Do Online Maths Tools Improve Undergraduate Mathematics Outcomes within the Block Teaching Model?

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Abstract

A notable decline in secondary mathematics enrolment has raised concerns over numerical capacity and readiness for STEM learning in tertiary education over recent years. This has prompted some university academics to shift from traditional pedagogical delivery methods to a constructivist teaching approach such as incorporating online teaching tools within a more interactive learning environment. While some online tools have been purpose build, none to the best of our knowledge have been contextualised for biomedical sciences, or supported by research into their effectiveness when taught within the block teaching model. The aim of this study was to investigate the use of freely available online mathematics learning tools when applied to the biomedical sciences taught in a time compressed block teaching format. One hundred and seventy-six first year students completed a survey reflecting on their level of comfort, competence, and enjoyment of mathematics, including their highest attainment level of previous study in the discipline. Students were also surveyed about their tertiary entrance rank and completed a short quiz to establish their pre-learning numeracy skill baseline. Students completed a post-unit assessment at the end of each unit, together with a survey about the extent of their online tool usage. Our results show that there is significant improvement ($p<0.001$) when students supplemented their learning using online maths tools, by a clear pre versus post increase in tests results. This improvement was statistically significant and remained consistent across all identified ability groups. However, this improvement was not linked to the students' university entrance rank score and interestingly nor was the result skewed by differential group usage of the online resources provided.

Keywords: mathematics, online tools, pedagogy, active learning technology, block teaching model

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1. Introduction

There has been a noted decline in enrolment in mathematics subjects at the secondary level (Di Martino & Gregorio, 2019; Kennedy et al., 2014; Timms et al., 2018; Weink, 2015), which has impacted the teaching of mathematics at the tertiary level and raised concerns about students' numerical capacity (Boyd et al., 1998) and preparedness for STEM learning (Faulkner et al., 2014).

This concern has led to a re-evaluation of traditional didactic approaches to teaching mathematics at the tertiary level. Historically, these methods have featured minimal class interaction, with learning being largely passive (Abdulwahed et al., 2012). One proposed approach to modernizing mathematics instruction is to encourage students to construct knowledge themselves, thereby promoting an active learning paradigm through constructivist pedagogy (Richardson, 2003).

At its core, a constructivist approach allows students to develop their own understanding by linking prior knowledge and beliefs with new information (Resnick, 1989). Key principles of this pedagogy include student-centred learning, autonomy, and real-world contextualization (Richardson, 2003). Technology has long been explored as a means of supporting these principles in mathematics instruction, leading to the development of various digital learning systems.

Platforms such as MyMathLab (www.mymathlab.com) and ALEKS (Assessment and LEarning Knowledge Spaces, www.aleks.com) have been widely adopted at the undergraduate level (Abdulwahed et al., 2012), while Khan Academy (www.khanacademy.org) has become increasingly prevalent in mathematics education across all levels. Additionally, MathBench (www.mathbench.org.au) has been specifically designed to enhance contextual learning in the biological sciences (Chunduri & Rylands, 2017).

Each of these platforms offers unique features: MyMathLab provides customizable mathematics-specific e-learning; ALEKS uses artificial intelligence to deliver individualized instruction without instructor involvement; and Khan Academy offers extensive, though non-individualized, learning resources for general mathematical concepts. Among these, MathBench stands out as the only system that contextualizes mathematical learning within the sciences at the undergraduate level, demonstrating improvements in mathematical competence (Di Trapani & Watters, 2017) except for the most advanced concepts (Thompson et al., 2010).

However, while MathBench is tailored for the biological sciences, no existing program focuses on the broader biomedical sciences. Furthermore, research on MathBench has primarily been conducted within a highly ranked, selective institution. To date, no study has examined its use within a disadvantaged student population or in a block-mode teaching context.

Victoria University (VU) has a uniquely diverse student population, including the highest proportion of students from non-English speaking backgrounds (NESB) and the second highest proportion of students from low socioeconomic status (SES) backgrounds or first-in-family (FIF) university students in Victoria (McCluskey et al., 2020; Messinis & Sheehan, 2015; Samarawickrema & Cleary, 2021). Given that many students have limited backgrounds in science, this study aimed to support them through online, asynchronous activities. Understanding the benefits of online tool use within a student cohort that is both academically disadvantaged (Klein et al., 2019a; Winchester et al., 2021) and commonly associated with low levels of numeracy (Downie et al., 2019) is an important step in developing mathematics learning within the block-mode setting.

In 2018, Victoria University (VU) in Melbourne introduced the VU Block Model, in which students focus on a single unit over a four-week period (McCluskey et al., 2019). Classes are small (maximum of 35 students), traditional lectures are eliminated, and learning is supported through an online learning management system (LMS). This model fosters a sense of community, provides frequent feedback, encourages active and collaborative learning, and removes the pressure of managing and studying multiple units simultaneously. In 2020, the first full cohort under this model demonstrated improved student retention and academic outcomes (McCluskey et al., 2020).

The constructivist curriculum design of the Block Model is built on the principles of active learning (Gauci et al., 2023; Klein et al., 2019b; Sinnayah et al., 2019). Many science educators have highlighted the benefits of active learning, particularly in face-to-face settings. A meta-analysis of 225 STEM studies found that active-learning interventions led to higher student grades and lower failure rates (Freeman et al., 2014). Flipped classroom models further enhance active learning by requiring students to engage with online materials—such as videos and readings—before class, allowing in-class time to focus on interactive, student-centred activities (Al-Samarraie et al., 2020; Bingen et al., 2019; Ramnanan & Pound, 2017).

This research gap has informed the design of our subject, where we have specifically considered how to integrate active learning into online resources for asynchronous delivery. Therefore, the aim of this paper is to investigate the impact of online tools such as MathBench and Khan Academy on undergraduate mathematics learning within the block-mode teaching framework.

2. Methods

2.1 Ethics

This study was approved by the Ethics Committee at Victoria University (HRE-17-192). Informed consent was obtained from all students and participation proceeded on a voluntary basis only.

2.2 Participants

One hundred and seventy-six first year students enrolled in the mathematics and statistics unit (unit code HHH1001) Mathematics and Statistics for Biomedicine within a Bachelor of Biomedicine degree participated in this study. This unit was taught in block teaching mode during both semester one and two in 2019 and 2020. On commencement of each unit, students completed a survey to map their predicted learning capacity in the subject, along with a survey to capture their tertiary entrance rank. They also completed pre- and post-unit assessment to establish their mathematical skill. Finally, at the end of the unit they completed a two-question survey on their use of online tools within the unit.

2.3 Mathematical assessment

The pre- and post-unit mathematics assessment consisted of a short, 10-question short-answer quiz composed of three subject areas: algebra, trigonometry and ratios, and percentages and averages. The basis for each section was taken from the Year 10 mathematics (elementary secondary school) learning outcomes. The same post-unit quiz was used including the same questions, delivered however in random order to maximise the pre and post comparisons at the end of the unit. Other than whether the answer was correct or not, no feedback was provided after the pre-assessment to minimise influence over the post-assessment score. The intent here was to encourage independent student review of their learning, in their preferred manner, and via the suggested tool options (MathBench, Khan Academy or via methods other than online).

2.4 Discipline capacity mapping, educational history, and online tool use

Students were classified based on their expected subject success via the Discipline Capacity (DC) tool described previously (Author, 2023). Briefly, a questionnaire was conducted prior to commencing the unit to determine their self-efficacy of, and previous studies in, mathematics. Three questions were included reflecting the work by Hart (1989), "How confident you are with maths skills?", "How competent are your maths skills?" and, "Do you enjoy maths?" Student responses were measured via a 10-point Likert-type scale (1 = "not at all"; 10 = "being absolutely"). The maximum discipline capacity score was calculated by adding the levels of self-assessed confidence, competence and enjoyment than multiplying these by the factor of highest level of mathematics education previously obtained or studied (1 for elementary; 2 for intermediate; 3 for advanced). Elementary level is commonly taught in primary and secondary education including concepts such as basic algebra, geometry, and number theory. Intermediate level mathematics included learning in areas such as algebra and pre-calculus. The aim for including previous mathematical learning was to incorporate the impact of previous level of education as this, despite the bias of the self-assessment of the student, may impact on their mathematical capacity. The maximum DC score from this formula was 90. First and third quartile ranges were determined within the cohorts DC scores, allowing for the identification of three groupings of comfort in mathematics: low (<= 17), medium (18-43), and high (=> 44).

Students were also asked to provide their Australian tertiary entrance rank (ATAR). The ATAR represents a number between 0.00 and 99.95 an indicator that indicates the students rank against all other final-year secondary students in Australia (UAC, 2023). If a student was to gain an 80%, for example, that would suggest that their performance is greater than 80% of Australian students at the same level. For the purposes of this study, seven groups were defined. No rank (group 1), below 49 (group 2), 50-59 (group 3), 60-69 (group 4). 70-79 (group 5), 80-89 (group 6) and above 90 (group 7).

Finally, to assess tool usage students were asked two questions. (1) What online tool (if any) did you use during the study of this unit (none, MathBench or Khan Academy), and (2) To what level did this tool use aid you in this unit? This second question involved a response using a Likert-type five-point scale (1 – no help at all, 2 – mostly no help, 3 – unsure/did not use, 4 – some help, 5 – very helpful).

2.5 Data analyses

Online tool usage was analysed by discipline capacity (low, medium and high), and ATAR score, via Chi-Square test. An ANOVA was used to analyse discipline capacity groups pre- and post-unit quiz scores, as well as score result changes.

All statistical analyses were performed using SPSS (v.26, IBM, USA) with the level of significance set at $p < 0.05$.

3. Results

3.1 Tool use differences grouped by discipline capacity

Table 1 shows tool use grouped by discipline capacity. While fewer students used no tools (n = 52) than did Khan (n = 59), and MathBench (n = 65) there was no significant difference in tool use measure between capacity groups (low, medium and high). Tool usage frequency was deemed similar for all DC groups. Indeed no tool usage (n = 52) acting as control correlated negatively with student outcomes.

Table 1. Tool use grouped by discipline capacity

	TOOL USE		
	Tool use	χ^2	*p*
Low (n = 51)	No use (n=12) MathBench (n=22) Khan (n=17)		
Medium (n =79)	No use (n=28) MathBench (n=28) Khan (n=23)	3.84	.43
High (n = 46)	No use (n=12) MathBench (n=15) Khan (n=19)		

3.2 Tool use by ATAR

Table 2 shows tool use, grouped by ATAR. While many the students without ATAR also used no tools for their learning, there was no significant group difference in tool use across ATAR groupings. Regardless of ATAR score the usage remained similar. Interestingly the lower the ATAR, the less uptake of the tools was noted, and the lower the ATAR, the greater the uptake with Mathbench (37%) and Khan (41%).

Table 2. ATAR differences in tool use

	Total (n = 176)	**None** (n = 52)	**Mathbench** (n = 65)	**Khan** (n = 59)	χ^2	***p***
ATAR						
None (%)	74 (42%)	26 (50%)	24 (37%)	24 (41%)		
< 49 (%)	4 (2%)	2 (4%)	1 (2%)	1 (2%)		
50 – 59 (%)	18 (10%)	4 (8%)	7 (11%)	7 (11.5%)		
60 – 69 (%)	24 (13.5%)	5 (10%)	6 (9%)	13 (22%)	15.46	.22
70 – 79 (%)	17 (10%)	5 (10%)	9 (13%)	3 (5%)		
80 – 89 (%)	22 (12.5%)	7 (12%)	7 (11%)	8 (13.5%)		
> 90 (%)	17 (10%)	3 (6%)	11 (17%)	3 (5%)		

3.3 Effect of Tool usage

Table 3 shows pre- and post-unit delivery quiz marks, mark changes and comparison of changes grouped by discipline capacity. There was significance change from pre- to post-unit quiz scores increasing within each group. Low (pre 7.58 ± 3.58, post 10.95 ± 3.49, change 3.35 ± 3.40, p <.001), Medium (pre 9.31 ± 3.21, post 11.82 ± 3.48, p <.001) and High (pre 10.72 ± 3.24, post 13.65 ± 2.04, p <.001). There was no significant difference in quiz score change between discipline capacity groups, however, indicating that the effect of using the tools did not favour any particular group more than the other.

Table 3. Discipline capacity grouped quiz changes

	Discipline capacity-based quiz marks, group median score change and significance				**Discipline capacity group median score change group comparison (*p*)**		
	Pre-unit	**Post unit**	**Change**	***p***	**Low v Medium**	**Medium v High**	**Low v High**
Low (n = 51)	7.58 ± 3.83	10.95 ± 3.49	3.35 ± 3.40	**<.001**	.41	1.00	1.00
Medium (n = 79)	9.31 ± 3.21	11.82 ± 3.48	2.51 ± 2.93	**<.001**			
High (n = 46)	10.72 ± 3.24	13.65 ± 2.04	2.93 ± 3.09	**<.001**			

4. Discussion

In this study, we demonstrate that there was a significant improvement in post-unit assessment scores ($p < 0.001$) when students used the online tools MathBench or Khan Academy, compared with students in each DC category who did not use these tools.

It is clear that students who accessed the additional online resources benefited in their mathematics learning, leading to improved final marks. This improvement was observed across all DGs equally, exceeding the performance of students who did not use online tools.

Interestingly, these improvements were independent of ATAR and the frequency of tool usage.

Our findings indicate a significant difference between pre- and post-assessment results in both quizzes, as well as in the change in scores between these quizzes within groups. This improvement could be attributed to the use of online tools within this study or other external learning methods. However, it may also be an artifact of the study design itself.

To minimize potential biases, no changes were made to the pre- and post-unit quizzes apart from randomizing the question order, ensuring that different questions did not skew the data. However, the repetition of the same questions, even four weeks apart, may have led to a learning effect, where students performed better simply by reattempting the quiz. Regardless of whether learning occurred through intended or unintended means, the overall increase in mean scores across groups suggests that the pedagogical approach adopted in this unit was effective.

Previous studies have shown that online tools positively impact the learning of mathematical concepts at both general (Zengin, 2017) and undergraduate levels (Chunduri & Rylands, 2017; Di Trapani & Watters, 2017; Thompson et al., 2010). MathBench, in particular, has been recognized for effectively contextualizing learning, although it remains somewhat basic in its coverage of general mathematical concepts (Chunduri & Rylands, 2017). Additionally, it has been noted for its ability to engage students effectively (Thompson et al., 2010). Khan Academy has also been shown to support mathematics learning, but its effectiveness is enhanced when supplemented by specific in-class guidance that provides the contextualization it lacks (Zengin, 2017).

However, in this study, there was no statistically significant difference in tool uptake across ability groups (low, medium, and high) or between MathBench and Khan Academy users. Additionally, no correlation was observed between tool usage frequency and ATAR scores. Specifically, there was no indication that students with lower ATAR scores used the tools less or that those with higher ATAR scores used them more frequently. This pattern was consistent across the entire cohort, suggesting that neither ability group nor ATAR influenced tool usage frequency.

In the broader literature, higher ATAR scores have been associated with increased engagement with online learning tools. However, our findings deviate from this trend, which may be due to the academically disadvantaged nature of our student cohort. These students may require more explicit encouragement to engage with available learning resources.

The academic approach in this unit involved presenting online tool options after the pre-unit assessment, both in class and via the learning management system (LMS), in a passive manner to maintain students' autonomy in learning— a central tenet of constructivism. However, the shift to online delivery due to the COVID-19 pandemic in 2019 may have influenced tool engagement. In cohorts with weaker academic backgrounds, a more structured and directive approach to utilizing support tools may be beneficial. Such an approach could help students recognize and capitalize on learning opportunities that they might otherwise overlook. Additionally, the absence of physical teacher presence may have contributed to a lack of follow-through on tool usage, reinforcing an “out of sight, out of mind” attitude among students.

5. Conclusion

Amid the continuing decline in interest and enrolment in secondary mathematics among students entering tertiary institutions, this study demonstrates the benefits of using online mathematics tools as an adjunct to learning, particularly within the time-compressed Block Mode Teaching (BTM) model. Notably, these benefits extend to students across all competency levels (DC groups).

This study makes an important contribution to the pedagogy of tertiary mathematics by highlighting the value of online programs in improving learning outcomes, even when using generic rather than purpose-built mathematics resources—such as those applied here in the biomedical sciences. This is particularly relevant in the post-COVID teaching landscape, where institutions continue to integrate online learning and where the availability of online mathematics programs has expanded.

Strengths, Limitations, and Future Research

This study is limited by its narrow population demographic, focusing exclusively on students at Victoria University in Melbourne. To generalize these findings, similar studies should be conducted at other universities with comparable socioeconomic demographics and discipline-related challenges.

Additionally, the small sample size presents another limitation. A larger and more balanced sample across different deliveries would help determine whether the observed outcomes hold across a broader student population.

It is also important to note that data collection for the second year of this study (2020) was conducted entirely online due to the COVID-19 pandemic. While assessments remained consistent, the shift in delivery mode may have influenced the results. However, the transition to BTM may have strengthened the study's findings, as the increase in post-assessment scores could be attributed to the intense, focused nature of mathematics instruction within the block structure. Furthermore, the stability of pass/fail rates between the COVID-affected and post-COVID years suggests the robustness of this teaching model under changing educational conditions.

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Disclosures

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