Journal of University Teaching & Learning Practice

Volume 12 | Issue 3 Article 3

2015

‘Capping off’ the development of graduate capabilities in the final semester unit for biological science students: review and recommendations

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Recommended Citation
Firn, J. (2015). ‘Capping off’ the development of graduate capabilities in the final semester unit for biological science students: review and recommendations. *Journal of University Teaching & Learning Practice, 12*(3). https://doi.org/10.53761/1.12.3.3

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Abstract

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Keywords

Capstone units, graduate capabilities, graduate attributes, student-centered learning, self-reflection, reflective professionals, metacognition, step-changes in study demands

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Introduction

Australian universities have undergone a dramatic shift in the philosophical underpinnings of learning and teaching practices: from transmitting disciplinary content to the development of explicit graduate capabilities or attributes (Hammer et al. 2009; Bridgstock 2008; Gilbert et al. 2004). This philosophical shift was prompted by pressures from changing labour-market policies and student expectations; for example, a 10-year study of first-year experience in Australian universities found that students became increasingly concerned about job prospects and the high costs of their education, generally expressing a desire for clearer career pathways (Krause et al. 2005). In 2005 Australian universities were required to post online graduate capabilities to continue receiving federal funding (Barrie 2005). Studies have shown, however, that tertiary institutions have generally not achieved this shift because learning and teaching practices have not been developed or implemented to help students develop these graduate capabilities (Barrie 2005; Hammer et al. 2009). It is suggested that the development and change management necessary to bring about this fundamental and dramatic shift within traditional tertiary institutions has been greatly underestimated (Hammer et al. 2009), and that most universities remain in a state of transition between traditional and modern philosophical underpinnings.

Along with this philosophical shift in learning and teaching practices came the development of final-year capstone units. Capstone units are defined as a culminating academic experience where knowledge of a discipline is brought together with activities aimed at assisting students to transition to the world of work (Julien et al. 2012; Holdsworth et al. 2009; van Acker & Bailey 2011). Capstone units are an opportunity for courses to link graduate capabilities, employer-desired capabilities and opportunities for students to take a more explicit step towards investing in lifelong learning (Figure 1). Universities and employers share a common desired list of graduate capabilities, including being a team player, having strong communication and problem-solving skills, being self-directed and having the capacity for lifelong learning. The development of capstone units for general-science courses, however, has proven difficult because of the diversity of employment opportunities and of student interest in broad majors like biology, along with the long tradition of reliance of rote learning of material delivered in lectures. Didactic direct instruction has been successfully applied in science teaching, but there has been less success in providing authentic opportunities for undergraduate students to discover new knowledge or make unique interpretations of existing phenomena (McCune & Hounsell 2005). Final-year or capstone units in science are generally designed for students to experience being “real” scientists by developing questions and hypotheses, planning investigations, carrying out their research, collecting data, critically analysing and evaluating their findings, communicating their results to a range of audiences and showing accountability for their own learning and scientific work (Ryder 2004; Holdsworth et al. 2009; Julien et al. 2012).

In 2013, QUT commenced a new science course in compliance with Australian Qualifications Framework requirements for a broader approach to science curriculum, and with the aim of re-designing the course to allow for more student-centred, constructivist approaches (Weimer 2002). This change in learning and teaching practices was led by the Dean of Learning and Teaching at the time, Prof. Susan Savage, whose inventive teaching practices in architecture were renowned for authenticity and the explicit teaching of learning-practice knowledge (Savage 2005). Development of the new science program was also guided by the QUT graduate capabilities

(Table 1), which, unlike those of many Australian universities, are generic for all undergraduate courses.

As part of QUT's new science courses, each major (biology, chemistry, physics, environmental sciences and geology) will provide a capstone unit in the final semester of the final year of a three-year degree. An outline for the biology capstone unit, called Integrative Biology, was written in 2012, prior to the initiation of the first year of this new course. In keeping with QUT's graduate capabilities (Table 1), this unit (Table 2), which will be offered for the first time in the second semester of 2015, covers five learning outcomes. The purpose of this study was to evaluate effective the content (curriculum) and methods for teaching (strategies, approaches, pedagogies, andragogy) in a capstone unit for Biology majors in the final semester of a three-year course.

There are three main challenges to the delivery of authentic projects in QUT's new capstone unit, and to science majors in general. First, the curriculum of the new biology major is broader than the previous curriculum, which had a narrow focus on ecological/environmental science. Biological sciences is the most rapidly changing science of the 21st century, and is at its core multidisciplinary, incorporating theories and processes from physics, chemistry, mathematics and computer science (Watters & Watters 2007). Biological-science graduates must be able to integrate concepts and contribute outside of their discipline (Baurele et al. 2007). It is thus imperative that biological-science graduates understand and can create new knowledge and adapt to change. Inquiry-based learning opportunities should cater for a diverse range of student career interests, such as microbiology, animal physiology, plant biotechnology, pre-medical education, entomology and ecology. Second, previous class sizes in the final year units had been between 10 and 40 students, whereas in the new capstone unit student numbers are anticipated to range between 80 and 150 students, with associated learning and assessment implications. Increased class size because of fewer units being offered is a phenomenon Australia-wide (Star & Hammer 2008). Third, not all students will pursue a career in scientific research; half of all science graduates will make careers in a range of professions other than science (Chubb 2014). Therefore, offering choices for students such as work-integrated learning options within the capstone unit, rather than a final-year research project, may provide a more relevant and worthwhile learning experience (McCune 2009; Scoullar 2008; Gomez et al. 2004).

In this study, I first review recommendations made for capstone units by the Australian Office of Learning and Teaching's Capstone Curriculum network, and then compare capstone units in general-science courses offered at other Australian universities. Next, I investigate studies on the delivery of the three main components of capstone units: 1) authentic learning environments and assessment, 2) opportunities to communicate findings to specialists and non-specialists and 3) building skills that help students achieve more meaningful learning. I then investigate strategies for helping students transition to being self-directed learners (Ryder 2004). Based on the findings of this literature review, I recommend a list of key components for capstone units in general-science courses with large cohorts and where students' immediate needs and interests, as well as their future career paths, are richly diverse.

Comparative Review of Third-Year Capstone Units in Biology Offered at Australian Institutions

Capstone units are not common in general undergraduate degrees in Australia, but several universities (e.g. Melbourne University, Latrobe University, Griffith University, University of

Sydney and University of Western Australia) have invested considerable efforts into their development, including generic guidelines and recommendations that are catered to the specific institution (Holdsworth et al. 2009; Julien et al. 2012; Scoullar 2008). In 2013 the Capstone Curriculum Network was established through an Office of Learning and Teaching Senior Teaching Fellowship, which was awarded to Associate Professor Nicolette Lee from the Victoria University (Lee 2013). This project is focused on four main questions: 1) What is the range of capstone models in use across the sector? 2) What are the key characteristics and dimensions of the capstone curriculum? 3) What challenges do academic staff face in reconciling capstone innovation with policy and standards expectations? 4) What tools are needed to support curriculum design? The outcomes have not been completed, but this project has developed a set of generic considerations when developing a capstone: scale (small and targeted or comprehensive and broad); overall focus (research, industry or both); how the learning environment will be organised (such as groups, individual or interdisciplinary); models of delivery (lectures, classes focused on progressing work, work-based and supervision); assessment items (such as presentations, journals and reports); and the elements that define assessment items (such as performance, artifacts, behaviours, self/peer review, client review and papers). In this section, I will compare and contrast the aims and learning outcomes offered in existing capstone students majoring in biology at five Australian universities.

A comparison of capstone units' main aims and learning outcomes across five universities – University of Melbourne (Holdsworth et al. 2009), Macquarie University (Macquarie University 2014), Latrobe University (Julien et al. 2012), Griffith University (Griffith University 2014) and Queensland University of Technology – found some distinct similarities and differences (Table 3). All biology capstones, whether flexible in subject matter, such as those offered by Macquarie University, Griffith University and Queensland University of Technology, or specific in content, such as those at Latrobe University (physiology) and the University of Melbourne (zoology), were focused on students learning through conducting a research project and critically evaluating the literature, and communicating the findings both verbally and in writing. Four of the unit outlines (those from Latrobe University, Macquarie University, Melbourne University and Queensland University of Technology) specifically mentioned experiences with group work in the learning outcomes. Interestingly, the learning outcomes for Griffith University referred to individual projects, with the term "small-group project" only being used if necessary for a specific project. Latrobe University and Macquarie University mentioned career development in the learning outcomes; Queensland University of Technology was the only university to list ethics as a learning outcome (Table 2).

Macquarie University's capstone-unit learning outcomes had a strong focus on careers and career development, to the extent where a biology lecturer and a specialist in career counseling jointly coordinated the unit. Scheduled activities in the generic biology and medicine capstone unit at Macquarie included explicit activities on writing CVs and time management. This is a novel approach amongst the capstone units investigated in this report, and CV writing and time management have been identified as graduate capabilities that are seldom considered in university courses (Bridgstock 2008), but are essential for the transition to employment. The inclusion of career-development activities and assessment could be a viable option for Queensland University of Technology, given the focus of the university on educating students for the "real world". Such activities would address key graduate capabilities, and provide biological-science majors with a competitive edge when transitioning into employment.

Characteristics of Authentic Learning in Tertiary Education

A major challenge when designing a capstone unit generally, but specifically at Queensland University of Technology because of its large student cohorts and their broad range of interests, is how to provide diverse projects that link to real-world problems in a learning environment where instead of simply going through the motions to complete assignments students can engage deeply with learning opportunities. According to Biggs (1993), this helps students move from a surface approach, where learning is viewed as the acquisition of knowledge and student motivation is the fear of failure, to a deep approach, where learning is viewed as making sense of information and the motivation is to understand. This challenge defines authentic learning; while it should arguably be a major objective for all units offered at the tertiary level, it is commonly recommended for capstone units (Holdsworth et al. 2009; Herrington & Herrington 2006; McCune 2009; van Acker & Bailey 2011). In this section, I will define the elements required for an authentic learning environment, focusing specifically on the issues of inquiry-based learning, graduate capabilities that are relevant to employers and collaborative learning.

A number of elements are identified as defining an authentic learning environment. According to Herrington and Herrington (2006), Kemper and Leung (2005) and Reeves et al. (2002), students should have the opportunity to: 1) solve a realistic problem that encapsulates the complexities and opportunities for failure that plague real-world problem-solving; 2) complete activities that are intentionally ill-defined and take time; 3) witness expert performance and the modeling of professional processes; 4) explore different perspectives and the roles of multiple stakeholders; 5) collaborate in a coordinated effort to solve problems; 6) be directed in self-reflection as both a process and a product; 7) communicate findings as a polished product, including presenting an argument and defending a position; 8) be coached and given assistance to solve complicated, ill-defined problems using scaffolding; and 9) complete assessments that are fully integrated into the unit and seamless with other learning activities.

Inquiry-based learning

The first two elements, solving realistic and ill-defined problems, could be delivered pedagogically using inquiry-based or project-based learning. Inquiry-based learning is thus essential to an authentic learning environment, and the connection to a realistic problem drives student motivation – an essential factor in a student-centred approach to teaching that is less acknowledged in tertiary education (Biggs 1993). A focus on scientific inquiry-based learning is not new; for example, American education regulatory bodies became interested in the process of science inquiry in the early 1930s, and placed a strong emphasis on scientific inquiry after 1957, possibly in response to the Russian launch of Sputnik, the first artificial Earth satellite (Schwartz et al. 2003). The term “inquiry” has multiple definitions in science, referring to how scientists investigate a question or how scientists create new knowledge by collecting evidence to test hypotheses and conceptual models, and also being a formal descriptor of a pedagogical approach that teachers can use to design their curricula (Minner et al. 2009).

However, science is not generally taught as open-ended inquiry. Science experiments are often delivered as closed activities, where both students and teachers know the results prior to the investigation (Minner et al. 2009). This is referred to as “recipe science”, where activities are contrived and more focused on developing content knowledge and less on understanding and applying scientific processes and complex reasoning. Science curricula can be designed that provide students with the opportunity to act as “real” scientists through experiencing the joys and pitfalls of scientific discovery, while at the same time addressing all the threshold learning outcomes for science (Australian Learning and Teaching Council 2011). Inquiry-based, or more involved and longer-term project-based, learning (Blumenford et al. 1991) should engage students in developing questions and hypotheses, planning investigations, carrying out their research, critically analysing and evaluating their findings, communicating their results to a range of audiences and showing accountability for their own learning and scientific work (Minner et al. 2009). Engaging undergraduates in research experiences was rated by students as highly beneficial in a study where 91% of 76 students indicated they experienced personal gains from conducting a research project (Seymour et al. 2004). However, creating a learning environment where students design and conduct science experiments was not found to effectively teach students about the nature of science, thereby not addressing the epistemological views of learners (Schwartz et al. 2003).

Graduate capabilities that are relevant to employers

The development of graduate capabilities that are relevant to employers, such as self-management, collaboration and planning (Figure 1), is often overlooked at tertiary institutions (Bridgstock 2008). , It is essential that student activities and assessment be authentic (Holdsworth et al. 2009), as evidenced by studies investigating the benefits of internships for general-science students. UK-based studies have found that students, whether male or female, increased their academic performance by an average of 4% after completing a work placement, with no bias found towards students with a higher academic performance prior to the work placement. The authors speculated that this increased performance was explained by increased student maturity, ambition, reliability and understanding of the importance of working towards a deadline (Gomez et al. 2004). Similarly increased performance with authentic projects was also found in a Hong Kong-based study (Kemper & Leung 2005).

These findings suggest that activities and assessment in capstone units should be focused on group performance, responsibility and the need to deliver on complex tasks to strict timelines. The provision of internships is not possible at all institutions, but it is possible to create similar experiences by connecting activities to real problems, perhaps sourced from and supported by outside agencies, as shown by Kemper and Leung (2005).

Collaboratively working in groups is an essential graduate capability that employers prize highly (Hammer et al. 2009). Evidence has shown that there is a strong link between critical thinking and social interaction (Ryder 2004; Springer et al. 1999; Resnick et al. 1991). A meta-analyses of 39 reports on small-group learning in science, technology, engineering and technology (STEM) found that students experiencing small-group learning achieved higher grades and were more positive towards learning; and that STEM courses incorporating small-group learning had higher student retention rates than those who were not taught in this way (Springer et al. 1999). It is recognised in Australia that science graduates should be prepared to effectively communicate science to disciplinary peers as well as non-scientists, and that a range of different formats can be used to motivate and engage students, including videos, news articles, blogs, wikis, podcasts and short vignettes (Colthorpe et al. 2013). Opportunities to communicate science to different audiences using a diverse range of media will help students develop skills for presenting evidence, developing arguments and defending results and interpretations.

Summary

The key elements of capstone units discussed above are consistent with recommendations generated in a large-scale regional study of 200 leading American biology faculties. This study interviewed researchers, faculty, pedagogy experts, undergraduate students, graduate students and professional agencies to develop a set of generic recommendations on how to improve undergraduate biology programs (Baurele et al. 2007). A key recommendation was that such programs should become student-centred; students should be active participants; multiple modes of instruction including traditional lectures should be employed; units should be outcome oriented, inquiry-driven and relevant; and authentic research opportunities should available, as they will increase students' persistence in biological-science careers (Baurele et al. 2007).

Although lists of essential elements for authentic learning environments are lengthy, the common elements are providing students with opportunities to work on complex, even messy, problems and collaborating in small groups (Herrington & Herrington 2006; Julien et al. 2012; Holdsworth et al. 2009; Lee 2013). Other elements could be viewed as essential but complementary to these two core elements. For example, for the learning environment to be authentic, students should be given opportunities to investigate relevant and engaging problems and assessment tasks that relate to these problems, while experiencing support from group members and teachers acting as facilitators of learning through coaching, scaffolding and the modeling of professional skills and behaviours. The overarching goal should be to create a learning environment where students construct their own meaning and conceptual understanding, but feel supported (Krockover & Shepardson 2002), instead of solely being given direct didactic instruction.

Metacognition: Explicitly Teaching Meaningful Self-reflection

Metacognition is defined as the ability to think about and evaluate one's own thinking processes (Ausubel 1968). Meaning cannot be transmitted by a teacher, but is instead only created by students in the activities that they undertake (Biggs 1999). There is a large body of literature on understanding the metacognition of science students at all different levels of their education (Watters & Watters 2007; Martin et al. 2000; Peters 2007), but few studies have been conducted on teaching science students explicitly how to experience more meaningfully learning at the tertiary education level. There is, however, considerable literature on teaching reflection for science pre-service teachers and for those in health-care professions such as nursing (Black et al. 2014; Langer 2002). Reflective practice and the impetus to become lifelong learners is a key graduate capability, but one often not explicitly addressed in science (Schwartz et al. 2003). Poorly integrated activities around self-reflection can feel contrived and meaningless for students.

Some students at the tertiary level may already have developed self-regulation skills, and strategies to effectively reflect and adapt over time, but the majority of even third-year students have not (Martin et al. 2000). It is necessary for learning strategies to be explicitly taught with opportunities for formative feedback and advice on both the process and product (Peters 2007). As mentioned above, the use of inquiry-based learning alone was not found to be effective at teaching students an epistemological perspective, but inclusion of a reflection diary as part of the research task was found to encourage a deeper, more philosophical understanding of the nature of science (Schwartz et al. 2003), and to serve as a primer towards becoming a self-regulated learner (Peters 2007; Schraw et al. 2006).

A study of the metacognition strategies used by graduate students in a 16-week advanced biology unit found that students who used self-regulation strategies to learn and revise their understanding of a complex topic were more cognisant of their own learning and were able to make advances in their thinking more quickly than students who used rote learning (Martin et al. 2000). The students who were more aware of their own learning were able to restructure their thinking and critically evaluate their own progress. Females in this unit were found to learn more meaningfully, showing a more advanced ability to monitor, regulate and control their learning (Martin et al., 2000). A study evaluating metacognition strategies adopted by first-year biological-science students found that more than 60% of interviewed students believed that learning was about acquiring knowledge as opposed to comprehension (Watters & Watters 2007). Recommendations from this study were interesting, as the researchers found it likely that the pedagogy of this unit, which involved lectures, textbook-driven driven reading and multiple-choice questions, fostered this belief in first-year students. This suggested, according to the researchers, that tertiary educators should do more to encourage students to see learning in science as comprehensive as opposed to rote (Watters & Watters 2007). Biggs (1993) describes how active teaching as opposed to passive transmission can bridge the gap between students whose learning styles are already at a deep level and those who still learn primarily at the surface level.

Learning journals can be used as guided autobiographies or personal documents to facilitate opportunities for students to critically evaluate their own learning process and develop a more meaningful metacognitive approach to learning (Black et al. 2014). Learning journal can assist students in the development of professional practice that is reflective – in other words, that involves the internal examination and exploration of an issue that is initiated by an experience that clarifies meaning and changes one’s thinking (Thorpe 2010). Three stages make up a critical reflection: awareness, critical analysis and new perspectives (Thorpe 2010). In critical reflection, students must consider a concept internally to understand it deeply, and they will only have the desire to understand it deeply if motivated by the belief that reflecting will result in a useful outcome (Langer 2002). Learning journals can help students build connections between content, put ideas and knowledge into practice and develop a better understanding of where and when to use knowledge (Thorpe 2010).

Learning-journal entries can take different structural forms including diary entries (where students describe reactions to, experiences of and opinions about unit content); notebook entries (where students summarise and critique unit content or report on group discussions); dialogue entries (where teachers and other students interact with ideas and provide viewpoints in response to entries); integrative entries (where students can connect unit content to their lives); and evaluation entries (where students reflect on their and their group’s performance) (Black et al. 2014). The inclusion of a learning journal as an activity or assessment must be carefully considered and meaningful to students; otherwise, the activity can feel contrived and perceived as a waste of time. Langer (2002) found that students in an adult continuing-education computer-technology program and displayed negative attitudes and skepticism towards the use of learning journals. The results of this study reinforce the need for learning journals to have a purpose within a unit, for students to be explicitly directed with regard to entries and for student perspectives to be valued as a contributing authority (Cook-Sather 2002).

Digital and online tools have increased the flexibility and range of ways students can receive formative feedback on their reflections in learning journals, including Blackboard tools and Virtual Learning Environments in WebCT (Hartford 2005; Gardner & Van der Veer 1998). Online communities of practice such as private Google Community sites could also be established to encourage reflective dialogue between students and lecturers (Sherer et al. 2003).

Step-Changes to Assist Students and Teachers with Transitions in Study Demands

Student participation in a capstone unit necessitates a change in students' learning strategies from surface or achievement-focused learning to deep learning (Biggs 1993; Biggs 1999). Capstone units can be structured to create learning environments that function as communities of practice, which can be defined as individuals working together to achieve a common goal for long enough that significant learning takes place (Wenger 1998). This transition to a less structured working environment can be confronting for students, with studies finding that they can experience frustration and discomfort with this change (McCune & Hounsell 2005; McCune 2009). Students' negative feelings can affect their willingness to engage in the practice of learning, particularly when they do not feel like valued and contributing members of the community (McCune & Hounsell 2005; Wenger 1998). Independent learning is both a learning style that some students have naturally developed and a pedagogical strategy that teachers can model to assist with the training of students who are not already comfortable with self-directed learning (McCune 2009).

Students should not be assigned an open-ended enquiry task and then left to figure out how to find solutions without coaching, mentoring and modeling. Teachers accustomed to traditional "chalk and talk" lecture-style delivery can feel confronted as well with change, moving from being a transmitter of knowledge to a facilitator of learning (Baurele et al. 2007). This represents a fundamental change for faculty members from a "pushed" style of knowledge delivery to a "pulled" style. Some academics, like some students, express feelings of doubt about student-centred learning, being concerned that students will not receive the content necessary to grasp a subject. These are legitimate fears, as poorly designed activities and assessments can lead to insufficient coverage of material and superficial learning experiences for students. In this case, teachers need assistance and training to adapt to what are often seen as radical shifts in pedagogy and curriculum. Recommendations to ease this transition include having teachers and pedagogy experts working together to clarify the knowledge and skills that are relevant for proficiency and mastery of the subject and to delineate learning activities and assessment that can provide appropriate training (Baurele et al. 2007). This is a key component of transitioning university courses meaningfully towards the development of graduate capabilities, as studies have shown that transitioning to a focus on skills at the tertiary level is confronting and difficult for students, teachers and administrators (Hammer et al. 2009).

5. Recommendations for Queensland University of Technology Science Capstone Units

Based on the investigations of the literature on capstone units, the following six core elements should be incorporated to foster the graduate capabilities that transition to employable capabilities:

1. Challenging inquiry-based learning tasks that are intentionally ill-defined and complicated, and address cutting-edge, relevant problems.
2. Small-group work activities and assessments that encourage positive-constructivist learning.
3. Student-centred learning, where teachers take the role of coaching and mentoring and students being provided opportunities to network with members of the professional community.

4. Authentic tasks that involve students articulating their findings to peers and experts, including the experience of having to defend arguments and decisions.
5. Learning opportunities that include career-development skills and training.
6. Explicit modeling of self-aware and meaningful learning to encourage deep learning strategies that foster an appreciation for the nature of science.

QUT general-science undergraduate courses start from the first semester teaching the scientific method, and Australian capstone units in biology, whether subject-specific or generic, are generally focused on reinforcing these skills in a final-year research project. The issue with this common focus is that the majority of science graduates in Australia will not work in the field of research, but that understanding the scientific method is valuable for students, as it is a rigorous and systematic inquiry-based strategy that is prized by employers because it is evidence-based, objective and repeatable (Chubb 2014). Macquarie University provides a capstone unit in biology that is unique among Australian universities, as it provides flexibility in which biological topic students can study, and focuses on career development.

The Queensland University of Technology biological-science capstone unit has many challenges in its design and delivery, including large class sizes and the broad interests of the student cohort. The six recommendations for inclusion in capstone units that have arisen from this literature review suggest that achieving graduate capabilities in a capstone unit does not have to come from students designing and then carrying out individual or group research projects. Conducting an experiment is only a minor component of the nature of science, and one that students are likely to experience repeatedly over the course of their degree. Complex problem-solving, collaborative learning environments, self-regulated learning, professional and academic mentoring and coaching, articulation and career development can be generated in a learning environment centred around alternative activities and assessment. Student groups could instead be presented with “real” biological problems and conduct all the necessary investigations, networking and planning for a scientific study, including presenting their ideas and decisions, without ever collecting the data.

The most significant finding from this literature review is the lack of focus in tertiary science education on explicitly teaching science students how to transition to being self-regulated learners. There is a large body of research on metacognition in science, and even specifically in the biological sciences, but there are remarkably few studies investigating the efficacy of strategies to build more meaningful learning in science. I highly recommend that opportunities for directed reflection be incorporated into all science majors using learning journals.

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Table 1: Queensland University of Technology generic graduate capabilities for undergraduate students (**http://www.mopp.qut.edu.au/C/C_04_03.jsp**, viewed September 2014)

Graduate capabilities	Description
Knowledge and skills pertinent to a particular discipline or professional area	○ Coherent theoretical and practical knowledge in at least one discipline area at the level of entry to a profession ○ Technological skills appropriate to the discipline.
Critical, creative and analytical thinking, and effective problem-solving	○ The ability to critique current paradigms and contribute to intellectual inquiry ○ The capacity to exhibit creative as well as analytical ways of thinking about questions in at least one discipline ○ The ability to identify, define and solve problems in at least one discipline area.
Effective communication in a variety of contexts and modes	○ Effective written and oral communication with discipline specialists and non-specialists and in cross-cultural contexts.
The capacity for life-long learning	○ Searching and critically evaluating information from a variety of sources using effective strategies and appropriate technologies.
The ability to work independently and collaboratively	○ Managing time and prioritising activities to achieve goals ○ Demonstrating the capacity for self-assessment of learning needs and achievements ○ Being a cooperative and productive team member or leader.
Social and ethical responsibility and an understanding of indigenous and international perspectives	○ Active contribution to intellectual, social and cultural activities ○ Understanding and appreciation of indigenous perspectives ○ Recognition and appreciation of gender, culture and customs in personal and community relations ○ Valuing and promoting truth, accuracy, honesty, accountability and the code of practice relevant to the discipline or professional area.
Characteristics of self-reliance and leadership	○ The ability to take the initiative, to embrace innovation, and to manage

	change productively.

Table 2: Comparison of the main aims and learning outcomes for capstone units across five universities: Latrobe University (a subject-specific capstone in the field of physiology), University of Melbourne (capstone in the field of zoology), Griffith University (generic capstone unit across all offered science majors), Macquarie University (capstone for a broad biological-science major) and Queensland University of Technology (the focus in this report, capstone for a broad biological-science major).

Overall aim and learning outcomes (LO)	Latrobe University Physiology (Julien et al., 2012)	University of Melbourne Zoology (Holdsworth et al., 2009)	Griffith University Science capstone preparation and science capstone (generic across science majors) (Griffith University, 2014)	Macquarie University Biology (Macquarie University, 2014)	Queensland University of Technology Biology
Overall aim	To provide an effective culmination point for the Bachelor of Health Sciences course and to offer student orientations to opportunities for further study, employment and career development	To provide students with an authentic opportunity to engage in an authentic experience of scientific research as part of a group, and apply the knowledge and skills they have learned in previous subjects to challenging areas relevant to careers in the relevant zoological specialisation	To provide a range of activities that will further develop inquiry and problem-solving and put the professional responsibilities of science students into practice	To provide students the flexibility to explore an area of interest in biological or medical sciences and bring together their acquired knowledge and skills; to explore connections among the various disciplines of biology that would be beneficial in addressing contemporary issues of interest to society	To provide an opportunity to conduct a research project, applying knowledge of quantitative techniques and experimental design to answer a challenge
LO-1	Access and evaluate relevant literature	Assimilate and critically evaluate new knowledge within a scientific paradigm	Conduct investigation including collecting data, recording and interpreting (e.g. could be open, experiments, field assessments, application of theory) as individuals or occasionally in small teams	Articulate and present evidence of key learning strengths gained throughout the program of study for the purpose of adding value to students' future profession	Demonstrate advanced knowledge concerning a key aspect of biological sciences, as well as some interdisciplinary understanding
LO-2	Critically analyse and synthesise	Communicate that	Interpret findings using	Develop practical transition	Demonstrate critical reasoning

	published literature	knowledge to others	appropriate discipline-specific approaches	skills including effective job-search strategies and job-application skills (CV and interviews) and clearly understand the diverse career options where an understanding of biology is essential, valuable or advantageous	and evaluation skills as applied to the interpretation of scientific data
LO-3	Interpret and present experimental findings in effective written form for a variety of audiences	Manage a group research project	Draw conclusions and distinguish questions for future investigations	Acquire some of the key workplace skills that help maximise students' contributions to their field of work and build positive workplace experience	Demonstrate an ability to communicate complex scientific information and argument in a written report
LO-4	Design and implement a research project and present the results in an effective written and oral form	Analyse, interpret and evaluate scientific data critically	Communicate findings in a high-quality written report		Demonstrate competency in applying effective teamwork to solve scientific challenges within a set timeframe
LO-5	Develop, maintain and work as a member of a functional team	Write a scientific report, providing and responding to peer reviews	Defend the findings in the report in an oral defence		Demonstrate an understanding of ethical practice as applied to research
LO-6		Make an oral presentation			