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Inquiry-based learning to improve student engagement in a large first year topic

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Abstract*

Increasing the opportunity for students to be involved in inquiry-based activities can improve engagement with content and assist in the development of analysis and critical thinking skills. The science laboratory has traditionally been used as a platform to apply the content gained through the lecture series. These activities have exposed students to experiments which test the concepts taught but which often result in a predicted outcome. To improve the engagement and learning outcomes of our large first year biology cohort, the laboratories were redeveloped. Superlabs were run with 100 students attending weekly sessions increasing the amount of contact time from previous years. Laboratories were redeveloped into guided-inquiry and educators facilitated teams of students to design and carry out an experiment. To analyse the impact of the redevelopment on student satisfaction and learning outcomes, students were surveyed and multiple choice exam data was compared before and after the redevelopment. Results suggest high levels of student satisfaction and a significant improvement in student learning outcomes. All disciplines should consider including inquiry-based activities as a methodology to improve student engagement and learning outcome as it fosters the development of independent learners.

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Introduction

What is inquiry-based learning?

Inquiry has been described as a teaching method which combines student-centred, hands-on activities with discovery (Uno, 1990). Importantly, the educator acts as a facilitator of the learning activity, promoting student discussion and providing guidance rather than directing the activity (Herron, 2009; Uno, 1990; Wood, 2009). Inquiry-based learning fosters the development of independent learners, by encouraging students to take responsibility for their own learning. Based on the principles of the scientific method, in inquiry-based learning students observe a phenomenon, synthesise research questions, test these questions in a repeatable manner and finally analyse and communicate their findings (Uno, 1990; Weaver, Russell, & Wink, 2008). The learning is directed by the student with the educator providing a supportive role. The level of input from the educator depends on the level of inquiry. In open-inquiry students independently formulate a question to research while in guided-inquiry the educator provides guidance with the construction of a question (Weaver et al., 2008). Although based on the scientific method, inquiry-based learning is a teaching method which should be considered in other disciplines as it supports the development of students who are responsible for their own learning.

What are laboratories and why do we need them?

One of the goals of science education is to engage the learner in the process of scientific inquiry. It is through hands-on activities in the laboratory that learners are often first introduced to the scientific process and scientific inquiry. Research suggests that learners benefit from experiencing the hands-on activities in the laboratory and that these activities are vital for their development as independent learners and as future professionals (Cherif, Siuda, & Movahedzadeh, 2013; Hofstein & Lunetta, 2004; Matz, Rothman, Krajcik, & Banaszak Holl, 2012). In recent years, there has been much discussion about the role of the science laboratory in higher education and whether the traditional step-by-step nature of laboratory activities promote the skills fundamental to research science (Alozie, Grueber, & Dereski, 2012; Gormally, Brickman, Hallar, & Armstrong, 2011; Herron, 2009; Wood, 2009). Many traditional laboratories or cookbook style laboratories have students follow step-by-step instructions and result in a known conclusion, with limited opportunity for students to ask scientifically-orientated questions and develop higher order thinking skills (Lord & Orkwiszewski, 2006).

What evidence is there to support inquiry as good practice in laboratory learning?

Inquiry-based laboratories are defined by activities that engage students in scientific reasoning. Recent studies have examined the degree to which inquiry is implemented in the laboratory in higher education and have presented inquiry-based activities as a continuum, with traditional verification laboratories at one end and authentic research laboratories at the other end (Weaver et al., 2008; Wood, 2009). As inquiry-based laboratories have been introduced into the biology curriculum in higher education, a large number of studies have been carried out to examine their impact on student learning (Beck, Butler, & Burke da Silva, 2014; Brownell, Kloser, Fukami, & Shavelson, 2012; Gormally et al., 2011; Malau-Aduli et al., 2012; Myers & Burgess, 2003). The introduction of inquiry-based laboratories has been shown to result in a deeper understanding of scientific content, increase confidence in understanding and performing science, improve students' attitudes towards science and act to lower attrition rates

(Brownell et al., 2012; Myers & Burgess, 2003; Weaver et al., 2008; Wood, 2009).

The move to inquiry-based learning at Flinders University

The first year biology student cohort is the largest at Flinders University with approximately 800 students enrolling in the first semester topic (Molecular Basis of Life) and 700 enrolling in the second semester topic (Evolution of Biological Diversity). The students come from a diverse range of study, socio-economic, cultural, age and ethnic backgrounds, representing 39 degree programs, encompassing all faculties across the university. The challenges facing students transitioning to university are well documented in the literature including engagement, establishing friendships, fostering a sense of belonging and building relationships with teaching staff (Grebennikov & Shah, 2012; Larmar & Ingamells, 2010; Lowe & Cook, 2003; Nelson, Quinn, Marrington, & Clarke, 2012). Many researchers cite engagement both in the social and academic aspects of university life as important predictors of student success and retention (Larmar & Ingamells, 2010; Lowe & Cook, 2003; Nelson et al., 2012). Building friendships with peers facilitates a sense of belonging which improves engagement and contributes to better learning outcomes and increased retention (Larmar & Ingamells, 2010; Wilcox, Winn, & Fyvie-Gauld, 2005). Positive engagement with university life in the first year improves retention, contributes to better learning outcomes and improves overall student satisfaction with higher education (Larmar & Ingamells, 2010; Lowe & Cook, 2003).

Thus, to improve the engagement of our student cohort, the laboratories in both first year biology topics were redeveloped as guided inquiry-based laboratories. By improving student engagement with the learning material, we aimed to improve their first year experience and learning outcomes. The format of the laboratories was changed from three hour laboratory sessions per fortnight to two hour laboratory sessions per week. This increased the time students spent in the laboratory over the semester from 18 to 24 hours. Groups of 100 students were led by an experienced educator and divided into teams facilitated by a postgraduate student. In teams, students worked together on a guided inquiry-based exercise which ran over one or two weeks depending on the activity. This encouraged students to foster new friendships and strengthen the staff-student relationship as students worked with the same peer group and staff members each week.

Measuring the impact of the redevelopment

A research project was designed to assess the impact of the redeveloped laboratories on the student experience. The first part of the project aimed to assess the student experience of the laboratories and to understand from the student perspective the role of the laboratory in their learning. This was achieved by surveying students at the end of each semester using both Likert and open response questions. The second part of the project aimed to determine whether the redevelopment improved student understanding of discipline based content. It also aimed to investigate the impact of the laboratory exercises on student understanding of topic content material. This was achieved by analysing multiple choice exam question answers before the laboratory redevelopment in 2013 and after the laboratory redevelopment in 2014.

An analysis of 710 students' responses to the survey questions indicated that students thought the laboratories in both semesters improved the quality of their university experience, helped them to understand the major concepts of the topics, challenged them intellectually and helped to develop their data analysis skills. Many students commented that the laboratories allowed them to apply the content taught in the lectures which improved their understanding of the material. Students often used the words “applied”, “hands-on”, “visualise” and” real-life” when describing how the laboratories helped them to learn the concepts in the topics. One student commented *I learn more when I use my hands and things are in front of me more than just reading words on a page so it was easy to understand*.

Table 1: ***Summary of statistical analysis on exam question data. Standard deviation (SD) is shown in brackets.***

Exam Question Category	Number of questions	2013 Mean (SD)	2014 Mean (SD)	*t*	df	*p*	*d*
All	108	59.60 (18.86)	61.15 (18.68)	-3.37	107	.001	.32
Subdivision into Laboratory and Content Related							
Laboratory related before and after redevelopment	15	68.21 (18.65)	67.63 (19.30)	.36	14	.726	.09
Lecture related before redevelopment, laboratory related after redevelopment	21	52.46 (16.62)	56.39 (16.11)	-5.45	20	.000	1.19
Lecture related before and after redevelopment	72	59.89 (18.95)	61.20 (19.07)	-2.43	71	.017	.29

Comparison of student answers to a common set of exam questions before (2013) and after the laboratory redevelopment (2014) from semester 1 showed an increase in the overall mean score, with students in 2014 scoring higher (M=61.15, SD=18.68) than those in 2013 (M=59.60, SD=18.86); $t(107)=-3.37$, $p=.001$, $d=.32$; (Table 1, Figure 1). The common set of exam questions was divided into two broad groups: laboratory related and lecture related. Laboratory related questions were covered in both lectures and a laboratory session whereas lecture related were only covered during lectures. With the redevelopment of the laboratories, activities were expanded to address material previously only covered during the lecture series. This allowed the comparison of student success for material covered only in lectures before the redevelopment and in lectures and laboratories after the redevelopment. Overall three categories of exam questions were identified for further analysis: laboratory related (these questions had a related laboratory both before and after the redevelopment), laboratory

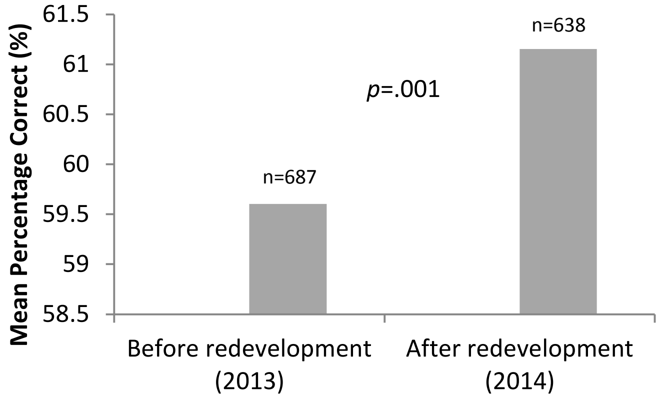

Figure 1: **Exam questions analysed for semester 1 before and after the laboratory redevelopment.**

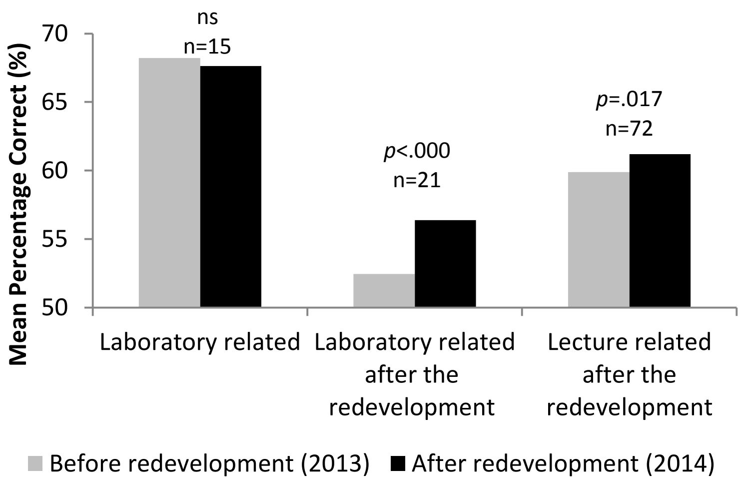

Figure 2: **Categories of exam questions used in the analysis. The n value indicates number of questions in each category.**

related after the redevelopment (these questions were lecture related before the redevelopment) and lecture related (these questions were lecture related both before and after the redevelopment) (Table 1). There was a significant improvement in student answers in the laboratory related after the redevelopment category, with students from 2014 scoring higher (M=56.39, SD=16.11) than those from 2013 (M=52.46, SD=16.62); $t(20)=-5.45$, $p=.000$, $d=1.19$ (Table 1, Figure 2). There was also a significant improvement in the scores on the lecture related questions, with students from 2014 (M=61.20, SD=19.07) scoring higher than those from 2013 (M=59.89, SD=18.95); $t(71)=-2.43$, $p=.017$, $d=.29$ (Table 1, Figure 2). There was no improvement in scores on laboratory related questions (Table 1, Figure 2). This last finding was not unexpected as it was noted that the mean was higher in this category than other categories both before and after the redevelopment suggesting that students understood the laboratory related exam questions better than lecture only exam questions (Table 1).

A Cohen *d* analysis of effect size ranged from $d=.09$ to 1.19 across the comparison categories. The lowest effect size (.09) was associated with the laboratory related category for which there was no significant difference between the 2013 and 2014 cohorts. For all other comparisons, the difference between means was found to be near moderate (.29) to high (1.19) (Table 1).

Conclusion

Overall these findings suggest that the redevelopment of the laboratories in first year biology has had a measurable impact on both student outcomes and student satisfaction. This indicates that the shift to inquiry-based learning and the additional contact time in the laboratory have improved the learning outcomes of first year biology students at Flinders University. These findings also highlight the importance of incorporating student-centred learning in the undergraduate curriculum. The development of independent learners requires providing students with the opportunity to formulate and explore questions based on evidence. Although inquiry-based learning is based on scientific principles, it is a teaching method which can be used in other disciplines to promote discovery.

Questions for consideration

What is the role of the laboratory in 21st century science learning? Should we be offering first year science topics without a laboratory component?

What are the challenges in moving to inquiry-based learning? How can these be overcome?

What is the minimum laboratory time required to achieve the best academic outcomes for our students?

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