Quantitative Skills and Complexity: How can we Combat these Challenges and Equip Undergraduate Students to Think and Practice as Biologists?

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Abstract

Mapping the pedagogical process of learning in biology has shown that fieldwork and laboratory practicals require students to use quantitative skills in a high-level learning context. These tasks include creating graphical representations of data and performing statistical analyses, and are major areas of student disengagement and poor performance. Biology educators face a challenge: how to keep students engaged in mastering new techniques and methodology to develop the 'thinking of a biologist', while developing confidence using quantitative mathematical skills. Here we investigate the use of an online learning module in molecular biology to simplify this complex process of learning in biology. The module emphasised the links between the concept (gene regulation), experiments (growing *Escherichia coli* in the presence of different effector molecules and substrates) and the data recorded. An audit of student assignments and surveys before and after the introduction of the module indicated that students improved their data presentation skills. Results highlight the cognitive and practical complexity of the task. The usefulness of consolidating information by providing extra time using a blended approach to laboratory practicals is discussed. Finally, the relationship between the practical activity and threshold concepts, thinking dispositions and mindfulness is made to better understand how we can assist students to become quantitatively confident and competent in their practice as biologists.

Introduction

Students learning biology spend significant amounts of time in laboratories or the field making observations and performing experiments to test concepts and questions. The aim of these activities is to demonstrate particular concepts outlined in lectures, such as gene expression (switching genes on and off) and biodiversity, and to develop the practical skills required of a biologist, including the ability to employ the scientific method to answer questions. This way of teaching, and the approach by which we expect students to learn, models our professional practice, a signature pedagogy that appears deceptively straightforward and logical. To examine it in more detail we utilised the valuable threshold concept framework developed by Meyer and Land (2005). The idea of examining the 'transformative thresholds' to assist student learning is not new, but was given a new direction by this seminal work. The threshold framework was used to identify the key points in the learning process where students get "stuck". The struggle for students to understand

and progress was identified as discipline-based conceptual steps that are, by definition, transformative, irreversible, integrative and troublesome for learning. The threshold framework enables an analysis of student learning by distinguishing threshold concepts from simpler, non-transformative concepts by careful unpicking of the liminal transitional steps that enable a novice to understand the concept of complexity.

The biology threshold concept framework, developed by Ross, Taylor, Hughes, Kofod, Whitaker, Lutze-Mann and Tzioumis (2010), offered a much needed discipline context for those in 'life sciences' generally. In our work, we have applied the threshold framework to elements of our undergraduate biology courses and found the learning process to be complex, multi-faceted, and to contain significant threshold concepts (LeBard & Quinnell 2008; Quinnell, Thompson & LeBard 2012). As biology educators, our broad challenge is to assist students as they navigate learning, overcome obstacles, stay on track and reach the expected endpoint. By mapping and making explicit the concepts, skills and way of thinking we expect students to master as they become biologists, we clarify for ourselves the places where they will need our assistance.

Declining mathematical abilities

One area we see as critical to learning in biology is the development of quantitative skills, *i.e.* numeracy. We are concerned with the decreasing numbers of students undertaking higher mathematics courses and their increasingly negative perceptions of mathematics. Such disengagement has implications for how students learn and how they respond to our teaching, since quantitative skills are integral to the practice of biology. Indeed, in Australia, the number of Year 12 students undertaking mathematics is declining, falling from 76.6% in 2002 to 71.6% in 2010 (Office of the Chief Scientist 2012). Coupled with this, amongst students who do elect to study mathematics, there is a continuing shift in standards from *advanced* and *intermediate* to more basic level mathematics (Officer of the Chief Scientist 2012). In 2012, to accommodate students the state of New South Wales (NSW) introduced a new and simpler course called 'Essential Maths'. The introduction of this new and lower standard mathematics option prompted the Mathematic Association of NSW to raise concerns that more able final year high school students would opt for this, contributing further to the decline in higher maths study (Topsfield 2013). Ominously, this falling-off in high school students taking mathematics is mirrored in a decline in mathematics *ability* of primary and secondary school children in Australia as detected by the Organisation for Economic Co-operation and Development (OECD) (2010). Consequently, it can be predicted that there will be a continued fall in the level of mathematics preparedness of students commencing tertiary education. This is a concern because Sadler and Tai (2007) have demonstrated a correlation between the advanced study of mathematics in high school and academic performance in science at university level, including biology (Sadler and Tai 2007). Indeed, they deem the development of advanced mathematical skills at high school to be one of the 'two pillars' supporting higher education science learning. The other pillar being the study of the same science subject at high school level. It is likely that a major challenge of biology educators will be to support the academic achievement of students who are increasingly deficient in essential mathematical skills.

Basic and more advanced mathematical skills are key skills for life after higher education. A survey of over 50 organisations from diverse industries showed a unanimous agreement with the statement 'We highly value strong mathematical skills when considering job applicants' (Tinsdale 2013). Given that 53% of working age Australians have difficulty with numeracy skills (Industry Skills Councils in Australia 2011); it appears that graduates proficient in mathematics will be preferred in the job market. Indeed, business groups cite mathematical ability as an 'employability skill' considered deficient in the United Kingdom (Department for Innovation, Universities and Skills 2008). This view is echoed in the report by the Australian Chamber of Commerce and Industry and the Business Council of Australia (ACCI and BCA) (2002), which stated 'there are not enough graduates who combine high-level mathematics and science knowledge with the capacity to work effectively in industry' (p.14).

Mathematics skills of students in biology at a higher education level

So, how are our students in biology performing in the development of mathematics skills? Studies have indicated that the mathematical skills of biology students are important. Tariq (2002) provided evidence of a decline in basic numeracy skills among first year bioscience undergraduate students over a five year period in Northern Ireland. This is of concern because the level of mathematics has previously been shown to act as a reliable predictor of overall performance in biology related disciplines such as psychology (Mulhern & Wylie 2005). In an extensive study of biology students in an undergraduate plant physiology course, Vila and Sanz (2013) found a highly-significant correlation between student scores in mathematics questions and final examination performance. This was in all of the eleven years over which they conducted their study. The finding occurred despite the final examination containing only 10-20% of questions of mathematical relevance.

Dis-engagement in numeracy-related tasks

In the biological life sciences, lack of interest in mathematics is prominent regardless of the successful completion or high performance in mathematics (Poladian 2013). Using a standard student feedback survey, Poladian (2013) highlighted the poor recognition for the value or purpose of service teaching mathematics and similarly, the relevance of this course within the life sciences degree at a major metropolitan university. He also highlighted that the attitudes and perceptions of students are difficult to shift. To accommodate student attitudes, and in line with scholarly research, he redeveloped his course to be contemporary and relevant and as a result the course has received better feedback from students. This example shows that student attitudes play an important role in students' ability to engage with the mathematical aspects of biology, supporting our assertion that biology students fail to see mathematics as relevant.

Why do students often fail to perceive maths to be integral to biology? Rather than transferring their maths skills to the study of biology, students appear to transfer their aversion of mathematics and/or transfer their maths anxiety (LeBard & Quinnell 2008). Maths anxiety results in a lower performance in maths-related situations (Richardson & Suinn 1971), and avoidance of such situations and has been shown to inhibit student learning of other disciplines (Hembee 1990). Students who are anxious about maths report feelings of tension, apprehension, and fear when anticipating a maths task, with increased activity detected in the area of the brain associated with threat detection and pain (Lyons & Beilock 2012). Simply stated, learning in biology is disabled when students are anxious about maths. Having completed tertiary mathematics, it would be rare for our students to lack an ability to perform the calculations required in their biology courses, instead they lack the confidence and inclination to do so.

Transference of maths skills to science learning

In the literature, no single strategy has been identified as the key to solving students' self-perceptions of their maths capabilities. Studies have, however, found that intervening to improve student confidence may improve student performance (Quinnell & Wong 2007; Vila

& Sanz 2013). Quinnell and Wong (2007) discovered that half of biology students surveyed lacked confidence in quantitative tasks, especially when performing bench calculations. Follow-on conversations with these students indicated that many of these students appreciated knowing that for them it was unlikely that maths *skills* were their problem; in fact, as they knew *how* to do the tasks, they needed to work on their *confidence*.

Students who possess confidence and capability are able to carry out inter-disciplinary 'low road' transfer (Perkins & Salomon 1992) from maths to science. The transfer of numeracy skills from maths to science is where most interventions seem to focus and these interventions aim to put students in the position where, with more practice, they can automatically complete their calculations. This 'low road' transfer is typified by students being able to perform simple arithmetic operations (multiply, divide, add, subtract, convert between milli, micro, etc., convert between mL, L, m^3) while maintaining their main focus on understanding the biology in an experiment. Interventions that require reflection, where students address their confidence as a critical part of the transfer process, target a different subset of students. For our students, confidence building starts with reflecting on the misalignment between their ability and confidence (Quinnell et al. 2012; Quinnell & Thompson 2010).

Learning in biology is complicated

It is critical for biology students to be competent and confident mathematically so they can start to practice as biologists. The practice of many professional academic biologists is reflected in the learning and teaching activities they set for students in the laboratory and in the field. That is, students are required to make observations, record quantitative/qualitative information, handle raw data sets, perform calculations and present data according to conventions, and then interpret meaning from these data. Finally, students need to synthesise this information to explain the concepts being taught in the curriculum.

Simply stated, students in biology need to exercise their mathematical skills fluidly within a complex learning environment. The process of converting raw data to something meaningful, and conveying this in a graphical form, is at the highest cognitive level of SOLO taxonomy according to Biggs and Collis (1982). In our teaching and learning context it is common for students to carry out an experiment and write up their experimental findings in a laboratory report, which involves students *analysing* data and *evaluating* the relevant literature and then *planning* and *producing* a written report. These italicised terms align with relatively high-order cognitive processes as described in the revised Bloom's taxonomy (Krathwohl 2002).

The tertiary path to becoming a biologist is a transformative and complex learning process. It is not merely learning a set of practical and technical skills, the scientific method, and specific content explaining the biological world that surrounds us. The way we teach biology, our signature pedagogy, prepares students for the profession of biology by instilling a way of thinking in which the ability to grapple with numbers is integral. The practice that needs to be mastered ultimately is an approach where numbers are handled fluidly. This includes: knowing how to quantify and organise the observable; knowing the evidence that needs to be collected; interpreting, thinking and understanding collected results; and putting this together to build new knowledge (Meyer & Land 2003, 2005; Redish 2010). The aim of this study was to use interventions in the complex cycle of learning in a molecular biology course to improve student confidence and competence mathematically.

Molecular Biology students' participation in the practice of science

Methodology

This study was done with students in a second year undergraduate molecular biology course in a faculty of science at a large metropolitan university. The course is for students who do not intend to continue in molecular biology in third year. It is compulsory for the food science and technology program, but may also be taken as an elective in the nanotechnology program. There were 100, 101 and 86 students enrolled in the course in 2007, 2008 and 2009, respectively. These students had completed first year undergraduate courses in mathematics and biology. Learning activities each week comprised two one-hour lectures, a one-hour tutorial and a three-hour laboratory practical.

The course aims to provide an introduction to modern molecular biology and covers the molecular mechanisms of gene expression and the fundamental aspects of recombinant DNA technology. One of the topics covered in the course is the regulation of gene expression. This is covered in lectures, a large group and a small group tutorial, and a practical experiment that spanned two three-hour laboratory sessions. In 2008, an online module was first implemented as a revision tool. This was accessible *via* the course website within the online learning system Blackboard Learn^{TM} (version 9). The online module was designed and implemented as part of a large faculty learning and teaching project (Allen, Crosky, Yench, Lutze-Mann, Blennerhassett, Lebard, Thordarson & Wilk, 2010). It aimed to support students exercising their quantitative skills and make the quantitative process less abstract. To do this it consolidated all the laboratory class content, eliminated waiting times, and displayed the relationship at a molecular level with data on macroscopic changes. The success of student learning of the regulation of gene expression was measured through submission of a practical report and within the final examination.

The practical experiment involved students in pairs taking samples from a growing *Escherichia coli* culture and performing a β-galactosidase assay. Students carried out the procedure under one of six different conditions, *viz.*: a negative control of the culture with no additions; the addition of the inducer isopropyl-p-D-thiogalactoside (IPTG) (switching on β-galactosidase production); IPTG and glucose (β-galactosidase production does not occur until the glucose is exhausted); chloramphenicol or streptomycin (inhibits protein synthesis); and rifampicin (inhibits transcription). The amount of β-galactosidase was quantified using a spectrophotometer. Students were instructed on how to convert the absorbance readings into units of β-galactosidase produced.

The online module was provided for students to access either at home or from the computer laboratory. The module provided students with an animated step-by-step visualisation of the concept of regulation of gene expression (Figure 1). The experiment was performed virtually online, with students able to conduct and obtain results for each of the six conditions done practically in class. In particular, the module allowed students to view the absorbance data obtained which was plotted on the same screen. Students could move the mouse over the points on the graph to see how each absorbance reading could be fitted into the equation for calculating the amount of β-galactosidase produced (Figure 2). The aim here was to allow students to visualise the process whereby data are manipulated and make it less abstract. However, students were still required to present these final β-galactosidase values as a table and as a figure in their report to be assessed.

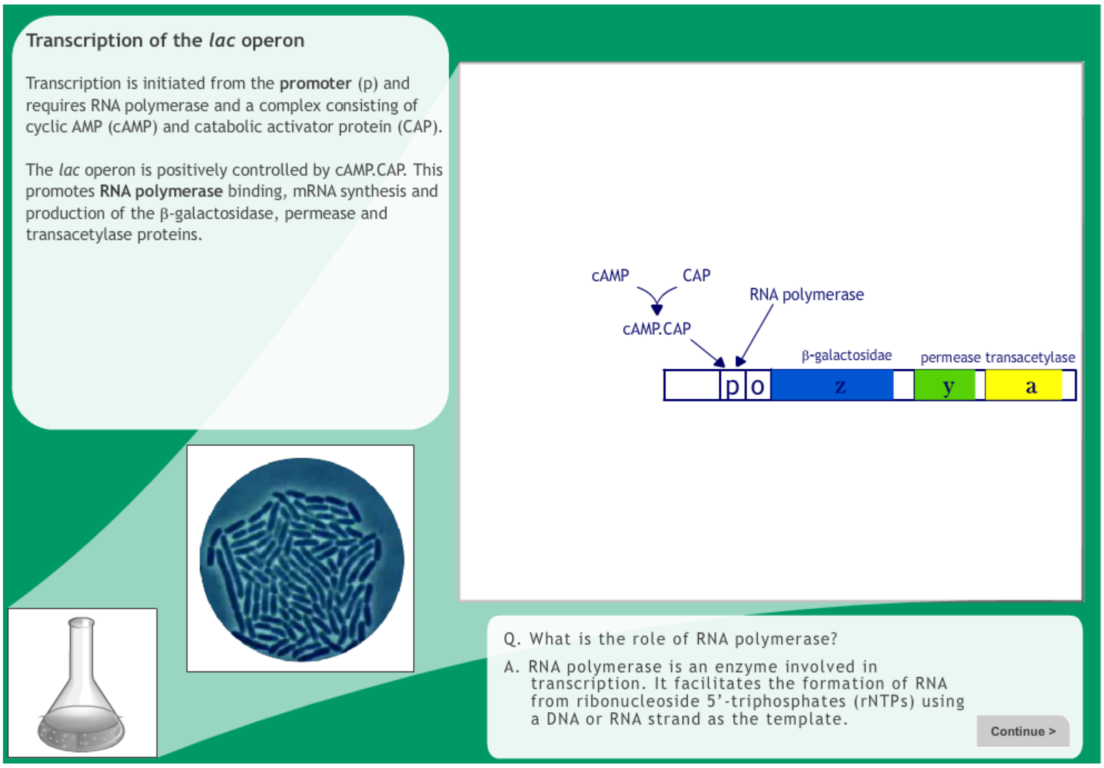

Figure 1: Screen shot of the Molecular Biology online module. The module takes students step-by-step through the concept of regulation of gene expression. The experiment could be performed virtually, with students able to conduct and obtain results for each of the six conditions before the laboratory session.

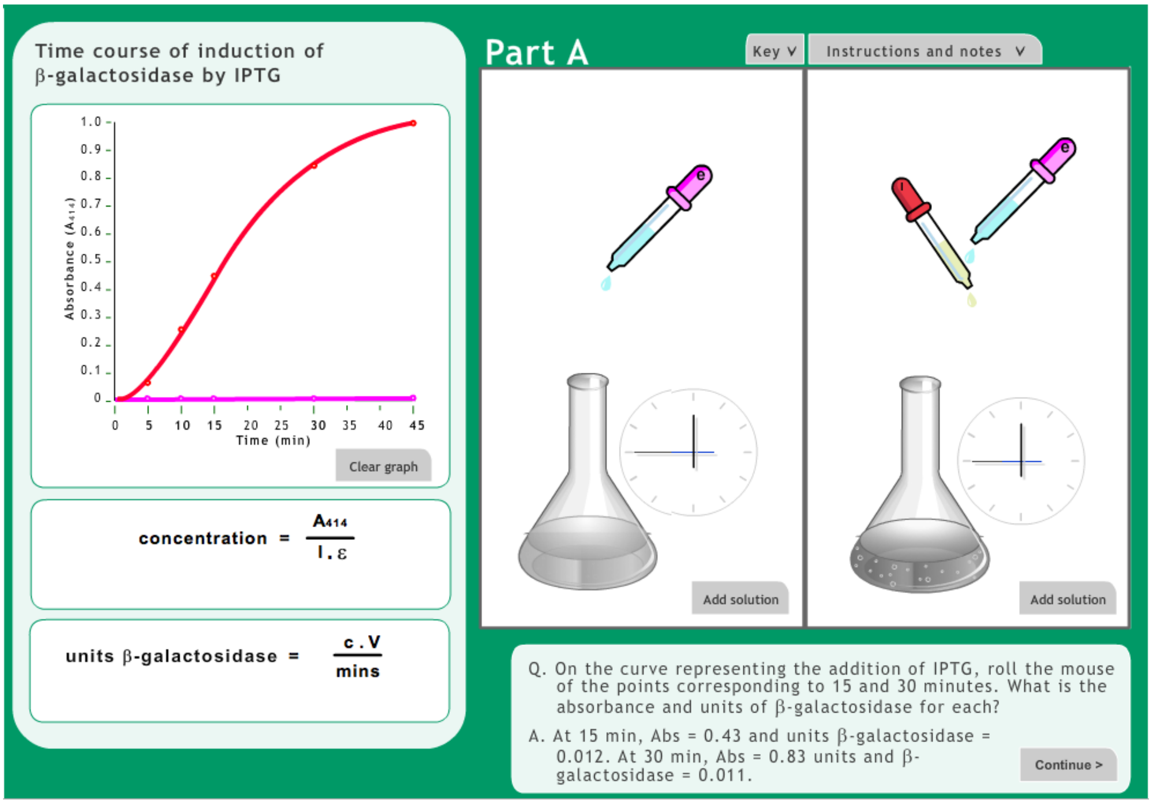

Figure 2: Screen shot of the Molecular Biology online module. The module allows students to see their numeric data on the same screen as the virtual experiment.

In 2008, students were surveyed. The study survey comprised three parts: the first part focused on student perceptions of the subject molecular biology and the relevance of molecular biology to their degree (two 5-point Likert-scale questions and two open-ended), the second on the online module *regulation of gene expression* (six 5-point Likert-scale questions) and the third related to their approach towards data handling in the practical on the regulation of gene expression and its associated laboratory report (six 5-point Likert-scale questions and two open ended).

The surveys were distributed, collected and de-identified by one of the investigators not involved in teaching of the course. The de-identified dataset was made available to the course convenor after the student grades were finalised. Likert-scale items have been summarised into agree (strongly agree and agree), neutral and disagree (strongly disagree and disagree). Open-ended response data were analysed phenomenographically with responses that were similar grouped and quantified. Student laboratory reports were analysed in the year before (2007) and the year after introduction of the online module (2009). Three factors were investigated that related to calculations, data representation and data interpretation. A tutor independent of the course and this study performed the assessment audit. Students were asked follow-up open-ended response questions in an online survey offered *via* Blackboard to assess what they thought was the best thing about using the *Regulation of Gene Expression* online tutorial (‘*What was particularly useful or interesting?*’).

Results

As the molecular biology course is a service course and cannot be used as a prerequisite for third year molecular biology, it was necessary to gauge whether students perceived the course as relevant because this can impact on attitudes to learning. There were 71 student surveys completed of 101 enrolled (70% response rate) from the 2008 cohort. Overall, students saw the relevance of this subject to their degree; one of the students who did not see this subject as relevant was enrolled in nanotechnology (Table 1). From the open-ended responses to the question ‘*What is it about learning molecular biology that you liked learning the most?*’ the students found the content: interesting (42%), relevant (12%) and they enjoyed the practical work and/or the tutorials (20%). Students found both the relevance of this subject to their degree and were interested in the content. Only 3% of students disagreed with the statement ‘*I can see how molecular biology related to my degree*’ (Table 1). The level of detail and the language/terminology used in learning molecular biology were cited as areas where students have found difficulties.

Table 1: Relevance and understanding of the subject, molecular biology

	agree	**neutral**	**Disagree**
I can see how molecular biology relates to my degree	65%	32%	3%
I find concepts in molecular biology difficult to understand	25%	45%	30%

The online module was perceived as useful by the students for: understanding the concepts of molecular biology (87%); linking the theory and the practical work (92%); and for assisting in the preparation of the report (62%) (Table 2). These students’ perceptions have translated to improvements in the standard of data analysis required in the report.

Table 2. Student responses to the usefulness of an online data-handling module.

	agree	neutral	Disagree
The concept covered in the online module on the regulation of gene expression was difficult to understand.	13%	24%	**63%**
The online modules assisted with my conceptualisation of the regulation of gene expression.	**87%**	11%	1%
The content of the online module explains how the theory, *e.g.* regulation of gene expression, relates to the phenomenon observed in the laboratory practicals.	**92%**	7%	1%
Using the online module helped improve my understanding of the regulation of gene expression.	**85%**	11%	4%
Using the online module improved how I approached my laboratory report.	**62**%	18%	20%
Using the online module has improved my confidence in writing my laboratory report.	**55%**	32%	13%

Student engagement in data handling and interpretation was greater than student confidence (Table 3). While 63% of students knew what to *do* with their data, only 56% were confident with *how they presented* these data (Table 3). Some students (54%) found working with others helped, and half of all the students did not agree (i.e. 'disagree' and 'neutral') that the instructions were easy to understand (Table 3). This latter point was one of the major themes of the open-ended responses to the question '*What have you found to be the most problematic aspect of preparing your laboratory report?*', where 23% of students indicated that the instructions needed more detail and/or that they were struggling with the specific details of the report requirements.

Table 3. Student engagement in data handing and interpretation

	agree	neutral	disagree
I knew what to do with my experimental data.	**63%**	23%	14%
I am confident about the way I presented my data.	**56%**	28%	15%
Working with others in the class made it easier to do the assignment.	**54%**	35%	11%
I found the assessment criteria for the group project easy to understand.	**51%**	36%	13%

The online module appears to have assisted some students in analysing data (calculations performed correctly rose from 33% to 51%), and in presenting data correctly (graphs presented correctly 41% to 51%) (Table 4). The percentage of students, however, who were able to interpret results, fell from 60% to 51% (Table 4).

Table 4. Student report audit: 2007, pre-online module, and 2009, post-implementation of the online module.

	2007	2009
Performance of calculations		
No data included or raw data, in the form of absorbance	3%	6%
Calculations performed incorrectly	69%	43%↓
Calculations performed correctly, tabulated and the correct units used	33%	51%↑
Presentation of data		
No graph or an incorrect graph	15%	6%↓
The graph included shows the correct trend, but includes significant errors	44%	43%
The graph represents data clearly, uses the correct units and axis labels	41%	51%↑
Interpretation of results		
Results are not described	2%	6%
Incomplete description of results	38%	43%
A clear written description of the calculation and presented data	60%	51%↓

When students were asked to nominate what they found the most problematic aspect of preparing their laboratory report, most of the comments were about finding relevant literature (31% of students). Some students grappled with the uncertainty of real data and/or integrating their results into a broader frame using relevant literature (23%). Some simply stated that they found writing the discussion problematic (10%).

The open-ended responses to the question '*What skills do you think that you have developed from doing the experimental work in molecular biology and the associated laboratory report?'* were categorized into four areas:

1. Understanding discipline-specific concepts, including the experimental process, presenting data according to conventions, explaining results and putting results into context (34% of responding students), *e.g. gave me a better understanding of gene expression; have learnt to think logically about cell function; how to interpret and relate data; enhanced skills in the areas of data presentation; critical analysis; to analyse experimental data and relate it with other people/ scientists findings.*
2. Discipline-related skills required to writing a report including formatting and finding references (18% of responding students), *e.g. finding appropriate journal articles; finding more references and referencing; the way in which [the report] should be presented.*
3. Discipline-specific technical skills associated to the experiments undertaken (18% of responding students), *e.g. gel electrophoresis; experimental technique; familiarity of pipetting [sic] in micro amounts as well as aseptic technique; be aware of the proper technique to handle experimental equipment*
4. Generic skills *e.g.* writing, time-management (15% of responding students), *e.g.*, *efficient usage of time; written communication and conveying my ideas in a clear succinct manner; time management, writing skills.*

Students indicated that the online environment offered good diagrams which aided in the abstract nature of molecular biology (to *visualize*; Table 5: comment 1b), but primarily the tutorial supported the consolidation of knowledge (Table 5: comments 1a, 1c, 2b, 2c) rather than being a place to gain new knowledge (Table 5: comment 2a – *helped me to understand certain concepts* could indicate 'new knowledge'.

Table 5. Blackboard open-ended survey responses.

1. 'The best thing about using **Regulation of Gene Expression online tutorial** was.....' (What was particularly useful or interesting?).
    a. *As before, allowed us to **go over what we'd learned** as we needed to and when we had time.*
    b. *Again it helped **to clarify** and **visualise** what we were learning in lectures - it provided another perspective.*
    c. ***Confirm** what was learnt in the labs.*
2. 'How has the use of Blackboard 9 **benefited your learning** in this course?'
    a. *Yes as I was able to do virtual labs, online tutorials, etc. on blackboard that helped me to understand certain concepts.*
    b. *the online tutorials allowed me to gain a **better understanding** of the topics covered in the course*
    c. *the visual lab exercises are very fun and effective in helping me **recall and understand the experiments more.***

Discussion

Overall, students in this course were intrinsically motivated, possessed an interest in the area of molecular biology and predominantly saw the relevance of this course to their degree. The online module was clearly useful to students who commented that the course tutorials were also helpful. These positive responses suggest that students appreciate time to grapple with concepts and like being provided with direction in this process, rather than navigating these complex practices alone. Significantly, a greater proportion of students were able to perform the calculations required to generate meaningful data and present it appropriately when the online module was implemented. Both groups of students (i.e. the 2007 and 2009 cohorts) received instructions on how to perform the calculations, in their laboratory manual and during class time. However, a multistep process was made less complex as students were able to repeat the experiment virtually and could immediately see how the absorbance readings were converted into amounts of β-galactosidase in a graphical form.

We also found that while students were able to complete the results section of their reports, they submitted less in the discussion. In essence, they failed to link the experiment successfully with the theoretical detail in the literature. Prior to the implementation of the online module, students discussed their knowledge of the topic using resources provided in lectures and tutorials that occurred in the practicals. The behaviour of students is not surprising given that students are now doing fewer written reports. Our estimation is that students are doing $1/10^{th}$ the number of reports than completed in undergraduate degree programs of 10-20 years ago (Quinnell et al. 2012). This means students are less familiar with the report genre than previously. In part this is due to an increased number of students, creating difficulties in marking and providing feedback to students. At the same time, university economics have pushed towards a reduction in the number of assessment tasks per course. In this current study nearly a quarter of students offered comments in response to an open-ended question that implied that they found the formulation of the report to be the most difficult part of the assessment.

A good report needs to be planned. It is contingent on several skills sets coming together in a complex way. First, students have to analyse and interpret their data, find, understand and evaluate the relevant literature, and then communicate in a way appropriate for the discipline. It is important to note here that the online module mainly focused on: 1) quantitative skills associated with taking the raw data obtained (absorbances) and converting them into something meaningful (the amount of β-galatosidase formed); and, 2) helping students make links between the concept presented in the lectures and how the practical work was carried out in the laboratory. The interpretation of results required students to perform a literature search that was outside the concepts addressed in the online module. Although some improvements in the student reports were observed after implementation of the module, the data tell us that ~40% of students have not been able to perform the calculations properly and ~50% of students cannot construct appropriate figures.

Clearly many students perceive that their skills have improved by 'doing' as shown by open-ended responses to the question '*What skills do you think that you have developed from doing the experimental work in molecular biology and the associated laboratory report?'.* Some students volunteered comments detailing they had gained skills in: understanding discipline-specific concepts, discipline-related skills required in writing a report, discipline-specific technical skills, and generic writing and time-management skills. These open-ended responses support our assertion that we are asking our students to develop a complex suite of skills (generic and discipline-specific) required to operate in the discipline. The development of a complex set of skills is difficult given the lack of space in the curriculum for students to do so. Students need to practice skills to build confidence and without this space and time to practice it is not surprising they are unable to create the appropriate figures. Online tutorials and learning modules are a strategy to provide students with more opportunities to practice and consolidate knowledge and skills (Quinnell, May & Lloyd 2004).

Setting this in theoretical context

When we use the threshold concept framework, we interpret students' engagement with practicing their quantitative skills as their entry to a liminal space, where they learn at their own pace in a nonlinear fashion before they are able to fully grasp the concept (Meyer & Land 2005; Ross et al. 2010; Quinnell et al. 2012). The liminal space is where students must be 'comfortable being uncomfortable'.

Previously, we have explained how the work of Perkins and Simmons (1988) on thinking dispositions also applies to this liminal, transitional state (Quinnell, Thompson & LeBard 2013). We described how our students seldom lack the *ability* to perform the basic mathematics required for biology, but may lack the *inclination* or *sensitivity* required to successfully apply their quantitative skills in a biological context. Perkins proposes that this triad is required for good thinking, and goes further to describe seven thinking dispositions, each with a unique combination of abilities, inclinations and sensitivities, that yield tendencies toward particular intellectual behaviours, such as being metacognitive or reflective (Perkins, Jay & Tishman 1993).

We assert that interventions, such as the one we implemented in this study, aimed at simplifying the processes that occur during biology and science learning, allow students to be more 'mindful'. Langer (1992) describes mindfulness as *openness* and an *awareness of the context* and *content* required for a task, so mindfulness is an appropriate descriptor of the state of mind in the liminal space. In contrast, mind*less*ness is associated with a rigidity of mind, so mindlessness is an appropriate descriptor of the state of mind in the *pre*-liminal space. Students struggling to apply their quantitative skills in biology need an awareness of the relevance of these skills, the context in which they are required and an openness to commence data handling *within the discipline* of biology.

Interventions appear to be a useful means to teach positive thinking dispositions. Tishman, Jay and Perkins (1993) proposed that thinking dispositions are best taught through enculturation rather than direct transmission and we concur with this, particularly with respect to developing numeric sensitivities appropriate for the discipline (Quinnell et al. 2013). In this study, the virtual laboratory allowed students to reflect on the practical model as an example of gene expression and to connect their actions in the real laboratory with the explanations of concept and purpose. The questions within the online module also prompted thoughtful interaction and provided feedback. Perkins and Simmons (1988) echo that this approach is required to instill good thinking; stating that multiple exposure to the practices and processes of a discipline are required. This interesting perspective allows us to see *why* interventions such as the one we have described are useful when deployed in a blended learning environment and permit us to map *where* students are within these learning frameworks.

Put together, the increase in successful student data calculations and results presentations reveals that our intervention assisted students in taking on a successful thinking disposition. The *process* carried out was also highlighted by students as the primary skill developed in this study, with the replies to the open question: '*What skills do you think that you have developed from doing the experimental work in molecular biology and the associated laboratory report?'* including: *'learning [how] to use my results and findings and comparing them with theoretical values and literature. Explaining why the results turned out the way they did'*. This encouraging response communicates the students were aware of the importance of the practice of biology.

The improvement in how students presented and interpreted their results indicated students were engaging more deeply with their learning of regulation of gene expression. As second year undergraduates, they have not entirely mastered the complexity involved in scientific experimentation and communication. Specifically, some of the results involved the addition of the antibiotics streptomycin, chloramphenicol and rifampicin to the cultures expressing β-galactosidase. While students were predominantly able to see the impact of these from their data, and the function of the antibiotics was mentioned in the module, they were not able to integrate this information with the concepts of transcription and translation covered earlier in the course. The antibiotics streptomycin and chloramphenicol inhibit translation, so their addition promptly stopped the production of β-galactosidase and a lower yield was obtained for these samples. In comparison, rifampicin targets transcription, therefore any mRNA remaining in the cells after the antibiotic's addition could still be translated and, subsequently, higher levels of β-galactosidase were produced compared to the streptomycin and chloramphenicol containing samples. For students to be able to achieve and demonstrate knowledge integration we propose that further support is needed within the course, possibly by use of a worked example. Hopefully, students will be able to take what they have learned in this course and use their new and old quantitative and discipline-specific skills together to tackle discipline practice more competently and efficiently in their final year of study.

Conclusion

Learning in biology is complex. The signature pedagogy of biology through experimentation aligned with the scientific method introduces students to an array of new concepts simultaneously. The number of virtual online laboratories is accelerating and here we present how these can be used to create a blended environment. The advantage of virtual online laboratories is to simplify the biology discipline, allowing students to make connections between the invisible molecular world with the macroscopic laboratory results and providing space for them to grapple with the various elements involved in a biological study. In particular, these activities can assist staff and students with the increasing challenge of developing quantitative skills in our practice as biologists. We believe the success of these interventions lies in their ability to present information, which promotes mindfulness, encourages good thinking dispositions through enculturation, and assists students to navigate around the transformative liminal space without being constrained by the linearity of time.

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