Bolstering Online Learning and Teaching in Mathematics

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Abstract. Choosing the right digital educational tools is essential to achieving successful outcomes in the delivery of an academic course. Elements to be considered in choosing a particular course include the ease of navigation, student interface, feedback mechanisms, assessment and grading options and the ability to integrate with various learning management systems. STEM courses present extra demands on requirements, especially Mathematics, where symbolic notation is key. It is not always easy to find mathematical education software where students are able to easily enter their responses in mathematical statements and where the system is robust enough to interpret acceptable variations in input, and successfully guide students where partially correct answers are given. We discuss the suitability of the BOLSTER platform in meeting the challenges of an online mathematical teaching and learning tool. Although initially designed to provide support to foundation students in mathematics, the platform has extended its support to courses in statistics, physics, chemistry, programming (Python) and advanced courses in mathematics. We review the data base of material and courses and the ease of augmenting and tailoring courses according to specific needs. The ability of BOLSTER to generate unique assessments for each student through randomization and the use of proctoring tools is elaborated on, in considering its suitability in ensuring integrity requirements are met under examination conditions.

Keywords: Digital educational tools, mathematical education software, BOLSTER platform.

1 Introduction

The use of digital educational tools in the teaching of mathematics, and in teaching in general, has had its fair share of detractors in the last two decades or so. Many were forced to re-evaluate their positions with the advent of the CoVid-19 pandemic and the drastic lockdowns imposed by many governments worldwide. With career-defining choices to be made, there were many converts to the use of online teaching tools. However, previously voiced concerns do remain legitimate and many new concerns emerged from the approaches adopted during the lockdowns. As students worldwide were forced to take classes remotely, a new era of teaching and learning was entered into. With the world emerging

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into a CoVid-19 post-lockdown era, there can be no question of a return to the status quo – the face of teaching and learning has been changed, indelibly. The challenge is not to find a way to return to old ways but to make the right choices for the new era we find ourselves in. One is choosing the right digital tools to suit the level of students being targeted in a particular course. Another is to ensure the integrity of the academic course being offered and that objectives can be clearly targeted. Whilst changes are inevitable, centuries old traditions should not be discarded. For instance, in the learning of mathematics, attention to logical construct and procedure has been key to providing proofs to the-orems or solutions to problems. A typical mathematics examination answer book prior to the pandemic era would contain several pages of 'working' and attached 'rough work.' One would be forgiven for believing that this has been completely changed since the onset of the CoVid-19 pandemic. In this era of 'post-lockdown,' it would not be unusual, on a cursory visit to an examination, to encounter students without a pen or pencil or any paper for 'rough work.' You may find students who would stare at the mathematical problem presented to them on a screen. After a while (from seconds to minutes), the student then selects one of the four answers available. When it comes to teaching, it would not be unusual to encounter a lesson where watching a series of videos forms the core of a lesson. The quality of a lesson is measured by the audio-visual content rather than the content of delivery and the effectiveness of conveying the essential details of the mathematic theory or proce-dures. In mathematics, self-study is key and it invariably requires many hours of reading of mathematical texts and countless hours of solving problems. The digital tools chosen for teaching should enhance this method of learning not counter it. Whilst many have lauded the inadvertent boon to the use of online teaching material precipitated by the pandemic, there are many areas of concern, with one being the poor choice of digital tools. It is clear that over the last few decades, progress in the teaching of mathematics has hardly proceeded in leaps and bounds and it would be tragic to see the painstaking gains made, reversed in the course of a couple of years. Students' attitudes to mathematics have not been overwhelmingly positive and the use of digital tools presents an opportunity to improve attitudes but only if the prop-er choices are made. In this paper we investigate the BOLSTER platform, which provides an online mathematics platform. We will look at the suitability of the platform in augmenting the teaching and learning of mathematics. Our focus will be on the suitability of the material available in matching or being tailored to meet the needs of the majority of students taking mathematics (and statistics) at the Higher Colleges of Technology (HCT) in the United Arab Emirates (UAE). To this end we contextualize the higher education landscape in the UAE to provide a background of the typical student en-countered at HCT. We will look at how material is presented in BOLSTER and the scope for self-study and self-assessment. Tools for instructors to monitor progress of groups and individuals will also be investigated as well as reporting mechanisms, class management and integration with learning management systems. The range of assessment options

is also considered as is the use of proctoring tools and its suita-bility in ensuring integrity requirements are met under examination conditions.

Mathematics education is in a crisis, worldwide, and this is made no better by the shortage of suitable instructors. One consequence of the pandemic is the loss of mathematics instructors at all levels of teaching. Many chose to resign, as priorities changed, and in other cases many were let go as institutions readjusted their budgets in response to the pandemic. Academics and instructors who chose to stay found increasing workloads and diminished research opportunities with this leading to a further decline in staff or declining motivation for remaining staff which in turn effects quality delivery. An eMathematics platform which acts as an online teaching assistant can help alleviate some of the burden on institutions and staff. For staff, particularly, if the platform offers opportunities for the easing of grading, consulta-tions and interventions, motivation will improve and this in turn will have a positive effect on the teaching and learning process. We consider the opportunities Bolster presents in alleviating some of the burdens experienced by institutions and faculty.

2 HCT in the UAE

The UAE, formed in 1971 under the leadership of Sheikh Zayed Bin Sultan Al Nahyan, is a relatively young nation and so are its higher learning institutions. Lane and Kinser (2011) identify three types of higher education institutions in the UAE: government owned and operated universities and higher institutes of technology which are part of the federal level public system; state level semi-public universities and so called 'free zone' universities. HCT falls into the first group described, together with the United Arab Emirates University (UAEU) and Zayed University (ZU). Campuses of these institutions serve mainly, and in some cases, almost exclusively, Emirati students. Tuition fees are, in effect, almost wholly funded by the state. As such these universities are an integral part of the national strategy of the state in empowering the nation and meeting its key national objectives, such as the 50 Year Charter. Our focus will be on this group and, in particular, HCT. The UAEU was founded in 1976 by the late Sheikh Zayed Bin Sultan Al Nahyan and positions itself as a comprehensive, research-intensive university. For a university that is less than 50 years old it is remarkable that it is ranked at 296 in the 2023 Quacquarelli Symonds (QS) university global rankings system. The university has about 7,000 students with a female to male ratio of 4:1 and with students of 54 nationalities represented. Established in 1998, again by the late Sheikh Zayed Bin Sultan Al Nahyan, and named in his honor, ZU posits itself as a modern scientific university. It is ranked between 701-750 in the QS global rankings of 2023. The university accepted only UAE national women until 2008. That same year, ZU became the first of the federal universities to gain international accreditation. 88The late Sheikh Zayed Bin Sultan Al Nahyan formed HCT in 1985, and as of 2022, with 16 campuses, and a student population close to 25,000, it is by far the largest of the federally funded higher education institutions. There are twice as many female

students as there are male. It would be unfair to compare HCT to the other two federally funded universities, UAEU and ZU, in terms of QS rankings, as its key priorities are different, with a focus on teaching rather than research. With research contributing substantially to the points accrued in the global ranking systems of QS and Times Higher Education (THE), HCT is unable to break into the ranking system of the top 1,000 universities worldwide for the time being. The HCT colleges are almost exclusively for Emirati students and its focus is in preparing Emiratis for the workforce. This is encapsulated in its strategic plan, entitled 'HCT 4.0 Employability and Beyond,' to ensure 'Technical Leaders,' 'Graduate Entrepreneurs' and 'No Emiratis Left Behind.' The goal is to 'provide an academic and professional education to prepare graduates to meet industry needs.' As of the 1st of May 2014, HCT has been licensed by the UAE's Ministry of Education (MoE) to award degrees and qualifications in higher education. The vast majority of students at HCT are 1st generation university students with very few being 2nd generation. This means that students, often, do not have an elder at home to which they can look to, to guide them through experience. That students are 2nd language speakers of the medium of instruction, English, also produces challenges, particularly in a subject like mathematics, were subtlety in language can change the meaning of a question or definition. Most academic programmes include a component of mathematics or statistics and a student who studies Human Resources (HR) or Business or Entrepreneurship is likely to have at least one semester of mathematics or statistics. The student who is in the social sciences would not have taken the same path during their high school learning as a student who has had an ambition of following a career in Engineering or in mathematics-based sciences. Their exposure to mathematics, and hence preparedness, would be different. Most students studying mathematics courses at HCT, fall into this category. This is not to say that those students in Engineering do not also require attention in bolstering their mathematics skills.

3 Bolster Academy

Bolster Academy has its roots in the Netherlands. Starting as a spinoff from the departments of mathematics and computer science at the Eindhoven University of Technology, it was originally called Software voor Wiskunde Onderwijs (SOWISO) which, when translated from Dutch, means software for teaching mathematics. The name was changed to BOLSTER as the software gathered momentum outside the Netherlands to a more global, non-Dutch-speaking audience. Primarily, SOWISO/BOLSTER was created as a response to the elevated levels of mathematics anxiety and demotivation felt by students in the social sciences who were taking compulsory courses in Mathematics and/or Statistics. This has a familiar ring to it and educators worldwide can recognise that the challenges faced are universal. The difficulties faced then, by students at Eindhoven University of Technology were not much different to those currently being faced by students at HCT. In its initial years, as the software gained traction in the Netherlands, the largest university in the Netherlands, the University of

Amsterdam (UvA), took notice in 2013 and identified the software as ideal for a more 'personalized and flexible' use in the teaching of its statistics course offered to its students in graduate programmes in medical related fields. The use of the programme was then extended to include students in the social sciences and commerce. who shared the same difficulties experienced by many other students globally. UvA is one of the top-ranking universities in the world, ranked at 60th in the 2023 QS rankings students, and yet the difficulties faced by its students in the social sciences and commerce were no different to those in many other parts of the world, such as the social sciences and commerce students at HCT, a university which does not enjoy a similar status of having existed for almost 4 centuries (UvA was founded in 1632). In 2013 the SOWISO/BOLSTER software transitioned to the mathematics e-learning platform, with the built-in authoring environment, that is very much a feature of the current incarnation. From 2013 Bolster Academy has been based at Amsterdam Science Park which houses UvA. Although Bolster operates as a separate entity with its own content developers and software engineers, there is considerable collaboration with UvA and its many other university partners.

4 Courses on the Bolster Academy eLearning platform

Whilst courses are offered as turn-key courses, they may be adapted and augmented or courses may be developed from scratch using the authoring tool. There is a hierarchical meta data system on each content level. Content is divided into chapters, with chapters further divided into sub chapters and so on. The basic mathematics course, as an example, consists of the following chapters:

- Numbers
- Algebra
- Linear formulas and equations
- Systems of linear equations
- Quadratic equations
- Functions
- Exponential functions and logarithms
- Trigonometry
- Geometry
- Differentiation
- Integration

The chapter on *Systems of linear equations* contains, for example the following sub-chapters which are further divided, themselves:

- An equation of a line
  - A linear equation with two unknowns
  - Solution of linear equations with two unknowns
  - The equation of a line
  - Composing the equation of a line

- Two equations with two unknowns
  - Systems of linear equations
  - Solving systems of linear equations by substitution
  - Solving systems of equations by elimination
  - General solution system of linear equations

The basic statistics course offers chapters on:

- Descriptive statistics;
- Correlation;
- Probability;
- Probability distributions;
- Sampling;
- Parameter estimation confidence intervals;
- Hypothesis testing;
- Testing for differences in mean and proportion;
- Regression analysis
- Categorical association

An instructor can choose to make certain areas of the course available while hiding others. She or he may choose to stitch elements of two or more courses together. A typical example is an introductory mathematics course with elements from the basic mathematics course, parts of the basic statistics course and an introduction to matrices from the linear algebra course. The lecturer may want to include her or his own notes and can append them to the tailored course. For non-mainstream courses, such as a postgraduate course in differential geometry, the lecturer will be able to present their own material in its entirety using the authoring tool.

For engineering students, the course on linear algebra may be appropriate in parts or completely. It has the following chapters: Complex numbers; Vector calculus in plane and space; Vector spaces; Inner product spaces; Linear maps; Matrix calculus; Invariant subspaces of linear maps; Orthogonal and symmetric maps; Differential equations and Laplace transform. The course on Data analysis contains chapters on Descriptive statistics; Variables and datasets; Mean comparison; Chi-square tests; Analysis of variance; Simple linear regression; Multiple linear regression and Logistic regression. Other turn-key courses include Financial Arithmetic, Calculus, Calculus for Social Sciences, and Differential Equations. There are also courses in physics and computing such as Statics and Python, respectively.

5 Navigating the Bolster basic mathematics course

For each topic, within a subchapter there are notes with interactive learning tools and randomly generated examples. In reading the theory for a particular topic if the student feels they require another example to better understand the topic, they simple request a regeneration of the example. A new example is

generated in the notes which could be of a different type but dealing with the same topic or sometimes the same type of problem but with newly generated values through the randomisation tool. At the end of each topic the student is presented with a set of exercises for them to assess their understanding of the topic. By utilising repetitive and randomised mathematics questions, the Bolster digital learning platform encourages the student to learn through practice. With questions mainly open-ended, students are compelled to indicate how they arrived at their answers. As students work through their answers they receive hints at various stages consistent with their inputs. Instead of merely marking a submitted response as right or wrong the system is robust enough to identify the error and guide the student toward the correct answer, when students, in practice mode, try different examples. In the instance where a student does provide a correct answer but it is incomplete or not yet in the required form, the programme indicates by way of a check mark shaded in yellow that the answer is partially correct. The program will then guide you through to the next steps. When the answer is eventually obtained in the requested format the student is provided with check mark in green and congratulated on their answer. The system identifies the error and guides the student in obtaining the correct answer albeit if it may take a couple of iterations of the procedure. Digital mathematical tools which provision for input of mathematical statements for students often have a confusing interface for this facility. Students struggle to enter their results. Bolster has several keyboard interfaces for students to enter their answers catering for the many different requirements from basic functions, to transcendental functions, to logical quantifiers, to vector and matrix notation as well as units commonly used in problems in problems involving physics. With the GeoGebra tool, topics are often interactive with the student able to vary, by using the slider tool, the values of the coefficient a or exponent n of the exponential graph, $f(x) = ax^n$, for example and notice the effects of the variations. In instances were rules are given, the accompanying proof and illustrative example are normally provided via a drop-down tab.

6 Course management and learning management system (LMS) integration

The databases of questions developed on Bolster Academy are currently being used for both formative and for summative testing. Instructors have the options of copying and editing existing Bolster Academy exercises, authoring their own exercises, and linking those exercises to the theory pages. For the generation of exercises, the computer algebra system (CAS) being used is *Maxima*, where students are provided with feedback and hints on strategies to adjust their submitted solutions to match that which is required so as to improve their answer attempts. In the instances where a student has not understood the material, they are guided back to the relevant theory or in the instance where they have a reasonable understanding of the theory but may have not understood the partic-

ular mathematical problem, they are then presented with the fully worked out solution detailed step-by-step.

Course coordinators are able to subdivide courses to various classes and apportion them to individual instructors. Teaching assistants and tutors may also be afforded various privileges for navigation within a particular class to monitor performance and intervene as per their duty. Classes can be divided further into groups and subgroups. Reporting mechanisms provide feedback on courses, classes, groups, and individuals. Specific assignments and additional tasks may be created and assigned to specific groups or to newly created groups in the instances where individuals require extra attention in a particular topic. Whilst working through examples and notes the student has the option to post questions directly to their instructor or tutor or to a forum of their classmates through peer collaboration. The instructor is able to monitor the forum and intervene if the suggestions provided in response to queries are incorrect.

Bolster integrates with almost any flavor of LMS and the backroom team will assist to resolve the matter in instances were a compatibility issue may arise.

7 Pedagogical foundations of Bolster

Cognitive-motivational dispositions inform people's self-theories, influencing achievement and wellbeing, which in turn impact on learning [5] One salient aspect of self-theories is its influence on notions of intelligence [2,3,17]. developed the concept of theories of intelligence, known as mindsets, to describe the two basic assumptions that people form on their own intelligence capabilities

- the fixed mindset is a trait associated with individuals who believe that intellectual abilities are unchangeable or fixed
- the growth mindset is a trait associated with those who believe that their abilities can be grown through sufficient perseverance

Mindsets may be domain-specific leading a person to have a growth mindset in one field but a fixed mindset in another and studies show that when it comes to the learning of mathematics, students tend to have more of a fixed mindset of math skills than any of the other intellectual skills [4].

Now, the pedagogical models of Guided Discovery [8] and Mastery Learning [15] can help facilitate the development of a growth mindset. Mastery Learning ensures that proper foundations are laid as the student moves to more advanced topics. Developing the adequate proficiency in earlier topics reduces the chances of frustration for the student when they encounter material based on earlier subject matter. Not all students will progress at the same rate and so accommodation must be made for students to progress at their own pace. Piaget's constructivist technique has inspired the pedagogical model of Guided Discovery encouraging pure discovery or *learning by doing*. The role of the teacher is central in guiding the student so that the learner is able to converge, timely, to the target information. Such a methodology ensures that students are actively engaged in learning and discovering knowledge, instead of simple being passive

learners. Combined with a growth mindset, these pedagogical models provide positive support strategies for learning math.

Bolster Academy has fashioned its eLearning tool for maths education, based on the pedagogical models of guided learning and mastery learning implemented in combination with a growth mindset teaching approach. The randomisation tool allows the user to generate as many examples or exercises they require to achieve the level of proficiency that will satisfy themselves to move on to the next topic. Student are this able to progress at their own pace wihtout being left behind or leaving others behind. This is mastery learning in progress. As students satisfy themselves in achieving the benchmarks they set for themselves, their confidence grows and their anxiety is reduced.

When it comes to problem solving, students may often be on the right path but the answers they present only partially respond to the question posed. By not simply mark an answer wrong but instead identifying where the student's answer is lacking, the Bolster software is able to guide the student toward the correction solution even if it may take several steps to do this. This is consistent withe the pedagogical influence of guided learning.

Research across the globe indicates a correlation between students' attitudes toward math and their academic achievement. The more positive their attitude, the more likely they are to perform better as elaborated on in [18,16,1,10,9,12,6,11]. Encouraging students to gain mastery through repeated guided examples instills confidence and helps alleviate mathematics anxiety. The pedagogic models of mastery learning and guided learning are key to a successful digital mathematics tool and are clearly prevalent in the Bolster package.

8 Proctoring tools and assessment integrity

The workload for instructors in creating new mathematics exams is decreased through the Bolster platform, as is marking with grading being automatic. The security of mathematics assessments is increased, as apart from randomizing the order of questions, questions are different for every student that takes the test through the randomization tool. The settings for exams can be modified from the number of attempts the student is allowed, to the time period during which the test is available, to the duration of the test and the release of grades. The variety of settings allows for instructors to create various types of tests: diagnostic, formative, and summative. Bolster Academy has been tasked with administering the admissions testing for universities in the Netherlands. This requires the following of strict regulations and assuring integrity of these exams. Through its Online Mathematics Placement Tool (OMPT) in partnership with ProctorU, the highest standards of exam integrity are maintained in online testing. The use of individual proctors online, the monitoring of the room the student is taking the exams, tools to monitor applications open on examinees' computers and the implementation of the latest artificial intelligence (AI) systems, ensure that the integrity of exams is maintained to the required standards. In addition to the

live proctors, augmented by AI, the entire process is managed by interventionists live sessions are who routinely audited.

9 Conclusions

Bolster Academy provides a comprehensive digital mathematics tool that ideally suits the needs of the majority of students taking mathematics at HCT. Workloads of instructors would be reduced, and the integrity of assessments enhanced through the randomisation facility. It would be instructional to ascertain the responses of students to BOLSTER and to consider the feasibility of using the platform to augment the teaching of the various mathematics programmes, especially the basic mathematics course.

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