Running Head:

Online Maths Skills Support Site for Bioscience Students

Title:

Undergraduate Biochemistry student difficulties with topics requiring mathematical skills: use of an online maths skills support site.

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Undergraduate Biochemistry Student Difficulties with Topics Requiring Mathematical Skills: Use of an Online Maths Skills Support Site.

Abstract

A number of areas of difficulty in basic numeracy and mathematical skills were identified, which hinder students' success in a foundational biochemistry course. Many students have difficulty with the concepts of pH and buffers (requiring proficiency with logarithms) and enzyme kinetics (requiring algebraic manipulations and graphing). The voluntary use by students of an 'in house' online support site, the Maths Skills Site, to address these difficulties was varied and seemed to be motivated by assessment deadlines, as well as deliberate instructions to refer to the relevant Maths Skills Site modules when completing assessment. The majority of the users of the online support site were those who performed poorly on a diagnostic test administered at the beginning of the course. There was a small but significant effect of Maths Support Site usage with users achieving improved grades for graphing functions compared to non-users. The combination of mathematical backgrounds and prior academic performance also correlated with success in first-year university biochemistry.

Keywords Essential concepts and skills for biochemistry; pH and buffers; Graphing; Enzyme kinetics; Online mathematics support.

Introduction

It been extensively reported that the mathematical skills of students entering university are deficient and that the “Mathematics Problem” is worldwide (Treacy and Faulkner, 2015; Atuahene and Russel, 2016; McAlinden and Noyes, 2018; Hodgen et al. 2018, Lawson et al. 2019). In this study we set out to address this problem by providing online support situated in a discipline specific context and examining student usage and performance on exam questions requiring mathematical skills.

Numeracy skills in bioscience undergraduates have declined over time (Tariq et al. 2013) and there is a general perception that students in the life sciences have a less positive attitude to mathematics (Quinnell et al. 2013; Wachsmuth et al. 2017). In Australia, the continuing decline in the numbers of high school students studying advanced mathematics has been attributed to the increased choice of subjects offered, students’ perceptions of their ability and subject difficulty, and the removal of mathematics pre-requisites for University entry (Kennedy et al. 2014; Wilson et al. 2014). Further reasons include dissatisfaction with mathematics, arising from a lack of confidence, interest and subject enjoyment (Hine 2017). Such negative academic attitudes lead to poor motivation (Kim et al. 2014). Students also tend to choose a lower level mathematics course to maximise their university entrance score and allow increased time for other subjects (Hine 2018). The value of the extra time and effort associated with higher level mathematics courses was not appreciated by students. Other contributing factors are low maths self-efficacy and maths anxiety, which have a reciprocal relationship with maths performance (Beilock and Maloney 2015; Foley et al. 2017; Zientek et al. 2017). The result of all these factors is that students are

coming to University under-prepared for Science, Technology, Engineering, and Maths (STEM) courses.

Students in STEM need to acquire a core set of skills for graduation and success in their future careers. For biochemistry students, experimental and mathematical skills have been identified as critically important (Adkins and Noyes 2017; Tansey et al. 2013; White et al. 2013; Wright et al. 2013), although these skills are applicable to all STEM courses and students. Application of quantitative approaches is an important basic skill required to understand biological systems. Biology is increasingly reliant on applications of quantitative analysis and mathematical reasoning (Koenig 2011). In a vision paper for undergraduate biology education, Brewer and Smith (2011) identified as core competencies: the ability to use quantitative reasoning and analysis to interpret biological data; the ability to develop and interpret graphs, and the ability to apply statistical methods to diverse data. Essential mathematics for the molecular life sciences includes using equations to define biological and chemical processes, as well as linear, exponential, hyperbolic (saturation) and sigmoidal functions (Wright et al. 2013).

Over many years of teaching biochemistry, we have observed that students have most difficulty with the concepts of pH and buffers (requiring proficiency with logarithms) and enzyme kinetics (requiring algebraic manipulations and graphing). Difficulty with understanding of pH has been attributed to a lack of understanding of logarithms (Watters and Watters 2006; Orgill and Sutherland 2008; Park and Choi 2013). Sgambato et al. 2012 suggested using the simpler, Henderson equation (without logs) when teaching medical students about pH (Sgambato et al. 2012). The ability to create and interpret graphs is also troublesome for many students (Angra and Gardner 2017). In a recent study, mathematical topics of functions/graphs,

algebra and logs/exponents were in the top five areas causing difficulty for students (Ní Shé et al. 2017). These topics are the same as those described above as being essential for the molecular life sciences (Wright et al. 2013).

In recent years, a range of mathematics support centers and online approaches have emerged in order to address the well-recognized deficiencies in mathematical skills of STEM undergraduates (Jackson and Johnson 2013; Pohjolainen et al. 2018). These are reported by students to have a positive impact on student retention, confidence, performance and ability to cope with the various mathematical demands of their courses (Jackson and Johnson 2013; Hillock et al. 2012; Ní Fhloinn et al. 2014), despite the fact that they are often stand-alone without discipline specific context.

Contextualising learning not only enhances attitudes but also improves understanding (Bennett et al. 2007) and Realistic Mathematics Education emphasises the importance of learning through problems located in real-life situations (Freudenthal 2006). Hence, it is important to integrate the learning of mathematics and science in ways that students can apply the relevant mathematical concepts to the solution of bioscience problems. Therefore, we developed and introduced a discipline specific online mathematical support environment, termed the Maths Skills Site (MSS), designed for chemistry/biochemistry courses, and integrated it into the first-year biochemistry curriculum.

The present study incorporates tracking data from students who used the MSS and correlates this with their performance in first year biochemistry topics requiring numerical literacy (e.g. ability manipulate exponents and logarithms) and mathematical literacy (understand graphing functions, algebra reasoning and solving simultaneous equations). The aims of the study were to explore the extent to which

students accessed the resource and what impact the resource had on learning outcomes.

Our research questions are as follows:

1. What are students' patterns of usage of an online maths skill support site when doing biochemistry topics requiring mathematical literacy and numeracy?
2. What are the outcomes for users of the MSS compared to non-users of the MSS for students studying biochemistry?

Methods

Course Context

The biochemistry course is a first year foundation course for a number of degree programs including biomedical and forensic sciences. It was delivered through traditional lectures (4h per week over a 13-week semester) with several assignments and online (virtual) laboratories to reinforce fundamental biochemical concepts. The lectures provided the theoretical content including topics such as the molecular organisation of cells and the biochemical properties of the major classes of biological compounds in the cellular environment e.g. amino acids, nucleic acids, carbohydrates and lipids, along with topics about the properties of water, pH and buffers, the structure and function of proteins, including an introduction to enzymes, the cell membrane and membrane transport. Solving and answering problems during the online laboratory, assignments and exams required students to use foundational mathematical skills, such as algebra, logarithms and graphing, as well as the simpler concepts

of exponents, significant figures, scientific notation and positive and negative numbers. The curriculum, assessment and lecture teaching team were the same for the course during 2014-2016.

Participants

Participants were students who completed the biochemistry course in one of the three years of the study (2014-2016). They had a range of mathematical backgrounds and were in their second semester of study during their first year of university. The student sample ($n = 740$ over 2014-2016, (2014, $n = 229$; 2015, $n = 256$; 2016, $n = 255$)) comprised those enrolled in the following a Bachelor degree programs – Medical Science, Biomedical Science, Forensic Science and Science. Entry requirements of the various degrees are different and reflect the students' mathematics background and prior academic performance as detailed below. This study presents the outcomes for 96.5% of the total cohort. The remaining 3.5% of students were in miscellaneous study, including those undertaking a Bachelor of Arts degree enrolled in the course as an elective, and study abroad students. They were not considered in the present study.

Student Background

Mathematics background of students

The mathematics background as defined by the Queensland Curriculum and Assessment Authority (Queensland Curriculum and Assessment Authority, 2014-2016) was defined by the admission pre-requisites for the degree program of enrolment by the student, where the pre-requisites were:

- No maths pre-requisite
- Maths A (basic level, covering financial mathematics, applied geometry and elementary statistics and probability)

- Maths B (intermediate level, covering periodic functions, exponential and logarithmic functions and their applications, derivatives and integrals, as well as applied statistical analysis)

The admission criteria for the degree program of enrolment which included their prior academic performance is detailed below:

- Medical science (12.6% of cohort)
 - very high prior academic performance (equivalent to the top 2.7% of senior school leaver students), intermediate maths pre-requisite, no concurrent mathematics study when studying the biochemistry course
- Biomedical Science (20.0% of cohort)
 - good prior academic performance (equivalent to the top 45% of senior school students), intermediate maths pre-requisite, no concurrent mathematics study when studying biochemistry course
- Forensic Science (20.0% of cohort)
 - Average (equivalent to the top 84% of senior school leaver students) to good prior academic performance, intermediate maths pre-requisite, concurrent mathematics study when studying biochemistry course
- Science (35.8% of cohort)
 - average prior academic performance with either basic or intermediate maths pre-requisite, concurrent mathematics study when studying biochemistry course

A diagnostic test, based on that described by Tariq (2002), was administered at the beginning of the course. Students in the Medical Science degree program scored on average of 65-71%, whereas those enrolled in the other degrees scored between 40 and 50%. These results reflect the prior academic performance and background of these students. The Medical Science students are high achieving and highly motivated to maintain a place in postgraduate medical school.

Maths Skills Site Intervention/Support

The extra-curricular Maths Skills program developed at La Trobe University (Jackson and Johnson 2013) supports mathematics learning for large enrolment first year courses with a diverse cohort of students, offering a choice of learning modes – online delivery, worksheets and drop-in sessions. Based on the La Trobe program, we developed and introduced a discipline specific, purely online mathematical support environment, termed the Maths Skills Site (MSS). As described elsewhere (Johnston et al. 2016), the MSS is a flexible online learning resource, designed for use in chemistry/biochemistry courses, comprising nine modules of mathematical support that specifically targets students' areas of difficulty. The module topics cover positive and negative numbers, exponents, significant figures, scientific notation, algebra, logarithms, quadratic equations, simultaneous equations and graphing. Each module had four key sections (Notes, Questions, Answers, and Links to Multiple Choice questions) and was designed to guide students to advance their knowledge and skills in the topics they find troublesome and therefore build confidence in using mathematics in a biochemistry context. Students could access context-based topic *Notes* that explained the topic clearly and contained many instructive illustrations and worked examples. The *Questions* were cross referenced to the notes and ranged from simple to more challenging self-paced questions to scaffold skill development. *Worked Answers* for every question were available to help build student confidence and provided self-paced feedback on questions. Links to *Multiple-choice Online Questions* that were biochemistry based and required mathematical manipulations were available to enable the students to practice the appropriate mathematical skills, in a low-stress environment, until they have mastered the required skill and gained confidence. Specific examples are described elsewhere (Johnston et al. 2016). The

MSS was linked to the course via the university's online Learning Management System (LMS) and available for all students for the duration of the course.

Information about the voluntary study, awareness of the MSS and how to access the materials was communicated through announcements in lectures, the LMS, and emails, notices and voluntary invitations to students. All data were collected in accordance with an approved ethics protocol.

Data Sources and Analysis

Sources of data for this study included students' use of the MSS, students' mathematical background and grades in the course, students' performance on tasks requiring numerical and mathematical skills and students' perceptions based on questionnaires.

MSS usage. The LMS Statistics Tracking tool was enabled, allowing determination of the use of individual items within the MSS modules (*e.g.*: logarithms multiple-choice questions, algebra questions and answers, simultaneous equations notes, etc.), frequency of use and 'hits per content area', where superficial hit equated to a single access by a user to the MSS. All student usage data were de-identified and aggregated for analysis.

Student Data. The data were collected from the students in the course for three academic years (2014-2016). Students who had withdrawn or dropped their enrolment by census date (end of week 4 of a 13-week semester), or not completed any assessment items were not included in the detailed analysis of the study. All student background data were obtained from degree program enrolment, and all student grade data for the course was de-identified such that all data contained no personal information. The data were aggregated by

number of hits or grade (7, 6, 5, 4, or ≤ 3) for analysis. The definition of final grades can be found in the appendix (Table A1).

Answers by students to written questions involving calculations and graphing in assignments and the final exam, as well as multiple choice questions in quizzes were analysed. For individual questions correct answers attracted full marks, partially correct answers were awarded part marks and no marks were awarded for incorrect answers. Examples of student work were converted into a digital format to de-identify any handwriting. Statistical analysis, in the form of a Chi-Square Test, was used to assess differences in performance on specific questions between users and non-users of the MSS. Overall performance in the course was determined as the final grade (7, 6, 5, 4, or ≤ 3) (Appendix Table A1). The null hypothesis tested was: H_0 ; the overall performance is independent of use of the MSS. Comparison of the final grades of users vs non-users was performed using a T-test. Use of the T-test was justified as the distribution of data did not violate any of the T-test assumptions.

Questionnaires. Students enrolled in the biochemistry course were invited to voluntarily respond to a survey questionnaire at the commencement of their course and participate in using the MSS. The questionnaire was administered during teaching sessions during weeks two and three of semester 2, 2014. The sample of biochemistry students who responded to the questionnaire was 70, representing 30.3% of the student cohort in that year. An anonymous, short follow-up questionnaire comprised of four Likert questions was administered online within two months of completion of the course in 2014. The sample of students who responded to the short follow-up questionnaire was 69, representing 29.9% of the student cohort in that year. All students were asked to participate in the study and gave their informed consent before

participating in the research and for the researcher's use of individuals existing data for research purposes. Students had the right to make a free choice over whether to contribute to the study or not. All student data were de-identified by an independent person and aggregated prior to analysis and were stored in a secure location.

As part of the initial questionnaire, students answered two Likert-style questions (Q1-2, Table A2) on whether they thought mathematics is important for the study of biochemistry and rated their confidence with maths. In the follow-up questionnaire further questions on student's perception of anxiety and importance of maths were included (Q3-4, Table A2). Two Likert-style questions on awareness and use of the MSS were also included (Q5-6, Table A2).

Limitations. This study focuses on students enrolling in the biochemistry course in the years 2014-2016 in one institution. Our analysis shows that these students are typical for this university and represent a full spectrum of students entering Queensland universities (University entry is managed by an independent state authority). As the use of online maths support was voluntary, the manipulation of groups and formation of control groups was not possible. Variables such as individual student motivation levels or alternate mathematics support during a student's semester of study are unknown and cannot be controlled or reported. It was not possible to determine what students did with the information presented once they accessed the MSS.

Results and Discussion

To address research question 1, we examined student usage of the MSS over the semester, and by topic.

Overview of MSS Usage

Understanding the mathematical background of students entering the biochemistry course was important to the context of the MSS usage. We carried out an analysis of the usage of the MSS during the period of the study (2014-2016) (Table 1). The medical science students (very high prior academic performance and intermediate maths pre-requisite) had lower overall usage for the MSS, with 68% being non users and only 14% being multiple users of the MSS. The remaining students (biomedical science, forensic science and science) were more bimodal in their usage of the MSS, with 53-61% being non users and 25-25% being multiple users. It was interesting to note that the Science students (overall average prior academic performance with either basic or intermediate maths pre-requisite), who were perceived as being in potential need of more maths support, did not use the MSS any more or less than the other students (biomedical science, forensic science). When the MSS was more heavily advertised to students (2015-2016), an increase in use by all students occurred. This was particularly evident in 2015 (Figure 1). The correlation between awareness of the MSS (by advertising on the LMS) and subsequent usage of the MSS by the students was particularly evident in 2015 (Figure 1).

Student Usage of the MSS over the semester

The statistics tracking feature of the LMS allowed us to analyse the patterns of usage of the MSS by students (Figure 2 a-c). The hit-count indicated a total of 55, 143 and 109 individual users in 2014-2016, representing 24%, 56% and 42%, respectively, of the course total cohort. Peak usage by students occurred after the in-class

announcements advertising the MSS to students during week 1 and before major assessment items, as previously observed for students studying 1st year chemistry. This was particularly noticeable for the 2016 assignment 2, where the assignment instructions directed students to the MSS graphing module as a resource, and there was increased usage (of the graphing notes) in week 11 (Figure 2 c).

Tracking of use by students revealed that a typical usage occurred where students (65%, 78% and 53% of users in 2014-2016, respectively) logged into the site multiple times during semester, accessing individual items (module notes, questions, etc.) across the various MSS module topics. The remaining students (35%, 22% and 47% of users in 2014-2016, respectively) were superficial users that logged-in to the site once to survey all topics.

Aggregated access by students indicated an overall preference for topic notes ahead of topic multiple choice questions involving mathematical calculations from a first-year online chemistry textbook, followed by short answer questions and answers (Table 2). Students preferred accessing topic notes within the MSS over the practice questions and answers (Table 2). By comparison, 21-27% of the students engaged with interactive learning through use of the multiple-choice online problems (Table 2). This may be attributed to the immediate feedback helping to improve student understanding. Students' usage (superficial or multiple user) of topics was mapped against the biochemistry curriculum (Figure 3). Whilst all the MSS topics were accessed, greater usage occurred for topics related to assessment items (e.g. graphing, Figure 3).

Student Performance for Calculations and Graphing in Biochemistry

To address research question 2, we examined the performance of students on multiple choice and written questions requiring calculations and graphing. Table 3 indicates the student performance on individual multiple-choice questions involving calculations, which were included in the quizzes held during semester and the final exam. The questions are given in the Appendix. For the multiple-choice questions, introductory questions (questions 1 and 4) involved a single-step calculation. More challenging questions (questions 2, 3 and 5) involved multiple steps for calculation of the answer. The use of a non-programmable scientific calculator was permissible in all quizzes and exams.

An overall comparable or decreased performance was observed between the different years for questions that were challenging, except for the - Medical Science students. By comparison, comparable or increased performance was observed for multiple choice questions that were of an introductory level and involved a single-step calculation of the answer.

The results indicate that Medical Science students (very high prior academic performance and intermediate maths pre-requisite) were able to carry out single-step calculations for logarithms and pH, as well as single/multiple-step calculations for pH and enzyme kinetics in multiple choice questions (Table 3). Similarly, this group displayed good performance on more challenging questions involving multiple calculation steps for pH and enzyme kinetics (Table 3). By contrast, those students with an average to good prior academic performance, and basic or intermediate maths pre-requisite background (Forensics Science, Biomedical Science and Science students) displayed various difficulties that included simple arithmetic operations,

manipulation of logarithms, interpretation of numerical data, and higher conceptual understanding of graphical issues associated with enzyme kinetics.

Next, we analysed student written answers to short answer questions on the final exam dealing with the troublesome topics of pH and enzymes and requiring calculations. Figures 4 and 5, show the answers given by two students (1 and 2) to a short answer question with parts A and B. Errors commonly observed in the answers from students in the final exam include: inability to divide exponents; multiplying instead of adding in the denominator of the Michaelis-Menten equation (despite being provided with the equation); decimal points in the wrong place; and inability to recognise if the answer was well removed from the expected range. Other errors included: ignoring units; incorrect unit conversions; incorrect significant figures; rounding errors; and applying concepts incorrectly, such as using $V_{\max}$ from part (a) for part (b) although these are different questions. These errors suggest that students have a poor grasp of foundational mathematics, a poor understanding of units, unit conversions and significant figures, as well as an inability to completely carry out algebraic calculations.

As discussed in the Introduction, the ability to generate and interpret graphs is an important skill for biochemistry students to acquire. Students were given a low stakes assignment on enzyme kinetics during semester and then tested on a very similar question in the final exam. The common errors (Figure 6) include: no points on the plot - just a straight line drawn; drawing a straight line through a hyperbolic plot of (initial velocity, V_0) versus substrate concentration (S); leaving no room for extrapolation on to the negative X-axis to determine K_m (intercept on negative X-axis = $-1/K_m$); no use of units on axes; plotting data on the wrong axis e.g. [S] on Y-axis;

and the misconception that $K_m = \frac{1}{2} V_{\max}$ even though K_m has units of concentration and $V_{\max}$ has units of rate.

The percentage of students who attempted the calculation and graphing questions on the written answer section of the final exam, and the percentage of correct versus incorrect answers, was compared for users of the MSS and non-users of the MSS (Table 4). The Chi-Square test of goodness-of-fit was used to determine whether there was any difference between the performance of users and non-users of the MSS. No significant differences were found except for the graphing question in 2016. Chi-square analysis for this question indicated $\chi^2 (3, N = 126) = 7.38, p = 0.025$. The Cramer's V coefficient (McHugh 2013) is 0.17, indicating a small to moderate effect, with those who participated in the MSS program being more successful on the graphing task than those who did not. The improvement with the graphing question may be correlated with deliberate instructions in assignment 2 in 2016 directing students to the MSS. It has previously been shown that students are extrinsically motivated by response to assessment (Armstrong et al. 2013), and that students' achievement in the use of learning strategies will also increase their academic achievement (Sen et al. 2014). Grehan et al. (2016) also showed that student engagement with maths support is linked to key critical events such as assignments.

Comparison of MSS Users and Non-Users

We mapped the student results in the diagnostic quiz (held in week 1) against their subsequent use of the MSS (Figure 7). It was observed that those students who received formative diagnostic quiz feedback of a mark of 10 or less out of 20 proceeded to be higher users of the MSS. An analysis of the final grades of users compared to non-users was performed using a T-test. Medical Science students were

excluded from this analysis as they all obtained grades of 6 and 7 (with one or two exceptions) and would thus skew the results. There was a significant difference between the users and non-users. The mean grade for users was 4.96 (Std Dev 0.93) compared to 4.76 (Std Dev 1.05) for non-users. This difference was significant $p = 0.033$, however the effect size was relatively small (0.3).

The final grade for the aggregated years (2014-2016) in the biochemistry course, was mapped against the background of the biochemistry students by program enrolment (Figure 8). Interestingly, the distribution of grades was reflective of the prior academic performance and mathematical background of a student, where the Medical Science students (very high prior academic performance and intermediate maths pre-requisite) were highly represented in the top grades of 6-7 and the remaining students in biomedical, forensic science and science had a varied distribution across all grades. Other studies have also shown that the level of mathematics studied in high school has an impact on the successful performance in university mathematics and science courses (Anderton et al. 2017).

The present study revealed that most users (excluding the Medical Science students) of the MSS were students who needed help, as identified by the diagnostic test (Figure 7). Research has strongly suggested that there is a correlation between student engagement with mathematics support and academic success. Those who avail themselves of support are more engaged, and engagement was found to be influenced by fear, motivation and social interactions (Grehan et al. 2016). Elsewhere it has been reported that students with lower and average mathematics achievement hold more positive attitudes toward using a web-based homework platform compared to higher achieving students (Leong and Alexander 2014).

Student Perceptions of Mathematics in Biochemistry

Student confidence and anxiety were captured in the initial and follow up questionnaires (Table A2), when students had almost completed a full year of study at this University. At the semester commencement, less than a quarter of the questionnaire cohort responded that they were not confident/not very confident with their mathematical skills (24%). After a full semester of study, respondents self-reported feeling anxious (44 % agree/strongly agree) when having to answer problems requiring calculations. The perception about the importance of mathematics to biochemistry was significant (87% agree/strongly agree) after completion of the course. The follow-up questionnaire indicated that the predominant reason for non-use was that students felt they did not need to use the MSS (66% agree/strongly agree) and this was unrelated to assessment, since 81% of respondents were neutral to strongly disagreeing to Question 5 (*I did not use the MSS because it was not assessable*).

One key theme of the literature review by Lawson and colleagues (2019) was the characteristics of students who engage with mathematics support and reasons why others do not. Maths support is often used more by good students wanting better grades than those trying to avoid failure (Pell and Croft, 2008). In the case of drop-in support centres, predominant reasons given by students as to why they do not use support are: - not being aware of the support or where it is located (Symonds et al. 2008) or times being unsuitable (Mac an Bhiard et al. 2013). In our study the questionnaire data (although limited) suggests that some students are unaware that they need support (Dunning, 2011).

Conclusions and Implications for Teaching

Student patterns of usage for the MSS (research question 1), revealed that about 50% of total students made use of the MSS, with periods of use coinciding with announcements, assessment item deadlines and assignment instructions. There was a preference for apparent surface learning, in that module notes were the most accessed with little use of practice questions and answers. Higher achieving students were less likely to use the support site perhaps because they were already confident with their mathematics ability.

In relation to research question 2, students who made use of the MSS showed noticeable improvement for the enzyme kinetics graphing question. Students accessed the MSS for the graphing module, gained practice through active learning in assignment 2 and then were tested on the graphics component in the final exam. Furthermore, there was a small but significant effect of MSS usage with users performing better than non-users overall. As with other studies (Grehan et al. 2016), student who demonstrate little or no engagement with curriculum support continue to be an identifiable group. Future studies should investigate in more detail the causes for student non-engagement with academic support.

The implication of this study for the teaching of first year biochemistry is the requirement to scaffold numeracy and mathematical skills into the student learning of troublesome concepts. In addition, the continued support of the students with more average prior academic performance in the digital environment with adaptive learning approaches should be of value to student academic success in biochemistry. A future focus on mathematical skills in context for curriculum and teaching is important for helping students attain the necessary skills for a career in biochemistry and science generally.

References

- Adkins, M., and A. Noyes. 2017. Do advanced mathematics skills predict success in biology and chemistry degrees? *International Journal of Science and Mathematics Education* 16(3): 487-502. <https://doi.org/10.1007/s10763-016-9794-y>
- Anderton, R., G. Hine, and C. Joyce. 2017. Secondary school mathematics and science matters: Academic performance for secondary students transitioning into university allied health and science courses. *International Journal of Innovation in Science and Mathematics Education* 25(1): 34-47.
- Angra, A., and S. M. Gardner. 2017. Reflecting on Graphs: Attributes of Graph Choice and Construction Practices in Biology. *CBE-Life Sciences Education* 16(3): ar53, 1-15.
- Armstrong, S., S. Brown and Thompson, G. (Ed.) 2013. *Motivating Students*. Routledge, Oxford and New York.
- Atuahene, F. and Russell, T.A., 2016. Mathematics Readiness of First-Year University Students. *Journal of Developmental Education*, 39(3), p.12.
- Beilock, S.L. and Maloney, E.A., 2015. Math anxiety: A factor in math achievement not to be ignored. *Policy Insights from the Behavioral and Brain Sciences*, 2(1), pp.4-12.
- Bennett, J., F. Lubben, and S. Hogarth. 2007. Bringing science to life: A synthesis of the research evidence on the effects of context-based and STS approaches to science teaching. *Science Education* 91(3): 347–370.
- Brewer, C.A. and Smith, D., 2011. Vision and change in undergraduate biology education: a call to action. *American Association for the Advancement of*

- Science, Washington, DC. visionandchange.org/finalreport. Retrieved from <http://visionandchange.org/files/2013/11/aaas-VISchange-web1113.pdf>*
- Chang, H., and S.L. Beilock. 2016. The math anxiety-math performance link and its relation to individual and environmental factors: a review of current behavioral and psychophysiological research. *Current Opinion in Behavioural Sciences* 10: 33-38.
- Dunning, D. 2011. The Dunning–Kruger effect: On being ignorant of one's own ignorance. In *Advances in experimental social psychology* (Vol. 44, pp. 247-296). Academic Press.
- Foley, A.E., J.B. Herts, F. Borgonovi, S. Guerriero, S.C. Levine, and S.L. Beilock. 2017. The math anxiety-performance link: A global phenomenon. *Current Directions in Psychological Science* 26(1): 52-58.
- Freudenthal, H. 2006. *Revisiting mathematics education: China lectures* (Vol. 9). Springer Science & Business Media.
- Grehan, M., Mac an Bhaird, C. and O'Shea, A., 2016. Investigating students' levels of engagement with mathematics: critical events, motivations, and influences on behaviour. *International Journal of Mathematical Education in Science and Technology*, 47(1), pp.1-28.
- Hillock, P. W., M. Jennings, A. Roberts, and V. Scharaschkin, 2013. A mathematics support programme for first-year engineering students. *International Journal of Mathematical Education in Science and Technology* 44(7): 1030-1044.
- Hine, G. 2017. Exploring reasons why Australian senior secondary students do not enrol in higher-level mathematics courses. In A. Downton, S. Livy, & J. Hall (Eds), *Proceedings of the 40th Annual Conference of the Mathematics Education Research Group of Australasia*. Melbourne, Australia (pp. 309-

- 3016). Adelaide, Australia: The Mathematics Education Research Group of Australasia Inc.
- Hine, G., 2018. Teachers' perceptions on declining student enrolments in Australian senior secondary mathematics courses. *Issues in Educational Research*, 28(3): 635-654.
- Hodgen, J., Adkins, M. and Tomei, A., 2019. The mathematical backgrounds of undergraduates from England. *Teaching Mathematics and its Applications: An International Journal of the IMA*. Published online 19 Dec 2018, <https://doi.org/10.1093/teamat/hry017>
- Jackson, D. C., and E. D. Johnson. 2013. A hybrid model of mathematics support for science students emphasizing basic skills and discipline relevance. *International Journal of Mathematical Education in Science and Technology* 44(6): 846-864.
- Johnston, P. R., D. J. Watters, C. L. Brown, and W. A. Loughlin. 2016. An investigation into student perceptions towards mathematics and their performance in first year chemistry: introduction of online maths skills support. *Chemistry Education Research and Practice* 17(4): 1203-1214.
- Kennedy, J. P., T. Lyons, and F. Quinn. 2014. The continuing decline of science and mathematics enrolments in Australian high schools. *Teaching Science*, 60(2): 34-46.
- Kim, C., S. W. Park, and J. Cozart. 2014. Affective and motivational factors of learning in online mathematics courses. *British Journal of Educational Technology* 45(1): 171-185.

- Koenig, J. 2011. *A survey of the mathematics landscape within bioscience undergraduate and postgraduate UK higher education* (p. 22). Leeds: UK Centre for Bioscience.
- Lawson, D., M. Grove, and T. Croft. 2019. The evolution of mathematics support: a literature review. *International Journal of Mathematical Education in Science and Technology*. Published online 22 Sep.
<https://doi.org/10.1080/0020739X.2019.1662120>
- Leong, K. E., and N. Alexander. 2014. College Students Attitude and Mathematics Achievement Using Web Based Homework. *Eurasia Journal of Mathematics, Science & Technology Education* 10(6): 601-615.
- Mac an Bhaird, C., O. Fitzmaurice, E. Ní Fhloinn, and C. O'Sullivan. 2013. Student non-engagement with mathematics learning supports. *Teaching Mathematics and its Applications: An International Journal of the IMA*, 32(4): 191–205.
- McAlinden, M., and A. Noyes. 2019. Mathematics in the disciplines at the transition to university. *Teaching Mathematics and its Applications: An International Journal of the IMA*. 38(2): 61-73. <https://doi.org/10.1093/teamat/hry004>
- McHugh M.L. 2013. The Chi-square test of independence. *Biochemia Medica* 23(2): 143–149.
- Ní Fhloinn, E., O. Fitzmaurice, C. Mac an Bhaird, and C. O'Sullivan. 2014. Student perception of the impact of mathematics support in higher education. *International Journal of Mathematical Education in Science and Technology*, 45(7): 953-967.
- Ní Shé, C., C. Mac an Bhaird, E. Ní Fhloinn, and A. O'Shea. 2017. Problematic topics in first-year mathematics: lecturer and student views. *International Journal of Mathematical Education in Science and Technology* 48(5): 715-734.

- Orgill, M., and A. Sutherland. 2008. Undergraduate chemistry students' perceptions of and misconceptions about buffers and buffer problems. *Chemistry Education Research and Practice* 9(2): 131-14
- Park, E. J., and K. Choi. 2013. Analysis of student understanding of science concepts including mathematical representations: pH values and the relative differences of pH values. *International Journal of Science and Mathematics Education* 11(3): 1-24.
- Pell, G., and A. C. Croft. 2008. Mathematics support – support for all? *Teaching Mathematics and its Applications: An International Journal of the IMA*, 27(4): 167–173.
- Pohjolainen, S., O. Nykänen, J. Venho, and J. Kangas. 2018. Analysing and Improving Students' Mathematics Skills Using ICT-Tools. *Eurasia Journal of Mathematics, Science and Technology Education*, 14(4): 1221-1227.
- Queensland Curriculum and Assessment Authority (2014-2016). *Subject enrolments and levels of achievement*. Report No. 2014, 2015 and 2016, Brisbane, Australia.
- Quinnell, R., R. Thompson, and R. J. LeBard. 2013. It's not maths; it's science: exploring thinking dispositions, learning thresholds and mindfulness in science learning. *International Journal of Mathematical Education in Science and Technology* 44(6): 808-816.
- Sen, S., A. Yilmaz, and H. Yurdağül. 2014. An Evaluation of the Pattern between Students' Motivation, Learning Strategies and Their Epistemological Beliefs: The Mediator Role of Motivation. *Science Education International* 25(3): 312-331.
- Sgambato, F., S. Prozzo, E. Sgambato, R. Sgambato, and L. Milano. 2012. The 100th anniversary of the invention of pH (1909-2009)-Part II. Was it really necessary

- to replace the Henderson equation with that of Henderson-Hasselbalch? *Italian Journal of Medicine* 5(4): 215-226.
- Symonds, R., D. A. Lawson, and C. Robinson. 2008. Promoting student engagement with mathematics support. *Teaching Mathematics and its Applications: An International Journal of the IMA*, 27(3): 140–149.
- Tansey, J. T., T. Baird, M.M Cox, K.M. Fox, J. Knight, D. Sears, and E. Bell. 2013. Foundational concepts and underlying theories for majors in “biochemistry and molecular biology”. *Biochemistry and Molecular Biology Education*, 41(5): 289-296.
- Tariq, V.N., 2002. A decline in numeracy skills among bioscience undergraduates. *Journal of Biological Education*, 36(2): pp.76-83.
- Tariq, V. N., P. Qualter, S. Roberts, Y. Appleby, and L. Barnes. 2013. Mathematical literacy in undergraduates: role of gender, emotional intelligence and emotional self-efficacy. *International Journal of Mathematical Education in Science and Technology*, 44(8): 1143-1159
- Treacy, P., and F. Faulkner. 2015. Trends in basic mathematical competencies of beginning undergraduates in Ireland, 2003–2013. *International Journal of Mathematical Education in Science and Technology*, 46(8):1182-1196.
- Wachsmuth, L. P., C. R. Runyon, J. M. Drake, and E. L. Dolan. 2017. Do Biology Students Really Hate Math? Empirical Insights into Undergraduate Life Science Majors’ Emotions about Mathematics. *CBE-Life Sciences Education* 16(3): ar49, 1-10.
- Watters, D. J., and J. J. Watters. 2006. Student understanding of pH: “I don't know what the log actually is, I only know where the button is on my calculator”. *Biochemistry and Molecular Biology Education*, 34(4): 278-284.

- White, H. B., M. A. Benore, T. F. Sumter, B. D. Caldwell, and E. Bell. 2013. What skills should students of undergraduate biochemistry and molecular biology programs have upon graduation? *Biochemistry and Molecular Biology Education* 41(5): 297-301.
- Wilson, R., and J. Mack. 2014. Declines in high school mathematics and science participation: evidence of students' and future teachers' disengagement with maths. *International Journal of Innovation in Science and Mathematics Education (formerly CAL-laborate International)* 22(7): 35-48.
- Wright, A., J. Provost, J. A. Roecklein-Canfield, and E. Bell. 2013. Essential concepts and underlying theories from physics, chemistry, and mathematics for "biochemistry and molecular biology" majors. *Biochemistry and Molecular Biology Education* 41(5): 302-308.
- Zientek, L.R., C.J. Fong, and J.M. Phelps. 2017. Sources of self-efficacy of community college students enrolled in developmental mathematics. *Journal of Further and Higher Education*: 1-18.

Table 1

Student usage of Maths Skill Site for 2014-2016 by prior maths and academic rank

Degree Program	Prior Academic Rank*	Prior Maths level	Multiple user (%)	Single user (%)	Non- user (%)
Medical Science	1	intermediate	14	18	68
Biomedical Science	9	intermediate	35	11	53
Forensic Science	12	intermediate	25	15	61
Science	16	basic or intermediate	32	11	57

*Students receive a position ranking value from 1 to 25 which is used for degree admissions, where a rank of 1 represents students scoring in the top 2.7% of all students state-wide and a rank of 16 represents the top 84% of students.

Table 2

Student usage of Maths Skill Site online module item types

Maths Skill Site online module item type	Users in 2014 (%; $n = 55$)	Users in 2015 (%; $n = 143$)	Users in 2016 (%; $n = 109$)
Notes	48	52	59
Questions	23	12	11
Answers	10	8	9
Multiple Choice	19	27	21

Table 3

Percentage of students with correct answer to multiple choice questions on pH and enzyme kinetics.

Questions by year, quiz, final exam	Medical science (%)	Biomedical Science (%)	Forensic science (%)	Science (%)	All students (%)
2015 Quiz 1 Q1	74	24	22	23	33
2016 Quiz 1 Q1	79	24	27	24	37
2014 Final Exam Q2	44	23	15	11	25
2016 Final Exam Q2	62	15	20	11	22
2014 Final Exam Q3	63	53	38	24	46
2016 Final Exam Q3	52	42	22	25	34
2014 Quiz 1 Q4	85	33	28	21	38
2015 Quiz 1 Q4	88	61	58	40	62
2016 Quiz 1 Q4	100	73	73	56	77
2015 Quiz 2 Q5	91	63	45	40	58
2016 Quiz 2 Q5	87	41	42	27	49

Note. Q1 = Question 1, introductory logs and pH; Q2 = Question 2, challenging pH; Q3 = Question 3, challenging enzyme kinetics; Q4 = Question 4, introductory enzyme kinetics; Q5 = Question 5, challenging enzyme kinetics.

Table 4

Percentage of students (Users and Non-users of MSS; all students) with answers to graphing and enzyme kinetics questions requiring calculations in the written answer section of the final exam.

	Number of students (MSS users) that attempted question (%)			Number of students (MSS non-users) that attempted question (%)		
Year	2014	2015	2016	2014	2015	2016
<i>Calculation question</i>						
wrong	11 (34)	12 (23)	20 (33)	24 (30)	7 (27)	28 (33)
partially correct	5 (16)	27 (52)	28 (47)	17 (22)	9 (35)	32 (37)
correct	16 (50) *	13 (25)	12 (20)	38 (48)	10 (38)	26 (30)
total students	32	52	60	79	26	86
<i>Graphing question</i>						
wrong	11 (46)	16 (42)	14 (27)	42 (46)	8 (35)	33 (44)
partially correct	6 (25)	7 (18)	23 (45)	30 (33)	7 (30)	17 (23)
correct	7 (29)	15 (40)	14 (27)	20 (22)	8 (35)	25 (33)
total students	24	38	51	92	23	75

Note. *For example: Of the MSS users in 2014 (total $n=32$) 16 students (50% of those who attempted the questions) answered the calculation question correctly. The graphing question in the 2015 final exam was optional.

Figure 1

Figure 2 a. **b.** **c.**

Figure 3

Figure 4

B. The K_m of an enzyme which obeys Michaelis-Menten kinetics is 1.0×10^{-4} M. At a substrate concentration of 0.20 M, the initial rate, $V_0 = 43 \mu\text{M}/\text{min}$. What is the value of V_0 for this enzyme at a substrate concentration of 0.2mM?

$$V_0 = \frac{V_{\max} [S]}{K_m + [S]}$$

$$K_m = 1 \times 10^{-4} \quad \leftarrow \text{No units}$$

$$[S] = 0.2\text{M}$$

$$V_0 = 0.000043\text{M}/\text{min}$$

$$0.000043 = \frac{V_{\max} \times 0.2}{0.2 \times 1 \times 10^{-4}} \quad \leftarrow \text{Multiplying instead of adding}$$

$$8.6 \times 10^{-10} = V_{\max}$$

When $[S] = 0.0002$ Did not notice that their $V_{\max}$ is 4 orders of magnitude smaller than given V_0 at 0.2M

$$V_0 = \frac{8.6 \times 10^{-10} [0.0002]}{0.2 \times 0.0002}$$

$$= \frac{1.72 \times 10^{-13}}{0.00004}$$

$$V_0 = 0.00000000043\text{M}/\text{min} \quad \leftarrow \text{Incorrect division. Mix of decimal and scientific notation}$$

$$= 0.0043\mu\text{M}/\text{min}$$

Figure 5

Figure 6

Figure 7 **Figure 8**

List of Figure Captions

Fig. 1. Student usage of the MSS by enrolled degree during the period of the study.

Fig. 2 a-c. Usage *versus* time for 2014-2016, with key assessment milestones (grey arrows) and key topic teaching (yellow). MS (mid-semester break); SW (study week); EX1 (exam week 1); EX 2 (exam week 2); **a:** Superficial user ($n = 19$); Multiple user ($n = 36$); **b:** Superficial e user ($n = 32$); Multiple user ($n = 112$); **c:** Superficial user ($n = 51$); Multiple user ($n = 58$).

Fig. 3. Percentage of students accessing MSS module topic for 2014-2016: logarithms applied in pH, assessment in online lab 1 and assignment 1; graphing applied in enzyme kinetics, assessment in online lab 2 and assignment 2.

Fig. 4 Annotated transcription of errors in the answer to final exam short answer question 1, part B by Student 1. The question part B is given in the top panel.

Fig. 5 Annotated transcription of errors in the answer to short answer final exam question 1, parts A and B (top panel) by Student 2 (Correct answer Part A = $6.3 \times 10^3 \text{ sec}^{-1}$; Part B = $29 \mu\text{M min}^{-1}$).

Fig. 6 Annotated transcription of errors in the answer to graphing question in assignment 2, by Student 3.

Fig. 7 Diagram of Usage Hits on MSS versus Diagnostic Test result (scored out of 20) for Biochemistry for 2015-2016.

Fig. 8 Student academic/mathematical background versus Final Grade for Biochemistry for 2014-2016.