A Review of the Value of Prior Learning in First Year Biology

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Abstract

Differences in the levels of prior learning of biology among commencing university students is a common and potentially problematic issue for students and academics alike. Amongst concerns is the requirement for extra support and/or provision of supplemental learning activities for students lacking biology knowledge. Such students often have lower levels of confidence in terms of academic achievement and generic skills, with consequently higher levels of study anxiety and rates of withdrawal compared to students with prior biology learning. Students with adequate prior biology knowledge generally achieve higher grades for coursework assessments and assignments, for at least a major part of the teaching semester. This review examines issues associated with disparities in the levels of prior knowledge among students entering undergraduate biology subjects. Enrolments in such subjects have increased dramatically over the past two decades, generating increased cultural, socio-economic and demographic-related diversity. The review also investigates best practice in ameliorating problems associated with different levels of prior learning, and discusses these issues in the context of future planning and practise in biology education. Finally, an examination is made of the factors that will likely impact on the future teaching and learning of undergraduate biology, such as the potential of information and communication technologies, the nature of blended learning approaches, and increasing connectedness of student learning.

The value of undergraduate biology

More than two decades ago, Gottfried, Hoots, Creek, Tamppari, Lord and Sines (1993) carried out a wide-ranging review of college biology teaching in the USA. Their review was pivotal in a number of ways, as it centred on the influence of entry level biology courses in enhancing student conceptions of science and the critical role of these perceptions for the future of science. Among their recommendations, Gottfried et al. (1993) argued for the re-evaluation and redesign of biology courses and curricula and their de-massification to enable more effective teaching practice. They also made a strong case for formal recognition and reward for high quality teaching in science and biology. Although Gottfried et al. (1993) made these recommendations more 20 years ago, little has changed and in fact, the opposite may have occurred to biology curricula. Over the last two decades, a complex set of interacting factors have impacted substantially on higher education policies, practices and curricula. These include the massification of higher education (Dobson, 2003; Krause, Hartley, James & McInnes, 2005), disruptions caused by technology, with concomitant increases in easily accessed information (Price & Oliver, 2007) and changes in the traditional academic role, with greater importance placed on research output at the expense of reward and recognition for high quality teaching (Bexley, James & Arkoudis, 2011).

Given the plethora of factors currently impacting higher education policy and programs, a better understanding is required of the value of prior learning and its effect on the future learning of students. This has particular relevance for subjects such as first year biology, which most often forms the basis for upper year level areas of study in zoology, ecology and the biomedical areas. The outcomes of future research into these areas, for which this review provides a basis, will be important for curriculum enhancement and renewal, the strengthening of pedagogical bridges between secondary and tertiary education systems, and 'downstream' impacts on the skills, capabilities and employability of science graduates.

What are the predictors of success – for first year and overall degree results?

There is no doubt that the transition from secondary to tertiary education represents a 'modern day rite of passage' (Clark & Lovric, 2008), something that Scanlan, Rowling and Weber (2007) describe as a type of identity discontinuity. Cherif and Wideen (1992) defined this disconnect as a form of cultural divide, with the sheltered, familiar and social secondary school atmosphere contrasting strongly with the less-structured, summative, assessment-driven university environment. This divide can be exacerbated in large enrolment first year subjects such as biology, assessment for which often involves practical activities requiring skills in particular protocols and the use of expensive, complicated equipment in unfamiliar laboratory environments. Disconnections in the structure, curricula, and skill standards between secondary and tertiary education may be a primary reason behind student failure or, more likely, an impediment to the success of students who would otherwise have achieved under a more streamlined and scaffolded framework.

The disconnect between secondary and tertiary education has provided a rich vein of research scholarship across a range of disciplines. For example, Venezia, Kirst and Antonio (2003) pointed out that the considerable differences in coursework and standards between high school and college study in the USA were compounded by the lack of a recognized transition system between the sectors. In the UK and Europe, this disconnect has been explored in terms of a lack of matching of expectations between the student and the course, and vice versa (EMBO, 2006). An example of this disconnection is the difference in expectations between secondary teachers, with a focus on the Academic Tertiary Admission Rank (ATAR), and the expectations of tertiary academics regarding the preparedness of students for university (Schwartz, Hazari & Sadler, 2008). Reported almost two decades ago, these disconnections represent a fundamental and persistent discordance between the sectors (Razali & Yager, 1994; Shumba & Glass, 1994).

Once at university, students' academic success in first year depends on a number of factors. These include their university entrance score (Dalziel & Peat, 1998; Green, Brown & Ward, 2009), level of prior learning in a subject (Sadler & Tai, 2007), degree of enthusiasm for and engagement with their learning (Kuh, Cruce, Shoup, Kinzie & Gonyea, 2008), and socio-economic status (James, Baldwin, Coates, Krause & McInnes, 2004). In a comprehensive review of the first year experience of Australian students across a range of disciplines, Krause et al. (2005) found a strong positive correlation between academic success in first year and students' perceptions of the extent to which they successfully coped with and managed their study. While a relationship between academic success and student perceptions dominates at first year, it appears to diminish as students progress through their studies, with other factors emerging and impacting on achievement and success. For example, the final year academic performance of sport and exercise degree students was found to depend on age (older students did better than younger students), gender (females did better than males) and hardiness commitment (Sheard, 2009). Hardiness commitment is loosely defined as a combination of two student attributes; hardiness - the extent to which students persist regardless of uncertainty; and commitment - the deep involvement of an individual in his or her studies. In a similar study of psychology undergraduates, Cassidy (2012) reported the strongest predictors of students overall academic success at university to be prior academic achievement, age, and what he termed ‘academic self-efficacy’.

The value of prior learning – general perspectives

In spite of long held and ongoing concerns about the disconnect between secondary and tertiary structures and standards, there is broad acceptance of the value to students of prior learning, understanding and skills upon their commencement at university. Prior learning in a discipline has been shown to have an important positive effect on undergraduate student achievement and success, determined by measures of engagement and persistence, particularly during their first year at university. This has been reported across a range of disciplines, including economics (Buschena & Watts, 2001), politics (Sachleben, 2010), business and communication (Plutsky & Wilson, 2000), medicine (Park, 2011), and in several STEM (Science, Technology, Engineering, Mathematics) disciplines including biology, chemistry and physics (Sadler & Tai, 2007), mathematics (Guzman, Hodgson, Robert & Villani, 1998; Choudhury, Robinson & Radhakrishnan, 2007), and physical geography (Birnie, 1999). Not unexpectedly, the value of prior learning on student success has also been reported for more generic skills such as writing (Ellis, Freeman & Bell, 2008).

Previous academic achievement in a related discipline area has also been widely reported as a common factor in student success in their first year at university (Evans & Farley, 1998; McKenzie & Schweitzer, 2001; O’Byrne, Britton, George, Franklin & Frey, 2009; Win & Miller, 2005). This is perhaps unsurprising, given what is known about the interactions among factors such as the type of material being learned, the role of memory in learning (Taber, 2003a), and the neurological processes associated with learning (Lawson, 2003). As Buntting, Coll and Campbell (2006) point out, complications arise for students who lack the prerequisite knowledge and conceptual understanding in discipline areas that they have not previously studied. These students can also develop misconceptions that obstruct their deeper learning. This is a particular concern in the sciences, where meaningful learning occurs most effectively when learners relate the new content to what they already know - their ‘cognitive structure’ (Ausubel & Robinson, 1971).

Although biology is generally regarded as an enriching and relevant discipline, and remains a popular area of study for undergraduates, a high proportion of first year students have little or no prior learning in biology (Burke da Silva, Young, Rayner, Blanksby & Familari, 2013). Students may choose not to study biology in senior secondary school due to the considerable importance placed on the tertiary entrance score, which is based on the subject scores students achieve in their final years of secondary schooling. Many students believe that biology does not scale well in comparison to other subjects (James, Bexley & Shearer, 2009), even though this may not be correct (VTAC, 2008). The combination of the ability of student cohorts in a subject and the subject itself are dual levers that generate potentially higher university entrance scores (Calderon, Dobson & Wentworth, 2000). Not surprisingly, a high proportion of students develop a study strategy, often adopted early during their secondary school years, to increase the likelihood of attaining the maximum possible university entrance score. Integral factors in this strategy include the choice of school, whether private (non-government) or public (government), subject choice and extra-curricula tutoring. Thus, while biology is a popular subject choice of first year students, many of them have no previous experience of biology, except in junior secondary school.

The value of prior learning for first year biology

Given this situation, a crucial question is: What effect does a lack of prior learning in biology at secondary school have on student performance in this subject in their first year at university? In Australia, first year biology cohorts tend to be large (n > 800) and consequently very diverse, comprising students from a range of educational and cultural backgrounds, and with different capacities and motivations for learning (Rayner, 2008). While enrolments in undergraduate biology are increasing, in stark contrast, those in mathematics and the physical sciences are decreasing (Brown, 2009). Many students incorrectly perceive biology as a relatively ‘easy’ science (EMBO, 2006). This is compounded by the fact that year 12 biology is often not a prerequisite for first year biology (Boud, 1995). In a recent benchmarking study of first year biology subjects at Australian Universities, Burke da Silva et al. (2013) found a strong degree of commonality among them in both content and structure, and strong alignment with respective state curricula and the recently published ACARA Australian senior biology curriculum (www.australiancurriculum.edu.au). Burke da Silva et al. also found that up to half of the students in first year biology subjects had not taken year 12 or equivalent biology. A major impediment to the development of strategies to cope with disparities in prior learning is that many institutions and subject coordinators are unaware of the proportion of their student cohorts lacking prior knowledge. For example, Burke da Silva et al. (2013) found almost half of the surveyed first year biology coordinators had no idea how many of their students had completed year 12 biology.

Although prior study in a secondary school subject may be a predictor of achievement in an equivalent first year university subject or discipline (Sadler & Tai, 2007), the evidence to date for biology appears to be somewhat equivocal. Bone and Reid (2011) found that the study of biology in year 12 was not a predictor of success in first year university biology, although completion of year 12 chemistry positively impacted student performance in first year biology. Johnson and Lawson (1998) found that the most significant predictor of the final exam score for college biology students was their reasoning ability rather than their levels of prior knowledge or the number of biology courses they had completed. In contrast, Graham, Addy, Huddleston and Stallard (2011) found that students without pre-requisite biology information did not perform as well as students with prior learning. This finding is consistent with that of Burke da Silva and Hunter (2009), who reported failure rates of first year biology students without year 12 biology to be almost double those who did. Further, McCoy and Pierce (2004) reported that students with prior learning in biology were significantly more likely to achieve a high grade than students without such learning. This may relate to the study strategies of first year students, which Hegarty-Hazel and Prosser (1991) found to be more effective in students with prior knowledge, and thus facilitating higher achievement in post-secondary biology classes.

These conflicting results suggest that for first year biology, and for other content and concept rich STEM subjects such as psychology, chemistry and physics, a range of prior learning experiences may affect student achievement. These include the content, structure and timing of the curriculum (i.e., no two biology curricula will be the same), the balance between formative and summative assessment types, the strength of the nexus among modes of learning (lectures, practical activities, summative assessments), and the pedagogical integrity of assessment tasks. Additionally, age, nationality, the learning style of students (Bone & Reid, 2013) and various cohort-specific attributes such as socio-economic status, and cultural and social aspects may affect students’ approaches to study, thereby impacting on achievement. Another possible factor is that although prior knowledge may serve as a basis for further learning, due to the fact that misconceptions are common among first year biology students (Lazarowitz & Lieb, 2006), prior (mis)learning can negatively influence understanding (Wright, 2004). Interrelated with the notion of misconceptions is the influence of lack of prior learning in channelling students' interpretation of subsequent learning, as has been noted for chemistry (Taber, 2003b). The general observation that students with prior biology learning achieve higher grades than students lacking such background knowledge clearly identifies a need to provide foundation material embedded within a subject, and to do it in such a way as to not disenfranchise students who have studied biology in senior secondary school.

Given the significant proportion of first year students that lack prior learning in biology, there is considerable difficulty in providing an optimal biology curriculum for all; one that effectively engages and enthuses students who have and who have not previously done biology. Students who have not previously done biology may perform more poorly in early, rather than later semester assessment tasks compared to students with prior learning. For example, students in a semester 1 biology subject (n=1200) who had completed Year 12 Victorian biology obtained significantly greater marks in the first three of five summative, invigilated assessments over the initial 8 weeks of semester compared to students who had not completed biology (unpublished data). Students who failed or who had not met their expectations for such assessments are likely to have experienced high levels of anxiety. Such anxiety can be compounded over the course of study, leading to significantly poorer grades at the end of the academic year compared to less anxious students (Lecompte, Kaufman, Rousseeuw & Tassin, 1983).

What should undergraduate biology students know and be able to do?

In the context of undergraduate bioscience education, a compelling question that must be asked is "*what do universities want their biology students to know, understand and be able to do upon graduation"*? In this era of connectedness and immediate access to information, as soon as novel, ground-breaking research is published, it is available for student acquisition and regurgitation. There is a general perception among students and academic staff that e-learning largely comprises the *delivery* of information (Alexander, 2005). Although ICT has been shown to enhance constructivist forms of learning (Hedberg, 2006), it is vital that the 'communication' element, involving articulation, discussion and reflection, be emphasised at least as strongly as the 'information' element. Pedagogies that promote higher order thinking skills are primarily based on interaction and dialogue. Such techniques also commonly integrate the posing of difficult questions, the solving of problems through collaboration, active debate and discussion, and importantly in the sciences, investigation of contextually-relevant content and processes that are complex in nature (Eberlein, Kampmeier, Minderhout, Moog, Platt, Varma-Nelson & White, 2008). The danger is that higher order thinking skills such as the synthesis, integration and analysis of data and evidence, which are crucial to the generation of new knowledge in STEM disciplines, may be among the first casualties of the technological age.

There is no doubt that biological sciences *research*, in all of its specialised forms, from molecular biology, biotechnology and biomedicine, through to broader integrative ecological and evolutionary sciences, is important and relevant, to societies, communities and individuals. The value of the laboratory or field-based 'practical' takes on greater importance in our technological age. The practical is well named, given that it involves 'doing' rather than reading or hearing, and is aimed at promoting a range of higher order thinking and other skills. Team skills, an enhanced ability to work independently, and proficiency in the use of equipment, methods and scientific approaches are all developed through laboratory and field based activities. The substantial range of benefits to students from practical-based science activities has been widely reported in the literature, for both laboratory (Hofstein & Lunetta, 2004; Hofstein & Mamlok-Naaman, 2007) and field-based settings (Smith, 2004; Scott, Goulder, Wheeler, Scott, Tobin & Marsham, 2012). In practicals, students discover meaning and connect concepts through activities and experiences that require the solving of problems, critical thinking, and inquiry. A recent study of first year biology subjects at Australian universities found that only 22% of students specified problem-solving as a learning outcome, 34% specified the use of numeracy for evaluating data, and 24% stated open inquiry in practical tasks (Familari, Burke da Silva, Rayner, Young, Cross & Blansby 2013). Such statistics are disconcerting given the range and scale of current environmental and sociological crises, and increasing demands for universities to provide meaningful, skills-enhancing learning opportunities that empower students to collaborate, research and advocate.

Another impediment to the achievement of first year biology students is that many appear to be deficient in quantitative and related skills. As experimental design, hypothesis formation and testing and the gathering and analysis of data underpin biological and medical research, biology undergraduates need a fundamental understanding of how to use such techniques, and the ability to correctly interpret the results and integrate them in relevant, contextual ways. Globally, it has been recognised that students need to be able to quantitatively reason and interpret information (American Association for the Advancement of Science, 2011; National Research Council, 2003). Feser, Vasaly and Herrera (2011) have suggested that the future of biology research will be dependent on how successfully quantitative methods are integrated into the undergraduate biology curricula.

What interventions address disparities in prior learning in biology?

A range of biology-specific and more generic interventions have been reported in the literature to address a lack of prior learning in biology. For example, of the first year biology subjects benchmarked by Burke da Silva et al. (2013), almost three-quarters had discipline-specific programs to assist students at risk of failing biology. Of these programs, optional or extra-assistance tutorials were the most common forms of supplemental learning. At-risk biology students were most commonly identified through poor performance or failure in early semester assignment or assessment tasks. Students were then referred to biology-specific tutorials or workshops, or to other disciplines and more comprehensive programs if their difficulties related to broader learning or transition issues. For students commencing at university with low tertiary entrance scores, targeted teaching and learning initiatives have considerable potential to enhance their engagement and achievement in biology (Simson, Kelly, Moore, Pittard, Mendis, Lukomskyj & Woolnough, 2012) and other first year subjects (Levy & Murray, 2005).

Peer study groups also have considerable potential to enhance student engagement in biology and science and alleviate difficulties with university transition (Peat, Dalziel & Grant, 2001) or lack of prior learning in a discipline (Menz & Burke da Silva, 2008). These approaches, which are forms of peer assisted learning (PAL), most commonly use knowledgeable peer leaders or senior biology students (Griswold & Gaines, 2005) to lead discussions on difficult concepts and promote active dialogue among students. Due to their student-centeredness, these methods enhance participants' preparedness to ask and answer questions and contribute to their understanding of content and concepts in undergraduate bioscience (Tariq, 2005) and related disciplines (Hughes, 2011).

Differences in prior levels of biology learning have important implications for the value and effectiveness of lectures, which remain common methods of content delivery in many biology subjects. Despite the widespread prescription of specific textbook or other readings prior to lectures, considerable differences in the lecture preparation of students have been reported (Chapple, 1999). Pre-lecture learning modules that enable students to familiarise themselves with key terms and concepts, or which provide formative feedback on students' understanding, have been implemented in a range of biology subjects. These modules use a range of approaches, including animations, visualizations or targeted software packages such as MasteringBiology® (Rayner, 2008) to overcome disparities in prior learning or address misconceptions, especially for more difficult threshold concepts such as genetics, cellular respiration, and evolution. Cost is a not an insignificant factor in the integration of such modules, particularly when student access is fee-based and often linked to an already expensive prescribed textbook. The increasing availability and adoption of less expensive but equally effective e-texts (Rockinson-Szapkiw, Courduff, Carter & Bennett, 2012), incorporating formative assessment and adaptive learning, may form part of the solution to the issue of cost, despite an apparent inherent resistance from students themselves (Woody, Daniel & Baker, 2010).

Summary and Conclusions

There is an increasing acceptance among university educators that performance at university is dependent on preparation of students at secondary school. This should not be thought of in terms of content acquisition, but also that students require skills in critical thinking and problem solving. Such skills provide students with a substantial advantage, in terms of engagement and success, upon commencement of their university studies. The re-introduction of focused inquiry frameworks into the Australian senior secondary biology curriculum (www.australiancurriculum.edu.au) emphasises the value educators and employers place on inculcating problem-solving and critical thinking skills. Inquiry-based approaches in secondary biology and related sciences curricula provide students with an ideal foundation for university studies in biology. Whether the hoped-for transformation of the biology curriculum will occur is unknown, especially given that inquiry approaches were first suggested more than three decades ago (Tamir, Amire & Nussinovitz, 1980).

It is likely that for the foreseeable future, increasing enrolments in first year biology will generate greater diversity among students in their levels of prior biology knowledge and related skills. Prime factors in this pertain to the importance of the university entrance scores for admission to highly sought-after degrees, and the focus of students on senior secondary subjects or combinations thereof that will generate the highest possible tertiary entrance score. The lack of prior biology study of many students may have considerable ramifications on the deeper knowledge and understanding they attain as they progress through their tertiary studies. This is because in many university biology subjects, large amounts of content, often delivered at a rapid rate and assessed by summative means, will collectively favour memorisation over deeper conceptual understanding (Donovan, Atkins, Salter, Gallagher, Kratz, Rousseau & Nelson, 2013). The future of biological sciences education is closely tied to that of other sciences and the pedagogical innovations currently occurring at the secondary and tertiary educational levels. Further research into the extent, value and connectedness of prior learning, and dissemination of the outcomes, will be key components of the future direction of educational reform in Australia.

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