software tools that require mouse use may be inaccessible, keyboard navigation may be preferred, options to record audio as an answer entry would help students demonstrate their understanding. Therefore, products that allow for full keyboard navigation and voice notes or speech-to-text will be needed to make the product accessible for students with dyspraxia. Spatial awareness is also some students with dyspraxia struggle in, which can affect interpretation of graphs and reading tables. Overlays that cover all but chosen cells or digits within a table can make it easier for those students work with a table (Trott, 2006).

4.2.6 Autism Spectrum Disorder (ASD)

Autism has many symptoms which include but not limited to: social difficulty, noise and other sensory sensitivity, special interests and fixations, stimming behaviours like body movements and making noises for soothing purposes. People who are on the autism spectrum can have any level of intelligence (NHS, 2019), and those with average or above average intelligence are often labelled as having Asperger’s syndrome instead in some literature referred to later in this section, but in the present study the term Autism and Autistic people is used to encompass all people on the spectrum. Each person's Autism is different, which is why many feel that they are impossible to accommodate for in a fixed design. Similar to the disabilities mentioned before, appropriate accommodation should be worked out on an individual level as the situation of each person is different.

Some general guidance on how to set up a good learning and/or assessment environment for Autistic people can be found in The autism spectrum and further education : a guide to good practice by Breakey (2006) which includes room set up, seat assignments and timetabling. Autistic people may gain less benefits from peer feedback in formative assessments because they are using too much energy and focus on the social interaction which will distract them from understanding their misunderstanding on the concept. Some activities in the classroom may become too simulating for them and cause sensory overload and shut down. This would include any noisy activities, it is not to say to eliminate them completely as noise sensitivity is individual to each student, but providing 'time out' or allowing them to leave whenever they need to and providing them a quiet room to retreat to can be very useful.

In terms of digital formative assessments during class, any software with bright colours, upbeat or intense music, sound effects or animation can become very overwhelming for the student. The limitation of sound effects and animations may also be beneficial to students with ADHD who also experiences sensory overload. Any work that is being shown to class should be anonymous whether it be a good or bad example as autistic people can find attention from a group overwhelming. Similarly in summative assessments, bright colours in diagrams should be avoided. Teachers providing feedback after formative assessments should also be autism aware such as avoid direct confrontation and arguments, be flexible in the approach (Breakey, 2006), and check for understanding after explanation because autistic pupils may not be as willing to ask questions even when they do not understand because of anxiety regarding social situations and confrontations. It is recommended that application of concepts are practised and explained more often in formative assessments as "a key skill that MSOR graduates are expected to acquire is problem-solving including transferral of expertise to unfamiliar contexts which students with AS may find more challenging" (Cliffe and Martin, 2012, p.33). If group work is required for some part of the course, assistance in forming social groups would be recommended, such as clearly timetabled activities designed to support all students such as informal group problem solving led by students in higher stages, or mathematical strategy games between students and even staff (Cliffe and Martin, 2012). These activities can help foster social relationships where autistic pupils would not know how to initiate and can be helpful to all students even without the need to do groupwork.

4.2.7 Social disadvantages

Aside from physical disabilities and neurodiversity, there are many social characteristics that are associated with lower participation in higher education, or lower attainment in secondary and higher education. The characteristics may include socio-economic backgrounds, postcodes, age and race. It is important to look at how each characteristic is affected individually and examine their intersection with each other as well as physical disabilities and neurodiversity. However, it is out of the scope of this project to examine the reasons for attainment gaps for pupils from disadvantaged backgrounds, but to suggest how those disadvantages can extend into digital assessments and thus contribute to the widening attainment gap between groups of students.

Pupils from poorer backgrounds can face many barriers in digital assessments, such as inadequate or lack of appropriate devices and no means to acquire one, inadequate or unreliable internet connection, lack of quiet study spaces where they would not be disturbed or interrupted. In a Teacher Tapp survey of school senior leaders in England (2021), it is found that 56% of the most deprived schools can only provide devices to half or fewer students who needed them, compared to 36% of most affluent state schools, and 0% of private schools (The Sutton Trust, 2021). Each university has their own practice to help students to gain access to devices, such as borrowing laptop for duration of their course or having a loan fund for buying laptops. It is also important for students to have a device that is appropriate for their needs, a university student who studies STEM subjects may need a different device compared to a graphic design student compared to a student studying international relations. A student with visual or hand impairments may need a keyboard with large keys. It should not be the case that only one type of device is available for all students who are previsioned a device for education because it may not meet their needs for their course or their abilities. Software chosen for digital assessments should support the devices students have, or their organisations should provide them with hardware that would work with that software as well as any assistance software they would need, otherwise those students would be unfairly disadvantaged.

Unconscious biases can also lead to pupils missing out on support that they require and otherwise would have gotten, this means that some pupils may not get the reasonable adjustments that they need, or software or hardware provisions they require to perform well. Gillborn (2015) examined intersectionality of race and disabilities through researching and interviewing Black middle class families in the UK with children who have disabilities. Despite the parents' are able to mobilise social and economic class capitals, they face much difficulties in getting their children's disabilities recognised and their needs accommodated. This means that when parents have to recognise the disability at home rather than teachers noticing it in the child during lessons because teachers seems to expect poor performance from a Black student, which is common in the UK as examined by many qualitative studies (Gillborn & Mirza, 2000; Gillborn, Rollock, Vincent, & Ball, 2012; cited in Gillborn, 2015). But when parents discloses the disability to the school after an independent assessment (using their own class capital) and seek reasonable adjustments, "in a minority of cases the school simply refused to act on the assessment but in most cases the school made encouraging noises but their actions were at best patchy, at worst non-existent" (Gillborn, 2015, p.281). This means that education institutions' data on provision of reasonable adjustments should be race sensitive so as to identify unreasonable denial of adjustments, educators should doubly examined their reason for denying requested accommodations and second-guess their own perception of Black students to catch and rectify any thought biases. If this is not done then implication on Black pupils in digital assessments can include inadequate support leading to poorer well-being, unfair academic integrity disciplinary actions affecting future prospects and lower attainment due to untapped potential.

The possibility of improved choice and flexibility that resulted in digital learning and assessment is potentially most beneficial to mature students. Since "mature students often have more complex needs than younger students. They are more likely to be disabled, come from more deprived areas, or have family or caring responsibilities"

(OFS, 2021, p.2), they may have more barriers to attend full time courses, thus have in 9.6% lower progression rate compared to younger students in full time, but 20% higher progression rate in part time courses (OFS, 2021). However, the number of entrants of mature students in full-time education has been increasing, while part-time entrance decreased although it is unlikely that there is a transfer from part time to full time students, and it is more likely that higher education has become more impossible for part-time learners due to lack of options (OFS, 2021). In terms of digital assessments, reliable internet could be a barrier for some mature students, “access to the internet varies by region: 38 per cent of students in the North West had experienced a lack of reliable internet access, compared with just 23 per cent in London” (OFS, 2021, p.1), which is an inequality that should be addressed by improvement of infrastructure and provision of wifi hotspots in the meantime. The increased possibility for flexibility of time and location to take assessments, as well as training and support for managing technical problems in their own time (Kara et al., 2019) should also aid in bridging the gap for mature students and their needs. Moreover, personal traits and contextual factors of online mature students should also be considered when designing formative assessments to fit the learning style of the learner (Kara et al, 2019), which may not be the case for most online learning course.

5 Evaluate Tools and Identify Gaps

5.1 Evaluation Criteria

5.1.1 Accessibility

From the literature review, similarities and differences of demands for students in formative and summative digital assessments are found, along with many potential barriers of meeting the needs of students with varying abilities and background. With those in mind, a shortlist of criteria is produced to access the inclusivity or accessibility of some software that are common in secondary and undergraduate Mathematics assessments. It should be noted that there are much more comprehensive accessibility standards for websites such as the Web Content Accessibility Guidelines (WCAG) which all digital content in public sector organisations in the UK should comply to its version 2.1, Levels A and AA according to the CDDO Accessibility Regulations campaign and some of the evaluated platforms have made their compliance of these guidelines available on their websites. This list is a simplified version so that the results are comprehensive, comparable, and specific to mathematics assessments.

Each platform or product is accessed by comparing their functions as described on their webpages or screen captures to the criteria list, if the associated website has documentation on how to provide those features such as an extension, it is accepted. It should be noted that not all platforms have extensive functionality overviews, or WCAG of their platform freely available on their websites and therefore the assessments made against them with limited information may not be fair. Some products are tested if free online trails are available, and online reviews on the products also researched. It can be argued that if a company has invested into making their product assessable, it would be a selling point for their product and they would advertise it as so, and therefore those with little information shows that accessibility is not a conscious part in the design of the product. Due to limited resources, the tests done on these platforms does not include screen readers. Also, note that recordings of sign language translation is in the WCAG Level AAA which means it is not covered in the CDDO Accessibility campaign, therefore organisations are not obligated to provide this accommodation, and none of the products have this as a feature, but for some products there can be alternative ways to provide this. The list of features are as follows:

1. Option to put in alternate text for images and graphs
2. LaTex compatible for writing math equations that is compatible with screen readers
3. Generally screen reader compatible (i.e. support input of headings for easy navigation)
4. Interface does not rely on colour to convey meaning, colours are in contrast and would show clearly even with colour overlay.
5. Software or website interface can be fully navigated with a keyboard
6. Multiple ways of input and manipulate maths equations and graphs
7. Option to provide sign-language videos for each question and answer
8. Closed captioning and transcripts for any video media
9. Adjustable size, font and colour of text and background colour
10. Compatible with external magnification tools or functional with browser magnification of at least 200%

11. Options for media of feedback (voice note, markup etc.)
12. All information needed on the same screen
13. Time not measured per question
14. Multiple ways of answering (typing, voice notes, markup)
15. Option for varied time limits or deadline for each student
16. Anonymous question asking option for in test communication with teacher
17. Windows and iOS compatible (if applicable, compatible with multiple popular browsers of both systems)
18. Tablet, mobile and desktop compatible
19. Option of offline mode
20. Technology technical support available for students and teachers on accessibility
21. Large buttons for easy interface, and/or buttons responsive in low resolution.
22. No music, sound effects or animation that cannot be toggled

5.1.2 Features for Enhancing Learning

The benefits of digital assessments that can be gained by the students are also dictated by the other features within the platform. As discussed in the literature review, formative and summative assessments have different demands that would allow for their effectiveness, and each platform offers different features such as question types, answer formats, feedback formats, time limits and proctoring options. Therefore, aside from the accessibility criteria, platforms will also be examined for their features and compared to students' needs for mathematics formative and summative assessments respectively. Table 1 shows an overview of features that are preferred for formative and summative assessments as found in the literature review. In this section, a summary of the target market and functionality would be given for each website, followed by their accessibility evaluation. The aim of this is to help any student or teacher looking for an assessment software to have an overview of what the market is currently offering, the evaluated platforms have paid and free, open-sourced options, and features to suit different needs.

Table 1: Preferred Features for Assessments	**Formative**	**Summative**
Include open-ended questions	✓	✓
Can show steps of developing the answer	✓	✓
Include graphs in answer to aid understanding	✓	✓
Time and progress displays which can be hidden	✓	✓
Technical support available	✓	✓
If only close-ended questions, elaborate feedback is given for embedded analysis	✓	
Raw and processed extracted data ready for teachers to use	✓	
Anonymisation of answers automated or with blurring tools available for teachers to use	✓	
Anonymous direct or group discussion with teacher during exam		✓
Individually customisable test accommodations such as extra time, dictionary available		✓
Online proctoring option developed with respect and fairness in mind, or no proctoring option		✓
Customisable time reminders, layout configuration		✓
Emergency management such as reporting and solving technical problems		✓

5.2 TopHat

TopHat offers a platform aimed at secondary and higher education to facilitate formative and summative assessments in the forms of polls or quizzes, class discussion, assignments, online proctoring and class insights. Aside from assessments, TopHat also offers attendance taking, interactive textbooks and digital lab manuals with videos, assessment questions and fillable experiment results template. Its in-class participation polls and quizzes has 14 different question types including maths response questions which is in beta, and 11 types for automatically graded assignments. Class discussion involves moderated live chat threads of specific discussion question, where participants can get graded for their participation and correctness. The basic features of TopHat is free, but the paid option of around £28 per student per year is needed to add on features such as creating tests and assignments and auto-grading. The maths response questions is said to support equivalent response however it is a third-party plug-in, which means that TopHat has little control over its quality and accessibility.

One of TopHat's selling points on their website is their accessibility features, the website features four articles on how to create accessible course on TopHat, focused on the platform, test accommodations, textbook and assignments, and synchronous content delivery respectively. Aside from those, they have VPATs for each of their applications, from the TopHat website to the professor web interface to student iOS and Android app. Although there are places for improvement, it is very good practice of a business being transparent about what the shortfalls are and what they are doing about it.

TopHat Web App meets most of the accessibility criteria set above, it has also achieved Student Web Experience WCAG 2.1 Level AA compliance in 2020. It is compatible with platform screen readers such as JAWS, NVDA and VoiceOver. Most images used in the Top Hat Web App are provided with appropriate alternative text, except for presentation slides which are presented as images and are not compatible with screen readers and no alterative text. Most of the web app can be control using only keyboard except for cases where third party widgets are used. The headings and labels in the Top Hat Web App are descriptive so that users can find information they need efficiently. Text can be resized without assistive technology up to 200 percent without loss of content or functionality. TopHat web app supports the 3 latest versions of Google Chrome, Firefox, Safari and Microsoft Edge, but it is optimized for Google Chrome and Firefox. The iOS app and Android app also supports most of the WCAG Level A and AA.

Its limitations include: The exception of third party widgets being included in ability to navigate fully with keyboard control means that it is unlikely that the maths input in the maths response type questions are supported, therefore not recommended for mathematics assessments. Also, there are currently no inbuilt option to change the background colour or contrast of the interface but it should work with browser extensions. Also lack alternative options to manipulate graphs and equations, no designated ways for sign language users to access questions and provide answers. However, it is possible to embed videos from YouTube and Vimeo videos in questions or discussions, also TopHat is running a demo of video assignments where students submit video assignments. So, this maybe a work around for students who may prefer using sign language to submit coursework. Overall, TopHat maybe a good tool for non-mathematics assessments, or only for simple multiple choice questions in class.

5.3 Numbas

Numbas is a free, open-source web-based system used for designing digital assessments from Newcastle University. It is used in higher education, schools, and commercial training. Its editor is free to download from their website, the produced tests can be taken online, in a VLE, or offline on a USB or DVD. So unlike most of the other programs, Numbas is designed to be primarily an assessment design tool, teachers can choose to distribute it in the way that suits them and their students, other than fixed on the same platform like most paid services. This also means that teachers would have to make their own arrangements in terms of communication between teachers and students during tests, technical logistics, and proctoring if applicable.

Numbas supports both formative and summative assessments, a plethora of settings allow for teachers to control the assessment style, such as different ways to sequential or randomise questions, allow translation of interface to different language, whether student can go back to previous questions, whether they can navigate from a list, whether is test is timed, if breaks are allowed, whether students can try a similar questions after they finished the current question, or reveal advice, an elaborate feedback which contains a worked solution of that problem and many more. Numbas do not automatically accept equivalent response, teachers have to set up specific alternative answers, or specific alternative errors where they can give relevant feedback message.

Numbas' programming is written in a way that would work well with many LMS i.e. SCORM compliant. Its documentations has extensive information on accessibility of the student view, the editor view, and the accessibility of its default theme, but states that the author of the exam has ultimate responsibility of making the test accessible for their students, Numbas cannot control third-party themes and extensions.

Overall, exams made on the Numbas platform has the potential to be very accessible, 18 out of 22 of the criteria met. Numbas is tested to be able to run on a variety of browsers in different devices, these include: Chrome, Firefox, Internet Explorer, Edge, Safari on desktop, iOS (iPhone/iPad) 8.0 with Safari, Android 5.0 (Lollipop) with Chrome. On its exam accessibility page, the following features are stated to have been designed around:

- *Still usable when zoomed to 200%.*

- *Colour is never used as the sole means of conveying information.*
- *Ensure a colour contrast ratio of at least 7:1 (WCAG level AAA) throughout the interface.*
- *The interface can be navigated entirely with the keyboard.*
- *All content on the page is screen-readable, with sensible descriptions.*
- *Very few animations; reduce motion as much as possible when browsers request it.*
- *Layout is responsive and usable on screens with a variety of resolutions, including mobile devices.* (Numbas, 2019)

Other than these features, Numbas also supports changing background and text colours, images can be enlarged to nearly fill the screen by clicking on the image. Its accessibility page also describes fully what to expect when interacting with a question, a particular interest is "When the answer is a mathematical expression, a rendering of your expression in conventional mathematical notation is displayed after the input box. This rendering updates immediately whenever your answer changes. If the answer you have entered is invalid, a box with an explanation of the error is shown next to the input box, as long as the input is focused. Screenreaders will read this explanation as soon as it appears" (Numbas, 2019). Numbas uses MathJax accessibility extensions to provide interactive exploration of mathematical notation.

5.4 Stack

Stack is a free, open-source automatic assessment software for mathematics, science and related disciplines by the University of Edinburgh. It is aimed at higher education but can be used in schools. Its philosophy comes from the believe that student provided answers are better than teacher provided answers such as multiple choice question in Mathematics, but at the same time, teachers and students should not need extra coding skills to author or answer questions. There are many input types, from simple true and false answers to mathematical expressions and plots, but the default input box is an HTML input box into which a student is expected to type an algebraic expression, students can be provided with a validation button where they can check if their expression entry is what they meant before submitting, mathematical equivalent entries can also be accepted unless stated otherwise. Stack also allows multipart questions, in which the assessment of part (b) of a question takes into the account of the student's answer for part (a) and therefore a student can get credit for part (b) despite getting the wrong answer in part (a). Step-by-step reasoning by equivalence is under development in 2021, in which Stack will check if each iteration is mathematically equivalent to the previous one, and if the first line is equivalent to the set question.

Stack is part of Moodle, which is a free and open-source learning management system (LMS), this means that its accessibility features are aligned with Moodle, and its mathematics display system is MathJax. "MathJax is an open-source JavaScript display engine for LaTeX, MathML, and AsciiMath notation that works in all modern browsers, with built-in support for assistive technology like screen readers" (MathJax, 2021). Stack's documentation does not include its accessibility features by itself, but rather point to accessibility features of Moodle and MathJax. The Stack demonstration site has a course that uses a series of sample questions and explanations to teach students and teachers how to use the tool, but no instructions as to how to make tests accessible. It is difficult to verify some of the features and criteria because the documentation on those websites are also vague, and not specific to the Stack tool itself. The layout of the demonstration site is not intuitive and unwelcoming. However, Moodle received WCAG 2.1 Level AA accreditation and its app also received WCAG 2.1 Level AA accreditation. Moodle officially supports the latest versions of the screen reader/browser configurations: Microsoft Edge with Jaws 15+ and Mozilla Firefox with NVDA 2014.1+.

5.5 Nearpod

Nearpod offers a platform aimed at primary to secondary education for in-class presentation, activities and formative assessments. It works in three modes: live participation in class, where students use their own devices to answer questions or engage in activities when teachers set it during the lessons in-person or online; student-paced, where teachers set the lesson as homework so students will work through the presentation slides and activities in their own time; front of class, where only the teacher is using the presentation in front of the class and students participate without need for devices. Nearpod does offer a variety of question formats for its formative assessment section, which include: open ended questions which can be answered with text, recorded audio, or both, matching pairs, quiz, polls and more. Some of these support reference media, which are media such as PDFs, audio, video, images that students can use as reference before answering the question. Teachers can access students' answers via post session reports as well as in real-time, answers can be anonymised by toggling to hide students' names before sharing with the class.

Nearpod uses Immersive Reader from Microsoft which works with most Nearpod's slides and activities, but not if a PowerPoint is shown on Nearpod platform (Torres, 2019). Immersive Reader may not pickup the nuances of more complex mathematical content, and alternative text is not available for images, but screen reader would work on Nearpod as with any other websites. Along with Immersive Reader, Nearpod offers different font, font size, spacing, background and text colours and focus mode of one and five lines, or paragraphs. Translation of single words are available in 60 languages. The variety of format to answer is encouraging, but not all are accessible, Nearpod is clear about what answer formats are available for each activity and what support media is available in each activity on their website. If any of the activities are not accessible to all of the students in the class, it should not be used. For example, if a visually impaired student is in the class, the matching pair quiz that features matching graphs to equations should not be used as it is not supported by immersive reader and screen readers as it is an image with no alternative texts. Lessons can be duplicated and activities can be swapped for students with different needs, so instead of a matching pair quiz, a student may get a quiz instead. There are 3 ways to join a Nearpod lesson, via entering a 5 character code on the Nearpod website, via a link, or embedded into a LMS, but all requires an internet connection throughout. Nearpod supports the following browsers on computers: all computers on the latest Google Chrome browsers, Mac OS devices using OS 10 or newer with Safari browser. On mobile devices they recommend using the apps: iOS version 13.0 or newer, Google play store app on Android devices version 6.0 or newer.

5.6 Showbie

Showbie is a tool used for mostly out-of-classroom formative assessments aimed at Key Stage 1 to 4, teachers can assign worksheets or diagrams to students in forms of pdfs and images, which students can annotate in the form of text comments, the pen tool (which allows them to draw and write directly on the page) and pinned voice notes. Teachers can use the same tools to annotate students' work to give feedback, as well as grade them in the teachers' interface. Teachers have a table for the updates on their assignments as students upload them. Showbie is not specialised in delivering maths content and math displays in is not supported.

Showbie's accessibility statement does not have any practical examples of what aspects on their platform is accessible, even though they stated that they are working to be more accessible. They stated on their website that their team is working towards accessibility by "compliance to WCAG 2.1 AA web standards and mobile accessibility best practices" (Palanca, 2021), it is unclear how much of the standard is currently applied to the product. By getting into contact though their website, more information is provided, such as Showbie uses a built in text-to-speech reader in their iOS app, and enlarge text by zooming; browser magnification is supported on the web-app. It should be noted that text-to-speech software is different to screen reader, text-to-speech does not recognise headings used for navigation, and also does not identify media such as images and tables and tell the user what they are hearing. They explained that they do not have a comprehensive list of accessibility features as most classrooms use the built-in features of the iPad or their own devices. Each classroom is setup so they do not have a list of these features. Their support website has a guide on Showbie symbols, in which some of those symbols are the same in shape but different in colour which indicate different meanings. This means that they do use colour as the sole indication of meaning in their displays.

5.7 Socrative

Socrative is an app that is focused on in-class formative assessments from Year 9 to higher education, it provides a tool to produce automatically graded close-ended questions, which teachers can see the result of in real-time. There are six type of activities: quiz, space race, exit ticket, multiple choice, true or false, and short answer. Teachers can adjust delivery methods, such as students receiving instant feedback or marked at the end of the quiz, or teacher can control the pace of the quiz. Other settings such as anonymity of quiz results, shuffling order of questions and answers, and whether student only get one attempt. For multiple choice and true or false, there are no options to enter the questions or answers in the interface, teachers are expected to read the question aloud or display it on the board themselves. As discussed previously, split screen medium maybe inaccessible to some pupils, so if teachers are aware that students may struggle with these, then do not use these tools. Space Race is a gamified quiz that can be played individually or in a team with the same device or multiple devices. Whereas the Exit Ticket is designed to get feedback from students before the lessons ends, it involves the students rating the lesson, write down what they learnt in class, and answer the teacher's question which the teacher would read aloud or display on the board.

Socrative is acquired by Showbie in 2018 and its accessibility statement is written by the same person, so it is expected that any questions on accessibility would get similar answers. However, maths editor is supported in Socrative and it does use LaTeX although students are not provided with the maths editor for answering questions, nor equations can be part of a short multiple choice answer so the possibilities are limited. There is an option to add feedback for students to view after they answer, the feedback appears regardless of the accuracy of the answer. From a short demonstration video on their website, there does not seem to have any instances where colour is the sole indication of meaning within the interface for students and teachers, such as accuracy of answer on the teacher instant feedback screen, the teams of the Space Race game and the types of questions or its status on the navigation bar. But the toggle buttons for teachers to adjust quiz settings are indicated only by colour (blue means on, grey means off). Some articles demonstrate further how the app works, which shows that images can be added to questions, but no alternative text option is allowed. However, teachers can and should add image description in the question if it is needed. It can run on mobile, tablet, laptop and desktop, with the two most recent versions of Chrome, Safari, Firefox and Microsoft Edge.

5.8 MyMaths

MyMaths is a tool used for mathematics lesson delivery and formative assessment aimed at primary and secondary schools in the UK. Lessons are available for students to do in their own time, with questions available within the lesson to check students' understanding. Homework tasks can be set by teachers, but students can also access them for revision by themselves. Teachers have access to students' results and answers, extracted analysis to help know students misunderstandings. MyMaths only offers close-ended questions that can be marked automatically, only instant knowledge of results feedback is given. However, each homework topic have an interactive lesson attached to it and MyMaths has been adding video content on secondary topics in 2021. Each student is given a different set of questions to their peers assigned the same activity, this can reduce copying between pupils, and since it is formative assessment, fairness is not prioritised over learning. This high volume of data means MyMaths cannot store students' answers for more than two weeks.

Its accessibility page has not been updated since 2018 and focuses on moving away from Flash, which as been disabled by default by the end of 2020. However, along with that change, all MyMaths lesson, homework tasks, worksheets, and booster packs for Key Stages 1 – 4 are tablet compatible. Also has features to aid keyboard navigation such as tabbing and initial page focus, this means that keyboard users who uses 'tab' keys to navigate pages can navigate to interactable items such as buttons, answer input spaces etc., and can be activated through the keyboard without using the mouse. It also changed its interface does not rely on colour to convey meaning and reduced iconography, options for colours for images to be in higher contrast, browser extension colour overlays will work on MyMaths and option for overlays within lessons in MyMaths as well. The teacher interface uses red, yellow and green to indicate students' score levels in assignments, overlaying the percentage scores. MyMaths is supported on Chrome, Microsoft Edge, Firefox and Safari. The interface of MyMaths is clear and does not have any scrolling elements, so all information is on the same page in the browser, there are sometimes pictures next to the homework tasks but irrelevant to the task itself, it is unclear if there are alt text for these pictures or any graphs that are in the homework tasks which is part of the UK curriculum.

5.9 Pixl Maths App (PMA)

PMA is an app aimed for providing online and offline mathematics practice for GCSE. It is provided by Pixl, which is an organisation that provides paid membership services for primary school to Key Stage 4 education providers. The app provides close-ended questions for formative assessments with embedded analysis and videos as elaborate feedback which the app calls ‘therapy’, it should be noted that the therapies are not answer specific, so the theory would not change depending on the misunderstanding. Extracted analysis is also provided in the form of PDF and CSV files. Its unique selling point is the built in scoreboard that is used by many schools in their rewards programme.

PMA has no accessibility statement on its website, but it does have a series of videos that show how the app works. From those videos, the following is observed: the user interface is unnecessarily small compared to the screen, most of the unused area of the screen is replaced with a distracting background, which is a blackboard with a series of mathematical equations scribbled over it. This may be because the demonstration is on a landscape laptop display when the app would normally be used in a portrait tablet display. There are no options for colour overlays, text to speech, size or font of text, and unclear if work with screen reader. There are more than one instances of colour being the sole indication of meaning within the interface.

5.10 Hegarty Maths

Hegarty Maths is an app for formative assessment aimed for Key Stage 3, GCSE and IGCSE, but have produced video content for A-Level mathematics online as well. The app provides close-ended automatically marked questions with embedded analysis plus knowledge of correct response, but it also provides a way for teachers to leave written feedback on the incorrect answer. Teachers get extracted analysis on their platform including time spent on the whole exercise, time spent watching the topic related video prior or during the assessment, number of questions attempted and overall percentage score.

Hegarty Maths also has no accessibility statement available on its website, but it does have one demonstration video. From that video, the interface does not appear to have colour overlays option, text to speech, size or font of text, and unclear if work with screen reader. However, it seems that there may be one instance of colour being the sole indication of meaning within the interface for students and teachers, which is the retry button being in orange or red depending on how well students did.

5.11 Mathspace

Mathspace is platform focused on formative maths assessment and teaching for secondary school students. It has adaptive learning assignment tasks, interactive textbooks, step by step hints and feedback. Its website has many articles on the layout and features for students and teachers, with annotated screen captures of the interface. Interactive textbooks are out of scope of this project but the adaptive tasks and hints and feedback on steps can be discussed further.

Mathspace has mostly close-ended questions but they support the steps in developing the answer. In some questions there are different valid paths which it can give hints and feedback on, and the engine recognises mathematically sound paths that were not part of the pre-set paths and therefore cannot offer hints, but students will not be penalised for the step. The automatic marking and hints system can help students to assess their own work, and make adjustments to their thinking using tools such as lesson notes or videos which can be opened on a different tab to be used alongside their work.

Students are encouraged to use tablets for the tool, where they can both use the screen interface to type their steps and write out their steps which the app will translate into typed mathematics, students can edit the typed mathematics if the translation was not what they intended. Students can also type their answer on a laptop or desktop in the browser, keyboard shortcuts are provided on screen, or can be clicked on the interface if needed.

Teachers can monitor students progress as a class or individually on their laptop, and use those to set tasks depending on the student’s needs. Teachers can set an adaptive task for students for specific subtopics and different mastery levels, which students can choose to stop working on after a set amount of questions if they find the task too difficult or exhausting. Adaptive task means that if students get similar type of questions right they will not be ask that type of questions anymore and more difficult ones will be asked. In order to gain Mastered status they would not need to answer all the questions but rather get some of the most difficult questions correct.

Mathspace is used as a part of a case study in the Raising Achievement through Formative Assessment in Science and Mathematics Education (FaSMEd) project led by Newcastle University. In which Year 10 Set 2 students and their teacher were interviewed after having three lessons, one of which delivered using Mathspace. As the case study was done in 2015, the software may have improved from then, but the input from students and teachers maybe valuable still. For example, students still found Mathspace too structured or rigid in its thinking, one student Annie said “I personally found it quite difficult, because it’s really structured and you couldn’t get one thing wrong, or you couldn’t do it any different way or you had to do it the way the Mathspace wanted you to do it. And so I found that quite annoying because if I had a different way of doing it, it wouldn’t let me do it, it would just say it’s wrong” (FaSMEd, 2015). Also, some students find that the hints and feedback not as valuable as a teachers because Mathspace would not be able to tell them specifically what they got wrong in their reasoning like a teacher would.

A possible limitation of Mathspace is that it focuses on individual learning, teachers cannot view the step by step work of each student, only students can view their own past work. Teachers used Showbie to project students’ work as example and review tasks that way, which led to problems such as the font being too small to read on the projector. However, teachers can see what questions most students are struggling with and can project a blank student view page of that question to work through in class.

It is recommended an iOS app is used when using on a iPad, it runs on the latest two versions of iOS and only when online. For Android tablet users, a minimum screen width of 768 pixels and latest three versions should be supported. The latest two versions of these browsers are supported: Chrome for macOS, Windows and Chrome OS, Safari for macOS, and Microsoft Edge.

It has an accessibility mode where the downloadable printable worksheets for specific exams can be used with a screen reader. These worksheets are designed to be done outside of the Mathspace interface, so students would need an alternative way to complete the work and send to teacher for feedback as the feature is meant for students to complete offline. Mathspace has comprehensive notes on how to use this feature, and what browsers and screen readers this feature is compatible with. Mathspace was contacted to confirm that screen readers can be used in tasks other than worksheets, whether students are in accessibility mode or not.

Some colour representation problems may arise from the icons in the teachers view that depicts number of correct, partially correct and incorrect answers, where both correct and partially correct icons are ticks, one in green, the other in yellow.

5.12 Möbius

Möbius is a platform for maths assessment with focus on Key Stage 4 to higher education. It has options for both formative and summative assessment, mostly focused on more out-of-classroom type assessments, with lessons that can be complete in students' own time. Assessments can be created from pre-set questions or teachers can author questions themselves, there are many assignment properties that can be adjusted such as the type of activity (Homework or quiz, proctored exams, anonymous practice, mastery dialog, study session dialog), set maximum attempts, individual time limits, toggle hints, control allowance of equivalent responses (algebraic, equation, numeric, unit), grading during assessment and more. These options are for automatically marked close-ended questions but there are other options to set assignments that are essay questions, or document upload question.

Möbius can be integrated into many course systems through its compliance with the LTI standard. It also has adaptive testing features, where teachers can organize assignment questions into separate branches or difficulty levels which the rules of switching branches are customisable for the teachers. Möbius also support calculating scores and setting up marking rubric that occurs outside of its platform so that teachers would not need to switch platforms to record offline assessments, or assessments that Möbius does not support such as oral presentations.

There are two ways to input equations in Möbius, the text mode and the symbol mode, in which text mode allows users to enter symbolic or numeric expressions in a single line using a regular keyboard, it uses the Maple syntax, and it allows you to preview your entry in rendered maths before submitting. Symbol mode uses an equation editor, where tools are given for users to find the symbols and operators they need and assemble the equation by clicking on a mouse, it is unclear if symbol mode can be operated on keyboard. Möbius VPAT statement by DigitalEd states that maths on Möbius is rendered using MathJax, therefore any screen reader that supports MathJax will be able to read maths in Möbius.

Teachers may set tasks that requires students to sketch or interpret a plot, or have responses that can be previewed as a plot. These are not supported with alt text. The items that would support alt text in Möbius are images within a question, slideshow or lesson. The platform can be navigated by keyboard, but sketching and Free Body Diagram response areas do not support keyboard input, but their inclusion in content is not required.

5.13 Gradescope

Gradescope is a platform for out-of-class assignments or assessments, it offers options for hand-written, paper-based assignments and digital assessments. It is mostly marketed to higher education, with a wide subject possibility such as mathematics, computer science, physics, chemistry, biology, economics and engineering. Its paper based assessment has a similar concept as Showbie, which is a document file can be downloaded and printed, edited by hand digitally or by ink, then scanned and uploaded again for marking. Gradescope is more sophisticated because it is more customisable, teachers can choose whether the work will be upload by students or teachers, whether the work is variable length or fixed length. Variable length work means students can mark which question is answered on which page of their uploaded document, whereas fixed length maybe more suitable for a printed worksheet which students answer in the space given. Teachers can manually form answer groups so multiple markers can mark different question groups simultaneously. AI Assisted grading is supported in paper-based assessment for multiple choice questions and fill in the blank answers for English and Maths notation (including fractions, integral signs, etc.) which the AI can read.

Digital assessments are in beta for Gradescope in 2021, it allows students to complete their assignments in the Gradescope interface. It supports automatically graded Multiple Choice, Select All, and Short Answer, but also provides Free Response, and File Upload fields. The question authoring interface allows teachers to format the question using Markdown (for inserting headings, images, alternative texts, clickable links, code blocks, tables, bulleted and numbered lists, bold/italicize text, and more) and LaTex (for formulas and equations). Explanations and answers can be set to become visible after students answer correctly, and/or after the assignment due date.

Mathematical equivalents can also be set as correct manually using LaTex in the question editor. Assessments can have a time limit and extensions can be set for individual students for individual assessments, no bulk edit of time limit for individual students is available yet, but course wide extensions can be done. LockDown Browser Powered by Respondus can be enabled for a formative assessment, which will open a separated, sevure browser where students cannot open other tabs, or have other applications in the background, but adding and removing applications from blocklist can allow students to use applications such as Zoom for proctoring, or screenreaders for accessibility.

Gradescope joined Turnitin in 2018 and its VPAT is available to download on their website, it accesses Gradescope using the WCAG Level A and AA, which it supports almost fully, with exceptions that are somewhat fundamental to the design of Gradscope itself. “A fundamental interaction of Gradescope is to grade images (or scans) of handwritten student work. While these images contain alt text to identify each image, it is not possible for Gradescope to translate the content of these images into text” (Gradescope, 2019). This can be worked around by using the digital assessment option, whist free response only allows multiple paragraph text response, file upload allows students to upload any file type such as PDFs, images, and codes. Gradescope supports the latest 2 versions of Chrome, Firefox, Safari and Microsoft Edge, it does not have a mobile app at the moment, but it recommends using Evernote Scannable and Genius Scan for uploading files via mobile devices as an alterative to a scanner.

5.14 Inspera

Inspera is an end-to-end assessment platform marketed towards higher education, public sector, awarding organisations and even primary school. They are focused on summative assessments, user organisations are provided with three options of assessment security: basic assessment portal that covers the whole assessment cycle (schedule, design, deliver, mark, share), the exam portal which includes a lock-down browser, and a proctoring tool which has options of human or AI invigilation through sharing of webcam, screen and microphone.

Inspera supports 24 question types, which includes numeric entry, maths entry, maths working, upload assignment and audio recordings. However, Inspera Assessment requires the answer to be identical and does not have options to mark equivalent answers automatically. Also, there is LaTex mode for writing LaTex directly in question text and can toggle modes to check accuracy, however, the feature does not seem to extend to student entry according to the help centre of Inspera. Maths working questions are manually marked questions, it is likely that maths entry questions will benefit from manually marking as well, because even a space in between symbols can make answers non-identical to the answer and be marked wrong.

Inspera does not have a VAPT but it does have an accessibility statement, in which the visual elements of Inspera is well organised for the test taker through "test taker's settings panel, exam content (including font) in Inspera can be magnified, both by using predefined enlargement sizes, regular, large and extra large, but also by using zoom functions on the web browser, keyboard/mouse shortcuts or accessibility tools. Test takers can also invert the colour scheme for better contrast" (Inspera, n.d.), they also say that they support screen readers as well as have a built-in text-to-speech tool that requires users to highlight the text and press play. Although the lack of LaTex maths input put question on the ease of access for full keyboard users and visually impaired and blind users, Inspera Assessment for test taker is compliant with WCAG 2.1 Level AA except for the 400% zoom requirement without horizontal scroll (200% zoom instead) and text spacing changes not compliant for drop down menus. This means that technically Inspera can be controlled fully with a keyboard for test takers, but that is not the case for content managers, invigilators, markers and test administrators. Normal assessment mode can be used on the latest two versions of Firefox, Safari, Microsoft Edge and Chrome, but the other two modes have more specific requirements that can be found on the website, they do not have an app and some question types tend to freeze when orientation changes on a mobile device. Since Inspera work with the public sector who have more obligations to comply with accessibility legislations, they are obligated to comply with those legislations as well, which means they work with their clients to make the tests they design to be compliant to accessibility legislation.

6 Recommendations

6.1 Key Points to Consider

Although the aim of the project is to make recommendations for both secondary and higher education in terms of assessment formats, content, and approach that will enhance learning for disadvantage groups in higher education, from the literature review and evaluation of tools currently on the market, it can be easily concluded that there is no perfect tool for digital assessment that would enhance learning for everyone. A good tool is always a tool that suits the needs of the pupils and teachers, this depends on many factors of circumstance. Therefore, key points to consider before choosing a digital assessment software are list below with some explanation and examples based on the information gathered in sections 5 and 6.

- **Accessibility of Digital Tool**: Consider the needs of students currently in your class, and future students, the features they would need to get the most out of digital assessments. Make sure that any tool adopted is accessible for current students at least, and it is best to find the most accessible tool possible to ensure future students will not be hindered by the tool chosen. From the tools evaluated, none of them are perfectly accessible, but some clearly have done more work to make their tool accessible, and the companies are transparent about what they need to work on. The ways that accessibility is communicated from the company indicates whether they are willing to work on improving access in the future. This is important because it is more difficult to change platform as data takes time and resources to transfer to the new platform if it is able to at all.
- **Accessibility of Devices and Internet**: Consider availability and quality of devices and internet connection as it will massively affect the accessibility of your course if you chose a software that student cannot use. For example, if some pupils have very poor internet connections, then Stack and TopHat would be preferred because they offer offline modes, Gradescope can work too if you give enough time to scan and upload documents. Also consider if there are sufficient resources to support students and staff on the technical side of the software.
- **Accessibility of Assessment Format**: Know that this product's accessibility is not the only one you would have to think about, the whole process of the

student's assessment must be assessable, for example, if a student need to use a tool such as Matlab to solve a problem with a graphical output, produce a report and submit on Gradescope, although Gradscope may be accessible, the work itself involving visual elements will not be accessible to a visually impaired or blind student anyways.

- **Free and open source or paid services**: Although free and open source platforms like Numbas and Stack maybe more budget friendly, be prepared to spend more time to prepare questions. Free platforms have some questions that are provided by other users, but they may not be suitable for your curriculum, or accessible to your students and need to be checked over and improved. Time is needed for staff and students to learn how to use the software for both, but usually there is more reliable support for paid services. Open source platforms may have more potential for customisation but they lack staff for support if problems arise. Overall, there are more paid services, but their fees and what they offer are all different, some have free offerings but need to pay for the full features. The decision would depend on your budget and the features your organisation needs. Note that some paid services have price plans that are per student, whilst others are per course/class or offer institution licences, so this may also be factored in when considering budget.
- **Formative or Summative assessment**: Most of the tools evaluated were for formative assessments, only Inspera is aimed at summative assessments. Some products such as TopHat, Möbius and Gradescope have options for proctored exams or submitted summative assessment such as reports for Gradescope, whist some such as Numbas and Stack have possibilities to integrate with other proctoring services. Choices are more limited if digital summative assessments is needed for your course, which narrows down your search.
- **In-class interaction and/or Homework**: Some tools are only for in-class interaction (Socrative); some are only for homework or individual work during class (Numbas, Stack, Showbie, MyMaths, PMA, Hegarty Maths , Mathspace, Möbius, Gradescope); whist others do both (TopHat, Nearpod). Having an idea what you primarily want to use the software helps you find what you need. It is entirely possible that you would need more than one software to enable different teaching and assessments.

- **Focus on Mathematics or used in Other Subjects**: Some schools may find it more helpful to have one system for most subjects due to ease of access, budget, and training time. However, a focus on mathematics is beneficial for the software in this case because in many cases the mathematics focused tools have specialised features for maths communication such as use of LaTex math displays and reasoning by equivalence. Mathematics computational intelligence of products vary, some can support much more complex mathematics than others, a specialised product is much more likely to have a powerful engine that can support university level mathematics.
- **Complexity of the Mathematics Taught compared to the Computational Intelligence of the Products**: Always try some sample questions of all of the courses planned to be assessed on this product and see if its math displays and reasoning by equivalence are acceptable for the level of maths you will be teaching. Products marketed for secondary level will most likely not be able to support university level mathematics.
- **More Customisable or more Rigid**: Depending on the purpose of the tool and teaching style, customisation may or may not be important for you. More rigid systems such as MyMaths, PMA and Hegarty Maths may be more desirable because teachers will spend less time to set up the work and mostly pre-set questions are used. On the other hand, customisable products allow for flexibility and adaptability, meaning that teachers maybe able to use the tool for more than one type of work and suit different needs.
- **Feedback Type and Medium for Feedback**: Each of the products considered have different medium of feedback, most of them have extracted analysis when automated marking is available, but only some give options for elaborate feedback which is considered to be the most effective. Elaborate feedback that can be tailored to the students' response is even fewer. However, this may not be the priority if teachers plan to use extracted analysis to tailor future sessions, or give individual feedback through one-to-one meetings. If long form answer summative assessments are considered, clear marking criteria that can be displayed to the students before and after marking might be preferred over other feedback types.

- **LMS Integration Support**: If your organisation uses a LMS to keep all students learning resources in one place, having a product that does not transfer their results and information to the LMS causes a lot of extra work and lead to poor communication. Therefore, checking the integration between product and LMS, even if the company claim that they can integrate, should be one of the major tasks before putting more resources and time into the product.

6.2 Information to seek out

- **Your organisation's accessibility obligation**: In the UK, websites and mobile apps used by the public sector has to meet accessibility requirements as set by the UK government. Check what obligation your organisation has to provide in terms of accessibility can give a useful guideline and motivation as to what product features you need to look for.
- **Your students' reasonable adjustments**: Communicate with students with or through your organisation's disability coordinator. Find any reasonable adjustments your students need, whether they have specific accessibility software that they already use and if the product you will choose will be compatible with their chosen software. For example, some products have recommended browser and screen reader combinations, so it would be more helpful for you and your students to work out the logistics of using the software before committing to the product.
- **Your students' devices and network connection**: Make sure that all students can use the software you choose with the hardware they have, check the technical requirements of the software either on their website or ask the product company directly. Inform students the technical requirements well in advance before purchasing a device, or make sure your organisation can provide adequate hardware, or choose a software that can run on students' current technology.
- **The Product's VPAT**: Check for accessibility statement and VPAT on their website, if it is not available, ask for the VPAT, it is voluntary so some companies might not do it, but that would also give you an indication of how seriously they take user experience. It would be better if a product specific VPAT is available, for example the browser interaction would be different to an iOS app, which can

also be different to an Android app. This is the time where knowing students' devices would be useful.

- **Trailing the Product**: Test the product before committing to fully integrate into your teaching, for example, if marking by equivalence is used, check if it works well with help from colleagues and even students, make sure that it works for the highest level of mathematics that is taught. Also, test the integration of the product to your organisation's LMS, some products and LMS system combination are more compatible than others. Ask the provider about trail periods and work with your organisations' IT department to examine the LMS integration, usability, consistency and data integrity.
- **The Company's support policy**: The type of support the product company supply, such as technical support to teachers and students, a comprehensive help centre web-page with multi-media instructions, and whether there is a priority list for paying or non-paying customers. The quality and efficiency of support will affect your workload and workflow, so it should be factored into planning.
- **The Company's developments**: Find out what the product company is working on, such as new features and accessibility improvements. Since some product company might work on a feature that is of no use to you, and therefore put less effort into the feature you would prioritise, then the quality of your user experience may decline over time.

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