Changing Curriculum Design to Engage Students to Develop Lifelong Learning Skills in Biology

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Abstract

Biological knowledge is central to many disciplines. Increasing popularity in areas such as medicine and environmental science has led to an increase in enrolments in core biology subjects at some Australian universities. Within many institutions, biology is taught traditionally through lectures and practicals. Often it is a challenge for academics to engage and motivate students and to develop the skills in lifelong learning. To address this issue we modified the curriculum and assessment methodologies in two large biology subjects (up to 550 students) at the University of Wollongong. Our multi-faceted approach involved the addition of group work dependent on the context and sub-discipline, inquiry-based learning opportunities which were based on the real world and self-directed and peer-assisted learning and assessment including regular feedback. This approach increased student engagement and interest in lifelong learning in biology. To evaluate this approach, we used a combination of peer observations, paper-based student evaluations and focus group interviews. We found that through these innovations students were more motivated to learn and engage with biological content. Through group work students were better connected with others. Students communication skills also increased and the model of reflective practice enabled students to view interconnections in biology concepts which could be applied outside the discipline.

Introduction

People learn throughout their lives, whether unconsciously or through deliberate and intentional effort. The latter being consciously planned, self-managed and generally in proportion to the learner's motivation, abilities and opportunities available to them (Candy, 1991). Deliberate self-directed learning is a key component of lifelong learning. It has been argued by academics and politicians alike that for nations to be rich in their capacity to utilise and deploy human resources productively in the 21st century there is a crucial need for the public to be lifelong learners (Karmel, 2004; Kemp, 1999). A career in biology requires lifelong learning skills as our knowledge of biology and indeed science is constantly evolving and expanding. Take for instance our knowledge of cells. Years ago, cells seemed much less complicated then they are now. In reality, cells were just as complicated back then, but as we develop more sophisticated tools to analyse cells, our knowledge has expanded. It is certain that our understanding of the complexity of cells will increase steadily in years to come. We now have much more factual and conceptual biological knowledge to impart on our students than our teachers did (Luen & May, 2005). How then do we teach students this vast body of biological knowledge that is exponentially expanding without overwhelming them? The simple answer is we cannot. What we can do, however, is illustrate clearly to students the essential functions of cells and highlight important advances and shifts in knowledge. With this knowledge students can further explore and expand knowledge on their own. In other words, as teachers of biology, we must not only be able to impart to students core knowledge that can facilitate continuous learning of the subject, but we must also find ways to encourage students to further their knowledge on biology through lifelong learning.

In 1994, the Higher Education Council commissioned a comprehensive report by the National Board of Employment, Education and Training entitled *Developing Lifelong Learners through Undergraduate Education* (Candy, Crebert & O'Leary, 1994). In this report it was argued that a lifelong learner would exhibit (among other qualities); an inquiring mind, critical spirit, capacity for self-evaluation, awareness of how knowledge is created in a field of study, breadth of vision, information literacy, critical evaluation of information, a range of strategies for learning in whatever context one finds oneself, and finally, an understanding of the difference between surface and deep level learning. Universities and science faculties clearly have a key role to play in building the national capacity for lifelong learning. To this end, an underlying obligation of universities is to enhance the acquisition and development of the above-mentioned qualities in their undergraduates.

A deep approach to learning is characterised by an intention to understand with a motivational emphasis (Biggs, 1999). Conversely, a surface approach is characterised by an intention only to complete task requirements for assessment, associating facts and concepts unreflectively (Leung & Kember, 2003). Deep approaches establish a collaborative learning environment, and use acquired theory, concepts, and knowledge to solve new problems. Learning tasks and assessment strategies can promote deep learning if designed and supported well. Authentic learning (the deliberate attempt to provide authentic learning tasks that stimulate real world practice) has been thought to stimulate deeper learning (Newman, Johnson, Cochrane & Webb, 1996). Within a science context, the opportunity to perform and communicate results from student-led research is considered an authentic learning task. Granting students the freedom to choose an area that interests them in the assessment design can allow students to feel they are performing a task authentic to their future careers, while exposing the whole cohort to the diversity of interests of fellow students. Authentic learning projects have been found to enhance a deep approach to learning and develop professional skills while also increasing student motivation, engagement, and confidence level, all of which aid in student learning (Gilardi & Lozza, 2009; Gulikers, Bastiaens, Kirschner & Kester, 2008; MacFarlane, Markwell & Date-Huxtable, 2006; Quitadamo, Faiola, Johnson & Kurtz, 2008).

Traditionally, many undergraduate science courses in Australian universities have relied on lecture/tutorial teaching, supplemented with laboratory practicals, seminars or other discipline specific approaches. This mode of delivery has been dominated by a teacher-centred approach to education (Phillips, 2005). It has been argued in the literature however, that moving away from this to a student-centred approach is paramount in promoting lifelong learning (Spencer & Jordan, 1999). A student-centred approach emphasises using a variety of different teaching methods to shift the role of teachers from givers of information to facilitators of student learning. The focus of the teacher changes from thinking about what they are doing to what the students are learning (Blumberg, 2008). Studies have shown that this shift in focus to student learning results in higher student retention rates and better prepared graduates, compared to students who are more traditionally trained (Matlin, 2002; Sternberg & Grigorenko, 2002).

In this manuscript we concur with Wood (2009), who, in a review of innovations to teaching, described the evidence to support certain student-centred educational strategies being more effective than others in promoting deep learning, problem solving and critical thinking. These learning outcomes translate directly into the characteristics for lifelong learning defined by Candy, Crebert and O'Leary (1994). In summary, to develop the capacity for lifelong learning in students, teaching approaches in the very least need to be aimed at promoting deep, self-directed, peer-assisted learning (PAL). Assessments should provide the opportunity to gain experience in experiential and authentic (real world) learning. Further, resource and inquiry-based approaches that incorporate reflective practice and critical self-awareness are crucial to developing lifelong learning (Boud & Knights, 1996; Candy et al., 1994).

For students to become self-directed learners and assume responsibility for specifying their own learning needs, goals and outcomes, they need to be involved in planning and organising the learning task, evaluating its worth and constructing meaning from it. From this student-centred perspective, the teacher becomes a facilitator, providing resources and support – guiding the learning process rather than just transmitting content (Anderson, Boud & Sampson, 1996). PAL contributes to the development of self-directed learning skills. In this context, advanced students model behaviours that help peers less experienced in the theoretical content, approach their studies with confidence and integrate the learning process with the course content. In this way, students observe that to achieve in their studies they will be required to take responsibility for their own learning, thereby developing personal agency.

Inquiry-based learning (IBL) is a method of learning and teaching used widely in the sciences that allows students to focus on how and what they will learn (Lee, 2012). In IBL, a problem, situation or task is presented to the students (by the teacher) as a stimulus for learning and students are required to determine for themselves how they will go about solving the problem (Boud & Feletti, 1998). This usually occurs through small group work and allows students to utilise their prior knowledge in the topic area and identify the gaps in their knowledge as they attempt to solve the problem. Process Oriented Guided Inquiry Learning (POGIL), is a student-centred inquiry-based learning strategy used mainly in chemistry and biochemistry (Bailey, Minderhout & Loertscher 2012; Moog & Spencer, 2008; Yezierski, Bauer, Hunnicutt, Hanson, Amaral & Schneider, 2008). In a POGIL learning environment, students are actively engaged in mastering the concepts and content of a discipline. At the same time they develop important learning skills by working in self-managed teams on guided inquiry activities designed specifically for this purpose and environment (Moog & Spencer, 2008).

These student-centred approaches, combined with reflective practice and critical self-awareness, encourage the learner to acquire knowledge by bringing together theoretical abstractions which are often taught in science. This is achieved through the interaction of the learner with his or her material and environment, and focuses the learner's attention on what is happening in themselves (Candy et al., 1994). By incorporating such approaches to assessment we can move away from the emphasis on assessment outcomes, to consideration of assessment process. The student gains an awareness of what is required to achieve the desired outcomes, thereby gaining an understanding of why they have or have not succeeded in certain tasks, placing them in a better position to improve upon and/or exploit their skills. This can lead to a component of self-assessment in the evaluation of the learning process.

In this article, we describe the key elements of authentic, inquiry-based learning innovations which were introduced into two biology subjects. Biol103 is a first year biology subject (550 students), while Biol213 is a second year biochemistry subject (400 students). Although these subjects cover aspects of fundamental biology and biochemistry, they have been historically viewed as 'service' subjects. These are subjects where a large proportion of enrolled students are studying less traditional biology degrees, however, they require foundation knowledge of biology provided by these subjects. The material in service subjects can be viewed by many students as peripheral to their learning. Such perceptions can create a situation where students become passive and uninvolved, adopting attitudes consistent with 'surface' learning (Brown & Atkins, 1988). To date there has been a lack of authentic, inquiry-based learning or group work in these subjects. Rather, the theoretical content has been largely delivered via a transmission of content approach in large lecture theatres which does not promote deep learning (Shank & Cleary, 1995). Given the information age we find ourselves in, where new knowledge is created rapidly and old concepts are being challenged, the importance of developing lifelong learning capacity in our biology graduates cannot be understated. Our overall approach involved creating supportive learning environments that included tasks designed to increase motivation and skill development and more effectively develop lifelong learning capacity in students. These innovations included self-directed learning opportunities for the students with the provision of regular feedback through changes in assessment and inclusion of peer assessment.

Project Methodology

Embedded in the design of each innovation was an evidence-based, educational approach that had good potential for building lifelong learning capacity in undergraduate students (Table 1). We define the details of each innovation below.

Table 1. List of the innovations and the teaching approach targeted to achieve lifelong learning skill development in students.

Innovation	Teaching approach			
	Experiential and authentic learning	Resource-based and inquiry-based learning	Reflective practice and critical self-awareness	Self-directed and peer-assisted learning
Peer-assisted study sessions			☑	☑
Inquiry-based learning labs		☑	☑	☑
Group research project	☑		☑	☑

PASS

Peer Assisted Study Sessions (PASS) is an academic assistance program that utilises peer-led group study to help students succeed in traditionally difficult subjects—those with high unsuccessful completion rates or those that are perceived as difficult by students. At the University of Wollongong, PASS is also offered in subjects to establish learning communities, target specific student cohorts in a non-remedial way, or to develop discipline-specific academic/learning skills. PASS has been successfully utilised for science subjects at external institutions (Field, Burke, McAllister & Lloyd, 2007; Parkinson, 2009; Tariq, 2005) and was offered to Biol103 and Biol213 for the first time in 2012. Based on successful outcomes and positive feedback from students, PASS was offered again in 2013.

The PASS sessions are facilitated by PASS peer leaders, being students who have previously completed the targeted subject (or a higher level version of it) and have demonstrated strong competency. The PASS leader's role models effective study behaviour during the PASS session. They combine specific study skills with key course content, integrating *what to learn* with *how to learn*. PASS and traditional tutorials can differ greatly. Tutorials typically cover work and assessments as indicated in the subject outline, determined by the course coordinator. In contrast, each PASS session has an agenda determined by the PASS leader and the students attending that week. Students work in peer groups and rather than being teacher-directed, they engage in self-directed learning thus ensuring students are accountable to one another. During a typical PASS session, students compare and clarify lecture notes, review textbook readings, and discuss key course concepts. This provides an opportunity to complete study activities while developing study skills specific to the course. PASS provides guaranteed study time, offers a relaxed, non-threatening learning environment in a smaller study setting, and facilitates discipline-based social interaction and networking with a facilitator who is only one or two years more advanced than students in PASS .

Inquiry-based learning labs (IBLL) - Biol213

Prior to the introduction of inquiry based learning labs (IBLL), students had poor performance in the final summative exams in Biol213, perhaps indicating that the amount of theory and the pace of delivery to students in lectures were overwhelming. Previous innovations in the introduction of POGIL in chemistry improved student responses and final results in first year (O'Brien & Bedford, 2012). Therefore, to improve student engagement and motivation, the School of Chemistry and the School of Biological Sciences collaborated. An award of support was granted from the Science and Mathematics Network of Australian University Educators (SaMnet). In an effort to move away from the delivery of content mode of teaching, we chose to implement the POGIL approach., POGIL inherently focuses on the process side of learning, where information is sought rather than given, reducing passive learning (Hanson & Wolfskill, 2000; Hein, 2012; Lewis & Lewis, 2005; Minderhout & Loertscher, 2007).

Our POGIL-style classes, which we hereafter refer to as inquiry-based, learning laboratories (IBLL), were held in the laboratory with 80 students, one academic supervising and three demonstrators helping to guide and direct students with their group work. Three IBLL workshops were designed to cover the three broad content areas delivered in lectures: (i) macromolecules and their building block, (ii) processes of the central dogma of molecular biology, and (iii) enzyme function (Figure 1).

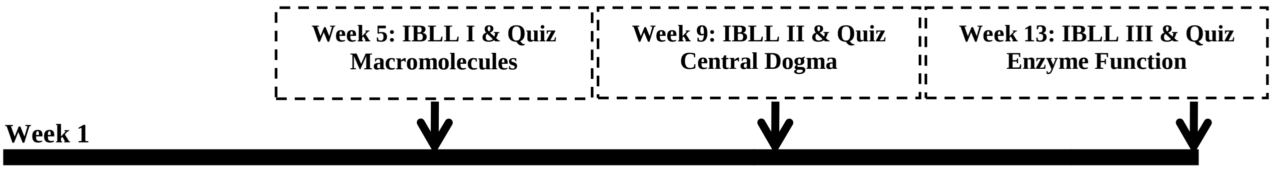

Figure 1. Inquiry-based learning laboratories timeline.

Prior to each IBLL, students were required to complete activities to prepare them for the worksheet activity to be completed as a group in class. Questions on the worksheet included visuals (figures or tables), which students used as a scaffold for their learning (Figure 2). In class, students worked in groups according to POGIL methodology, with a manager, technician and a scribe. To do this the group progressed through a worksheet, building knowledge with each activity, discussing and prioritising.

The reference material was brought by the technician, while the manager was responsible for time management and organisation of the group work. The third group member, the scribe, was responsible for recording answers. Staff members were facilitators during the session. At the conclusion of the workshop students completed an assessment based on the theory covered in the classes. In 2012, this consisted of a short quiz which was peer-assessed (6% of final grade) and a single mid-term quiz, completed separate to these classes, but focused on similar content (25% of final grade). In 2013, the short quizzes were removed and the mid-term quiz was expanded and split over the three IBLL classes (together making up 25% of final grade). In this way the students were being assessed on the content while it was still fresh in their minds.

Question: DNA Replication in both prokaryotes and eukaryotes is:

a. semi-conservative
b. bidirectional
c. semi-discontinuous

Define these terms and label the figures below with their distinguishing features.

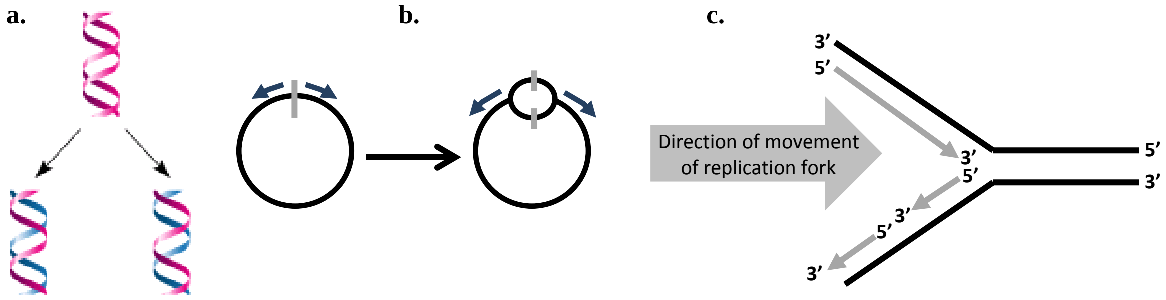

Figure 2. Example question from the IBLL workshop on the central dogma.

Group research project - Biol103

For Biol103, an authentic learning task was designed with reference to the framework for authentic task design (Herrington & Oliver, 2000). Three dry practical classes were focused on a group work research project. Groups of 20 students were supervised by one staff member for all three dry practicals, with class sizes of 20 for seminars or 40 for planning and posters. Typical wet practical classes in Biol103 consist of 80 students and run for three hours, whereas dry practical classes were half the size and half the duration. Students worked in groups of four to conduct research into a current practical application or a development relevant to an assigned theoretical topic covered in lectures. Students could research any application, often choosing research related to their discipline of study. In this way the task catered to the diversity of the student cohort. The first stage of the project involved presenting the group findings in a poster/booklet to the class during a scheduled poster session (Figure 3 and Figure 4). Feedback from students and staff, during the poster session was then used to complete the second stage of the project, an oral seminar. In 2010, the task made up 10% of the final grade. The assessment mark was broken down to 6% for the poster and seminar and 4% for peer assessment, with all students required to assess their own and all group member's contributions to the tasks. This same task design was utilised in this subject in 2011 and 2012 with minor changes to the weightings of the assessments based on student feedback in 2010. In 2011 and 2012, the poster and seminar were worth 10% and the peer assessment worth 5%, increasing the total from 10% to 15% of the final grade in the subject. Upon completion of this project students were exposed to cutting-edge scientific advancements across much of the fundamental theory being learnt in the subject, thereby contextualising their learning. In this way the task is iterative, highly structured and supported by both staff and student feedback.

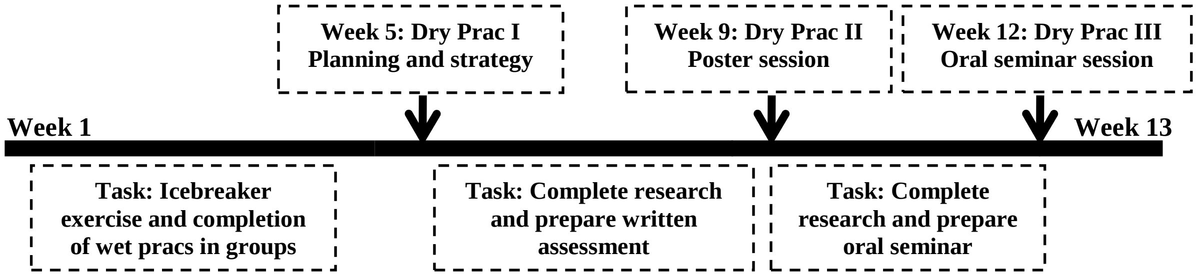

Figure 3. Group research project timeline.

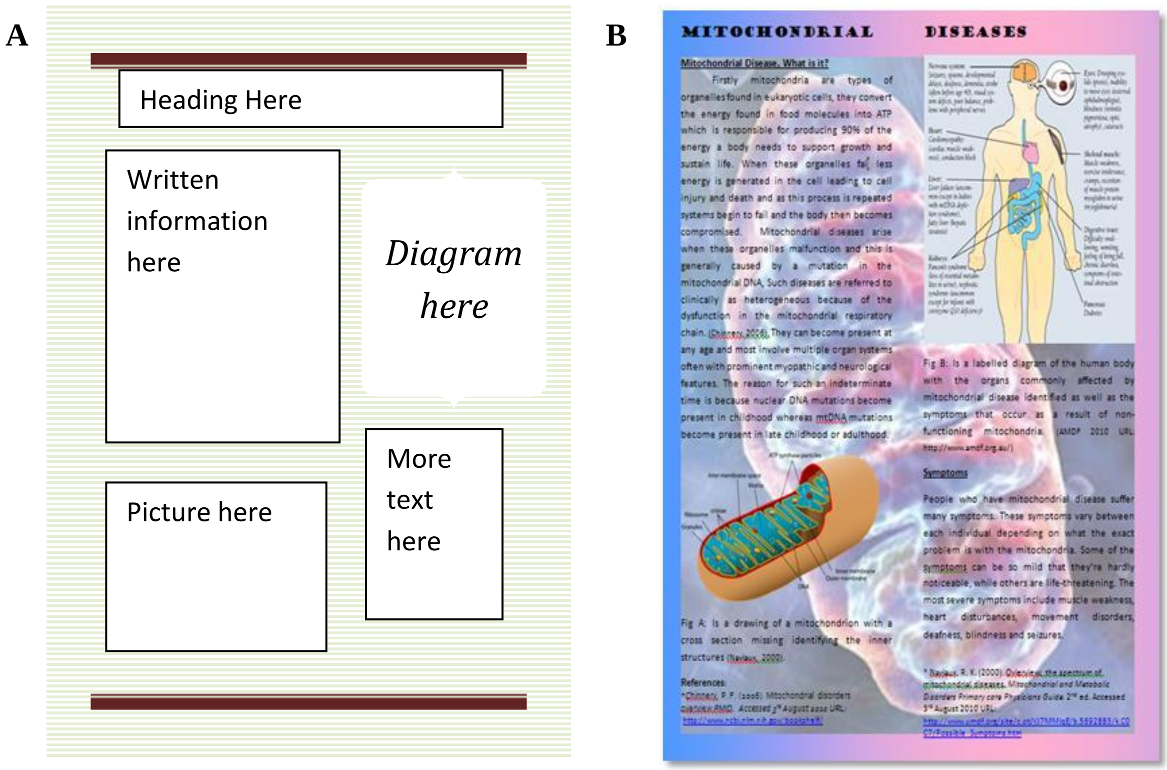

Figure 4. **A**. An excerpt from the subject manual describing for students how to prepare a poster/booklet. **B.** An example of a page from a booklet submitted by a student group.

In both assessment tasks, the product (poster or seminar) was graded by a staff member utilising the marking criteria which was provided to students in advance. Group members anonymously assessed their own and each other's contribution to the tasks using a peer assessment sheet (Figure 5), allowing for self-reflection and monitoring. This was designed to provide an opportunity to acknowledge group members who had shown good collaborative and teamwork skills, and to penalise those students who had failed to contribute adequately to the group work. This task is considered an authentic learning task. The conduction of research, and the communication of findings to audiences, through both written (posters) and oral (seminars), is seen as a critical skill which is commonplace in many disciplines, not just biology and science. It was also peer-assisted through group work, being self-directed and reflective.

Group self-assessment marking criteria:
Prac day & time: Student name:
Award a mark between 0 (poor) and 3 (excellent)

1. Meeting attendance, participation and contribution
2. Level of cooperation and collaboration with other members
3. Tasks completed on time and in accordance with group planning
4. Standard of work completed

Figure 5. Peer self-assessment sheet for group research project.

Evaluation

To evaluate the multi-faceted approach described above, a combination of peer observation, paper-based student evaluations and focus group interviews were utilised. Data from the staff experience of the initial pilot projects in 2010 (Biol103) and 2012 (Biol213) were collected through written feedback and staff meetings. Semi-structured focus group interviews were conducted with willing students at the conclusion of the piloted projects. The student experience was evaluated through questionnaires in 2010-2012 (Biol103; group research project), 2012-2013 (Biol213; IBLL) and 2012-2013 for PASS (Biol103 and Biol213). Human research ethics approval was granted for the evaluations (HE10/297 and HE12/214). The student evaluation results from the group research project and IBLL are expressed as mean percentage response to questions/statements between years, and all figures or figure legends include sample sizes (*n*).

Results

PASS

Peer group work and self-directed learning greatly enhanced motivation as seen in student surveys by both first and second year students. Many attendees expressed gratitude for the opportunity to study with peers, and requested that PASS be made available in more subjects. Results show that students who attended these sessions consistently received the most benefit, in terms of enhanced overall final mark (Kuit & Fildes unpublished data). Student surveys provided evidence that the students recognised improvements in their understanding of subject content (97% agree; Table 2). Further, learning skills were felt to have improved, which included exam preparation (95% agree), problem solving (78% agree) and communication skills (79% agree).

Table 2. Results from a survey of PASS students from Biol103 in 2012 (n = 45), Biol213 in 2012 (n = 63) and Biol213 in 2013 (n = 68).

Question:	Responses (%)								
Participating in PASS session has:	**Agree**			**Neutral**			**Disagree**		
	103	**213**	**213**	**103**	**213**	**213**	**103**	**213**	**213**
Assisted me in preparing for exams or final essay	96	98	91	2	2	6	2	0	0
Improved my understanding of subject content	96	98	97	2	0	1	2	2	1
Been an enjoyable learning experience	89	90	91	11	10	7	0	0	1
Helped me to understand how to succeed academically	82	83	78	16	14	22	2	3	0
Improved my problem solving skills	82	81	72	13	19	28	5	0	0
Encouraged me to take responsibility for my own learning	78	78	79	18	21	19	4	2	1
Increased my motivation to complete my course	82	78	78	16	21	19	2	2	3
Helped my feel more comfortable communicating with a group	82	75	81	16	22	19	2	3	0
Given me a better understanding of the demands of learning at UOW	78	73	79	20	24	19	2	3	1

Inquiry-based learning labs (IBLL) - Biol213

The results from a larger student survey, provided evidence of a high degree of student support and enthusiasm for the innovation (Figure 6). Students felt that discussion of theoretical concepts was an effective way to learn the lecture content (68.6% strongly agree/agree). Further, students responded that the dry practical quizzes motivated them to work harder to understand key concepts (72.3% strongly agree/agree). Both statements were aimed at evaluating whether students were adopting deeper approaches to their learning and whether they found the innovations engaging.

Student open ended comments regarding the IBLL innovation were generally very positive. In particular the students repeating the subject from 2011 found the added IBLL classes in 2012 helped them prepare for the final exam. They found the 'forced' study beneficial and many recognised that having to explain concepts to others did make them reflect on their own learning. In addition they found the quizzes motivating, especially if attaining poor marks. Selected student quotes from the survey are included here:

"Classes every couple of weeks made me study making it much easier to study for the final exam."

"I didn't do as well in quizzes as I liked, this motivated me to re-look over my notes."

"The class design meant you got another person's perspective, I wouldn't have usually done that."

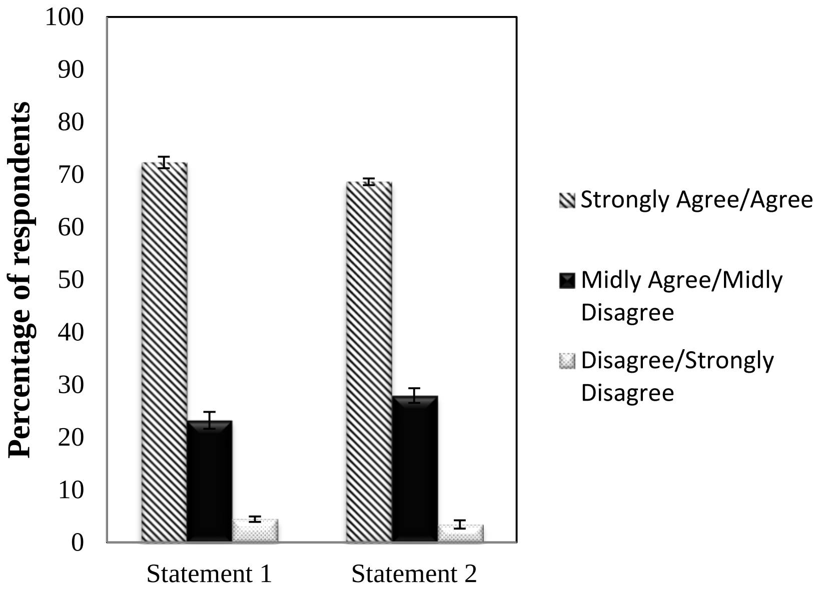

Figure 6. Responses to student evaluation statements on the inquiry-based learning labs distributed in 2012 and 2013 (n = 610 Statement 1 = The dry prac quizzes motivated me to work harder to understand key concepts in Biol213; Statement 2 = The discussion of theoretical concepts with fellow students was an effective way to learn the lecture content). Error bars represent the standard deviation between evaluations in 2012 and 2013. Response rate to survey was 82-93% (356/382-254/309) over the two years.

The original piloted Biol213 IBLL workshops were observed by a staff member from the Centre for Educational Development and Interactive Resources (CEDIR) at UOW. The observer noted that:

> *"All of the groups seem to be extremely engaged and focused on the task at hand. There is no evidence of mobile phones being used, Facebook or discussion not focused on completing the work. The vast majority of groups are highly interactive and collaboration in and between group members is strong…this format makes it easier to identify the students that are struggling as it is pretty obvious as an observer or as a facilitator which students are not engaged then to have a look at their quiz mark later…there are lots of opportunities for the students to interact with the facilitators and the groups are very pro-active in their engagement with the facilitators."*

It was postulated that perhaps because there was so much interaction between the students as they worked together they were more willing to seek assistance from the facilitators. This view was supported by the casual staff teaching these classes.

Group research project - Biol103

The results of the student survey provided evidence for a high degree of student support and enthusiasm for the project (Figure 7). Students felt the project resulted in them feeling more connected to fellow students (question one, 90% agreed). Further, the project contributed towards maintaining a positive attitude (question two, 61% agreed); motivated them to learn (question three 58% agreed); helped them to better understand the relevance of the key biological concepts learnt in the subject Biol103 (question four 73% agreed), and enhanced their skills in effective communication (question five, 72% agreed). They also recognised that the research skills learnt will be beneficial beyond this subject. Quotes from student questionnaires and interviews included:

"Once we went into depth in our topic area we could really see the relevance of the key ideas taught in Biol103."
"The project drew clearer connections to course content."
"Interaction with other people in the course is increased (with project) which helps me maintain a more positive attitude to this subject."

The relationship between the staff and students was improved by having fewer students in the lab during these activities. Staff also felt they were able to take on a different role with the students due to the research nature of the task. Quotes taken from written feedback from casual teaching staff included:

"I appreciated the opportunity to interact with the students in an environment that was about research so there were no right answers to the questions; it was more of an exploration together."
"The collegiality and collaborative learning displayed by the students through the group work initiative lent itself to establishing an easy and open approach between the students and staff."
"My participation gave me an opportunity to see the different strengths of students outside the normal practical aspects of class. The classes seemed to have a relaxed, non-critical atmosphere and the students generally supported each other well."

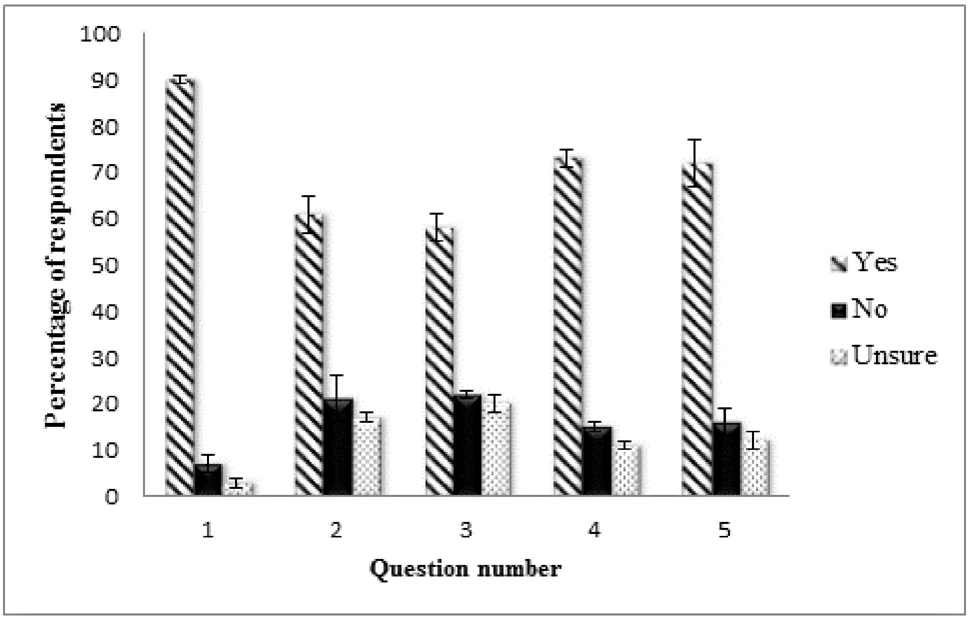

Figure 7. Responses to student evaluation questions on the 103 group research project distributed in 2010, 2011 and 2012 (n = 1295; Question 1 = Has undertaking group work in Biol103 helped you feel more connected to your fellow students?; Question 2 = Does group work help you to maintain a more positive attitude to the subject?; Question 3 = Has the group research motivated you to perform better in Biol103?; Question 4. Has undertaking the research project in Biol103 helped you discover the relevance of the subject to your field of study?; Question 5 = Has undertaking the research project in Biol103 helped you develop your communication skills?). Error bars represent the standard deviation between evaluations in 2010-2012. Questionnaire response rate was 91-95% (395/435-460/483) over the three years.

The enhanced skill development of first year students has been recognised by other staff members in the discipline with one commenting that *"since the group work project has run* *in Biol103 my students seem to have enhanced research and communication skills when completing similar tasks such as oral presentations in subsequent years"*. Senior staff believe this scaffolded approach is *"producing better quality graduates as a result"*.

Discussion

We introduced innovations and included tasks designed to increase motivation and skill development of students, with self-directed learning opportunities, through changes in assessment methodology and the inclusion of peer assessment. The students collectively agreed these innovations were beneficial to their motivation and learning skills. By providing opportunities for students to see the relevance of theory through authentic learning tasks, and IBLL, there was a deeper level of engagement which increased understanding of theoretical content. Group work motivated students to perform and, combined with PASS, helped them create connections with fellow students, and develop communication skills. Opportunities for reflective practice and self-monitoring were provided, where students could identify their own strengths and weaknesses.

Much has been written in the education literature on Peer Assisted Learning (PAL) and the associated cognitive, pedagogical, and social benefits (Goldschmid & Goldschmid, 1976; Maheady, 1998; Ross & Cameron, 2007; Topping, 1996; Topping & Ehly, 1998; Trevino & Eiland, 1980; Wagner, 1982). One such benefit of PAL activities in this innovation applied in the biology discipline was the contribution to the development of students' self-directed learning skills. This was achieved through peer leaders showcasing successful study techniques and students directing the study sessions. Further, to successfully complete the IBLL and the group research projects, the students needed to organise their time, set goals and devise ways of dealing with issues that arose within the group. Self-directed learning is an important step in developing lifelong learning skills through this creation of a sense of personal agency (Candy et al., 1994).

A deep approach to learning is thought to result in greater conceptual understanding of key biology content and concepts. In terms of developing lifelong learning skills, learning to engage deeply with conceptual and often abstract theoretical material, has arguably more, or at least, equal importance to memorising content. Using IBLL, PAL etc., students have the chance to memorise and understand simultaneously. Motivating and engaging students within large subjects of a service nature, is not always an easy task, but a necessary one to promote deep learning (Gordon & Debus, 2002). As has been argued in the literature, if students value the task at hand as worthwhile for their future studies, or their career in general, motivation will increase (Pintrich & de Groot, 1990). Our authentic research project allowed students to work on a biology topic of their interest. The results of this study provide evidence that incorporating authentic learning tasks and IBLL in assessment innovations, together with opportunities for PAL, improved motivation. We argue that resource and inquiry-based learning develops the capacity for deep learning in biology. This is supported by Herrington and Herrington (2006), who provided evidence that authentic, active learning tasks in numerous disciplines, including biology, increase engagement and are therefore a better approach toward improving lifelong learning capacity in undergraduate students.

In the group research project and the IBLL, students were required to locate, evaluate, manage and use biological information from textbooks, lecture notes, primary sources and web sites to complete the learning activities and assessments. In IBLL, students decoded information from graphs, tables, and diagrams, with each activity building onto the knowledge acquired through the last. In this way the students increased their information literacy skills. Intrinsic to this process is the necessity to critically evaluate the importance of the task at hand and gain understanding of how biological knowledge is interconnected. Ultimately, through such educational strategies, helicopter vision can be achieved, where the students see the interconnectedness of disciplines. This is particularly important when we are teaching students threshold concepts in biology, that is, those concepts that are central to understanding the discipline of biology. These concepts once understood are integrative, bringing together different aspects of biology that previously did not appear, to the student, to be related. In PASS, IBLL and in the group work research project, the exposure to background biological research completed by fellow students, affords a greater breadth of vision and contributes to the development of an inquiring mind, a key characteristic of the lifelong learner (Candy et al., 1994).

The interactive teaching approaches presented in this paper increased student's sense of inclusiveness and created learning communities. We know that involvement/interconnectedness among students matter. Numerous researchers have pointed out the greater a student's involvement or integration in the life of the university, the greater the likelihood that they will persist (Astin, 1984; Mallette & Cabrera, 1991; Nora, 1987; Pascarella & Terenzini, 1980; Terenzini & Pascarella, 1977; Tinto, 1997). The social aspects of student driven group work cannot be underestimated in importance for developing learning skills and integrating students in other aspects of university life (Lipman, 1991; Resnick, Levine & Teasley, 1991; Rogoff, 1990; Tanner, 2009). It can transform the course experience from competitive to collaborative, and help involve students who might not be otherwise actively engaged with the course content (Wood, 2009). Further, there has been significant research in the social sciences that provides evidence that groups can be more effective at complex problem solving than individuals and that this capacity increases with the diversity of the group members (Brophy, 2006; Guimera, 2005).

Staff involved with our innovations felt they were assisting learning by helping student groups navigate through the process, rather than directing them down a single uncompromising path. In this sense, teaching staff had a more student-centred perspective, with the students themselves directing the process, resulting in motivated and engaged learners, which in turn motivated and energised teaching staff. Our results concur with strong evidence from past studies that group work in undergraduate courses contributes to increased student learning (Johnson, Johnson & Smith, 1998; Springer, 1999). Further, having students accountable to a group stimulates intrinsic motivation, which in turn enhances students' responsibility and their perseverance (Valle, Cabanach, Núnez, González-Pienda, Rodríguez & Piñeiro, 2003). All these group work outcomes contribute to improving lifelong learning capacity by further developing personal agency in students.

Undergraduate science education to date has been based largely on delivery of facts rather than analytical thinking (Miller, Pfund, Pribbenow & Handelsman, 2008). Although effective teaching methods based on how people learn have been well described (e.g. Handelsman, Ebert-May, Beichner, Bruns, Chang, DeHaan, Gentille, Lauffer, Stewart, Tilghman & Wood, 2004; Laws, 1991; Udovic, Morris, Dickman, Postlethwait & Wetherwax, 2002), they are often not applied in undergraduate science courses and can be logistically difficult to apply in large biology service subjects. We argue, however, that science and biology are in dire need of teaching innovations. Although biology has been considered the "easiest" of science disciplines, it is increasingly becoming conceptually abstract and the amount of content is growing exponentially. As concluded by Gardner and Belland (2012), student learning can potentially be improved by creating courses with multiple active learning strategies. Using multiple teaching strategies, students are more likely to understand biology concepts and use this understanding more effectively. Prior to implementing the changes to teaching practice described in this paper, it would be true to say that our undergraduate biology subjects suffered from an excessive use of didactic approaches that insufficiently connected learning with the world of practice. Further, they neglected to incorporate literacy based skills to find and use resources for biological research. The introduction of more student-centred learning tasks in large biology subjects with high student diversity, in background and ability, has uncovered very powerful insights into what drives students to engage with biological content, what opens their eyes to see the relevance of biology subject material and what activities they deem to improve their study skills. Collectively, these initiatives have worked to develop the qualities or characteristics of a lifelong learner who will engage in future biological discoveries. These include: an inquiring mind, helicopter vision, information literacy, a sense of personal agency and a repertoire of learning skills (Candy et al., 1994).

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