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Repeating Knowledge Application Practice to Improve Student Performance in a Large, Introductory Science Course

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There is a tendency for lecture-based instruction in large introductory science courses to strongly focus on the delivery of discipline-specific technical terminology and fundamental concepts, sometimes to the detriment of opportunities for application of learned knowledge in evidence-based critical-thinking activities. We sought to improve student performance on evidence-based critical-thinking tasks through the implementation of peer learning and problem-based learning tutorial activities. Small-group discussions and associated learning activities were used to facilitate deeper learning through the application of new knowledge. Student performance was assessed using critical-thinking essay assignments and a final course exam, and student satisfaction with tutorial activities was monitored using online surveys. Overall, students expressed satisfaction with the small-group-discussion-based tutorial activities (mean score 7.5/10). Improved critical thinking was evidenced by improved student performance on essay assignments during the semester, as well as a 25% increase in mean student scores on the final course exam compared to previous years. These results demonstrate that repeated knowledge application practice can improve student learning in large introductory-level science courses.

Keywords: *Undergraduate; Active learning; Problem based learning; Learning performance; Course experience*

Introduction

Effective teaching and learning practice in large introductory undergraduate science courses can be challenging as these classes are frequently characterised by the complex interplay between information memorisation and application of knowledge

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which impacts students' learning (Momsen et al., 2013). Numerous studies have shown significant correlation between effective teaching in higher education and student performance (e.g. Strahan, 2003; Stronge, Tucker, & Hindman, 2004). What is effective teaching? According to a hypothetical statement attributed to Socrates by Murray (1994), 'Excellent teaching is that which produces learning and understanding'. Although the relationship between students' performance in a course and their learning preferences is imperfect (Eudoxie, 2011), an appropriate learning environment (i.e. classroom and/or course culture, nature of learning situation) can influence students' approach to learning, motivation to learn, and perception of the learning environment, thereby leading to improved academic performance (Micari & Light, 2009). Students are subject to numerous changes in learning environment during their first year at university. The provision of an effective learning environment and positive learning experience for first-year university students can help facilitate students' adaptation to the prevailing styles of teaching and learning in higher education. A student-centred learning environment which accounts for students' diverse learning styles and experiences during primary and secondary school education is an important means of optimising learning outcomes of first-year undergraduate students.

Student-centred learning, or the replacement of lectures with active learning, is widely recognised as an effective teaching approach to improve students' learning performance (Biggs, 1987; Handelsman, Miller, & Pfund, 2007; Overby, 2011). Based on a meta-analysis of 225 studies focused on undergraduate courses in science, engineering and mathematics disciplines, Freeman et al. (2014) demonstrated that active learning improves exam performance by an average of 6% and reduces the failure rate of undergraduate courses by 30%. The overall increase in exam performance as a result of active learning is marginal compared to traditional lectures (Freeman et al., 2014); however, it is important to note that active learning in large courses typically increases exam marks of students with cumulative scores on progressive assessment in the lower half of the class (Anderson, Mitchell, & Osgood, 2005; Mats, Rothman, Krajcik, & Banaszak-Holl, 2012). As a result of the improved performance of 'marginal' students, active learning results in a significantly lower rate of student failure (Freeman et al., 2014). Team-based and problem-based learning (PBL) are common active-learning styles and their implementation has been shown to yield improved learning outcomes related to professional skills (Hazel, Heberle, McEwen, & Adams, 2013) and problem solving using critical thinking (Anderson et al., 2005).

Specific challenges for introductory undergraduate science courses include: (1) integrating active-learning exercises with learning materials largely focused on lower-order cognitive skills (i.e. memorisation of terminology and concepts) rather than deep-learning experiences with higher-order cognitive skills (i.e. application of concept); (2) implementing active-learning exercises in large-sized classes, frequently with more than 100 students enrolled; and (3) effectively managing students' diverse approaches to learning, for example, surface (memorisation of course materials), strategic (assessment-oriented and focused on success rather than learning), and deep (understand for oneself and relate to previous knowledge and experiences) approaches

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(Momsen et al., 2013). It is clearly desirable for university students to engage in deep learning and exercise higher-order cognitive skills. Hrynchak and Batty (2012) demonstrated that implementing the constructivist learning concept as described in Kaufman and Mann (1999) as team-based learning in a large class encouraged the adoption of a deep approach to learning. Among the many possible approaches in active learning, a combination of team-based and PBL may foster development of students' meta-cognitive skills such as planning how to approach a task, monitoring comprehension and evaluating progress towards task completion (DeBono, 1976). As noted by King (2002), not all active learning is equal—to create an 'active thinking classroom'; teachers must formulate questions and activities which utilise higher-order cognitive skills. It can be challenging to implement team-based PBL activities in introductory science courses due to the large size of enrolment; however, this barrier can be overcome by dividing students enrolled in a single large course into small- to medium-sized classes for tutorial sessions.

The objective of this study was to determine whether active learning as implemented via the integration of team-based PBL in complementary tutorial sessions could significantly improve students' academic performance on the course final exam and perception of the learning environment in a large introductory-level science course compared to traditional lectures and practical demonstrations. Specifically, we sought to determine whether a gradual introduction of critical thinking and application of new knowledge in complementary tutorial sessions as part of a large introductory-level science course could significantly improve student learning as indicated by academic performance on critical thinking essay assignments and the final exam.

Course Description and Objectives

Small-group activities during tutorial sessions complementary to traditional lectures were implemented within the introductory course AGRC1031 at the University of Queensland. This course is compulsory for students studying agriculture-related majors, but also opens to enrolment by other undergraduate students majoring in scientific disciplines; as a result, the course typically involves a small fraction (approximately 8% in 2012–2014) of students majoring in Science, Engineering or Environmental Science. This diverse student cohort is characterised by a highly heterogeneous background with respect to learning skills and extant knowledge due to the different pre-enrolment requirements of each major field of study. In AGRC1031, three lecturers teach fundamental concepts and basic terminology within the three major components of the biophysical environment: climate, soil and water. AGRC1031 was developed in 2012 and is delivered annually with an average enrolment of 350 students; the enrolment in 2014 was a total of 401 students.

In 2012 and 2013, AGRC1031 was structured as 12 weeks of 3-hour lectures and 10 weeks of 1-hour practical sessions. These lectures and practical sessions were predominantly delivered using a passive lecture or demonstration format, with limited opportunities for students to participate or practice critical thinking and applying new knowledge to relevant scenarios. Learning assessment for AGRC1031 in 2012 and 2013 comprised 10% practical-session attendance, 10% practical-session notes, 10% field-trip attendance, 10% field-trip report, 10% short-essay assignment and 50% final exam. The final exam consisted of 50% multiple choice and 50% short-answer questions. Students were required to obtain a minimum 50% on the final exam to pass the course. The multiple-choice questions on the final exam were intended to evaluate 'understanding of terminology and concepts'. The short-answer questions on the final exam were intended to evaluate 'effective communication' and 'critical judgement'. In 2012 and 2013, a consistent problem for AGRC1031 was students' catastrophic performances in the short-answer portion of the final exam (average 43% of total points), which resulted in a high failure rate for the course (on average 49% of total enrolment). Considering the acceptable performance in multiple-choice questions (average 55–60% of total points), this high failure rate was presumably due to few opportunities to apply higher-order cognitive skills to solving problems as described in above.

The high student failure rate in 2012 and 2013 highlighted the critical gap between student learning and the method of evaluation used, particularly, the short-answer questions employed in the final exam. Facilitating the development of higher-order cognitive skills such as the application of new knowledge to an unknown scenario and critical thinking early in a university science program is a key to later academic success as upper level university science courses predominantly use short-answer or essay-style questions to evaluate student learning. Well-developed higher-order cognitive skills are also essential for graduates in science disciplines entering an increasingly competitive labour market; some of the more important core skills for students in science disciplines such as critical thinking, problem solving, data interpretation and effective communication of scientific information (Borrego & Newswander, 2010; Bradshaw, 1985; Payne, 2000) are inherently aligned with higher-order cognitive skills. The learning intervention applied to AGRC1031 and examined herein involved restructuring lecture- and demonstration-based practical sessions as tutorial sessions with small-group and PBL activities to provide a repeating practice of critical thinking and the application of learned knowledge.

Methodology

Outline of Re-Designed Tutorial Sessions

In 2014, AGRC1031 course content was delivered into three sequential modules: (1) climate and ecosystems; (2) soils and landscapes; and (3) water resources. Each course module comprised 12 hours of traditional lectures and a set of two 2-hour tutorial sessions. In the first of the tutorial sessions for each course module, students were expected to read a selection of assigned articles from newspapers or popular science magazines related to topics addressed within the respective course module prior to attending the tutorial session. Students were then asked to separate themselves into groups of six to seven and provided with an envelope filled with cards. Each card asked a meta-cognitive question related to the issues addressed in assigned readings and concepts delivered in the lectures. The questions in each envelope were developed by lecturers and were designed to prompt students to plan how they would explain the concept(s) to their group, monitor the group's understanding and independently determine when their respective task (answering the question and explaining the response to the rest of the group) was complete. Within the small groups, each student selects a card from the envelope and lead an approximately five-minute small-group discussion based on the question selected. This informal peer-review activity was designed to motivate students to employ a deep approach to learning key concepts as presented in the meta-cognitive questions.

In the second of the two tutorial sessions in each module, students watched a 1-hour documentary program or public debate related to the central topic of the course module. Students were then again asked to separate themselves into groups of six to seven and engage in small-group discussion using meta-cognitive questions delivered in an envelope similar to the first tutorial session. At the conclusion of the small-group activity, tutorial instructors led a large-group discussion during which the small groups of students were asked at random to provide their 'best' response to one of the meta-cognitive questions from the envelopes. Student autonomy within the large-group discussion portion of each tutorial session escalated during the semester to encourage independent application, analysis and evaluation of new knowledge consistent with demonstration of higher-order cognitive skills. During the six tutorial sessions throughout a single semester, students were exposed a total of six times to small-group PBL activities focused on developing meta-cognitive skills.

To accommodate the diverse interests and skill sets of the students enrolled AGRC1031, the tutorials were designed to use small-group discussion and PBL activities to build an understanding of selected key concepts in the first tutorial session of each module, followed by the application of new knowledge to a particular scenario or case study in the second tutorial session. The subsequent large-group discussion component of each tutorial session provided increasing opportunity for students to analyse, evaluate and extrapolate new knowledge to relevant scenarios. Further, the depth of information presented in each tutorial session and level of critical analysis required to complete small-group PBL activities increased as the course progressed and students were able to relate new information to content discussed in the previous course module(s), in alignment with increasingly higher-order cognitive skills according to Bloom's taxonomy.

In module 1, students undertook informal peer-learning exercises within their small groups and then shared those responses with the rest of the class in tutor-led large-group discussion. In module 2, small groups of students generated responses to a series of critical-thinking questions as a group and used the information generated to analyse a non-point source pollution issue and evaluate selected options for pollution attenuation. In both the module 1 and 2 tutorial sessions, all students were encouraged to contribute additional or different information as discussed during small-group activities to the large-group discussions. Finally, in module 3, tutorials after students self-organised into small groups of six to seven students they were randomly designated as a particular stakeholder group and asked to analyse data and create a position statement regarding a contemporary water resource-related issue from the viewpoint of their designated stakeholder group. The different stakeholder groups then discussed their responses and debated the merits of the different actions proposed with the other assigned stakeholder groups in a mock town hall-style debate.

Assessment

Two types of progressive assessment were used to evaluate student learning during the semester. Online quizzes each comprising 12 multiple-choice questions were assigned following the second tutorial of each module to examine student learning with a focus on lower-order cognitive skills. These quizzes were designed as self-assessment tools for students and to provide familiarity with the level of understanding required to complete the multiple-choice portion of the final exam. Hence, the marks of the online quizzes were based on participation rather than the actual performance. In the present study, the effects of online quizzes are excluded as the quizzes were not a part of the implemented educational intervention.

For each of the three course modules, a 1,500-word essay centred on an emotionally charged and/or frequently politicised agro-environmental issue related to the material addressed during the respective module was assigned after the second tutorial session. The essay assignments were designed to collect data regarding meta-cognitive student learning and higher-order cognitive skills including evidence-based critical thinking, formulation of scientific recommendations based on previous knowledge and experience and the logical expression of scientific concepts and relationships as related to the issue presented. Each essay assignment presented several questions related to a central issue or tasks to practice applying new knowledge and critical-thinking skills. The essay assignments were designed to foster the application of new knowledge to a specific scenario coupled with an opportunity to critically analyse a given scenario or statement, similar to the requirements for the short answer questions on the final course exam.

At the end of the semester, students were required to complete a 2-hour-long written final exam. The exam consisted of multiple-choice and short-answer questions. Multiple-choice questions were used to assess student learning with respect to lower-order cognitive skills whilst short-answer questions were aimed to assess student learning with respect to higher-order cognitive skills. The contents of each course module were equally weighted with regard to the number of multiple-choice and short-answer questions on the final exam.

Other Data Collection

The outcome of the final exam was used as an indicator of overall residual effects of the implemented small-group and PBL tutorial activities to the students' performance. The results of the three short-essay assignments (details below) were used to evaluate

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the effectiveness of the active-learning experience and environment on student performance.

At the end of each course module, a brief online survey was conducted to collect data regarding the students' learning experience and learning environment. Hounsell (2009) suggested a total of four methods to obtain feedbacks from students: (1) questionnaire and pro forma surveys; (2) focus groups; (3) email messages and web boards; and (4) student–staff liaison committees. In this study we combined two of the above methods in data collection, namely short questionnaires posted on the course website (Blackboard®; Blackboard Inc., Washington DC, USA). The frequency of student surveys via questionnaire on the Blackboard® site was an important consideration. Handelsman et al. (2007) state that 'effective assessment informs instructors how students are progressing toward learning goals while the leaning is occurring'. Hence, the outcome of frequent student surveys via questionnaire could provide high-resolution data regarding students' progress throughout the semester. However, Hounsell (2009) has indicated that 'overenthusiastic canvassing of student opinion in some universities has led to "questionnaire fatigue"'. To maintain a balance between adequate data resolution and student questionnaire fatigue, one questionnaire was conducted for each module, resulting in one student survey every four weeks during the term (Figure 1). Each questionnaire was formatted as a short online questionnaire with only six

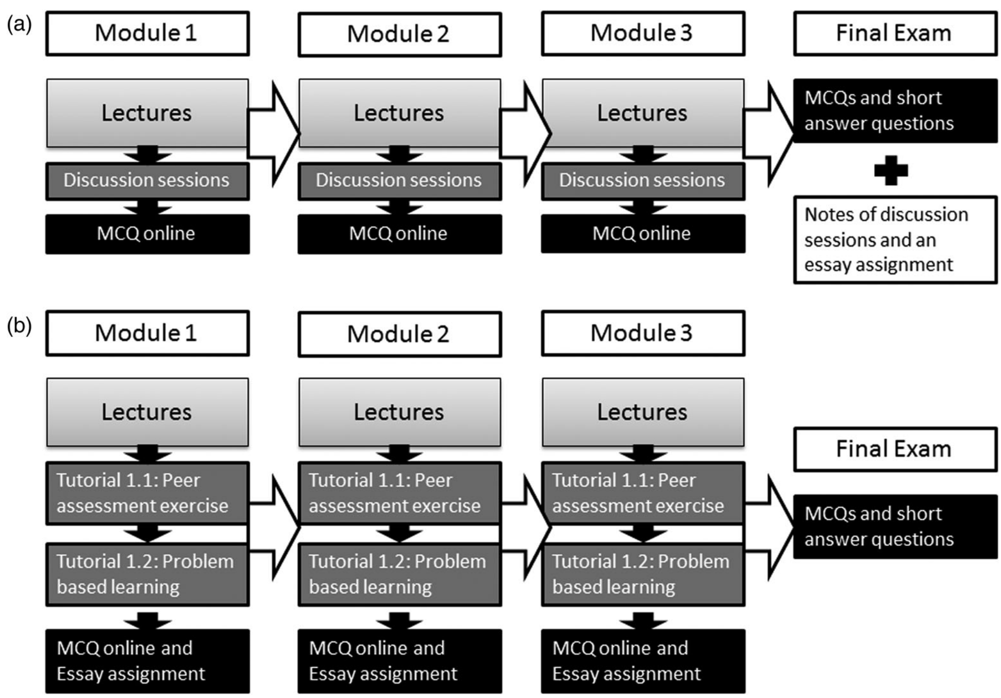

Figure 1. Conceptual diagram showing the structure of lectures, tutorial sessions, assignments and the final exam for AGRC1031 in (a) 2013 and (b) 2014

multiple-choice questions such that the questionnaire fits within a single screen for most computers or tablets (Table 1).

The major limitation of a questionnaire as a data collection tool is that it can provide only the information requested (Filene, 2005). As a result, each question must be expressed as concisely and directly as possible and response options provided in a quantifiable format. Ten levels of scale (1–11) were utilised in the student surveys for this study because data along a 10-level scale could provide reliable, fine resolution of students' feelings and experiences (Alwin, 1997), and data were easily converted into comparable values with the outcomes of the short-essay assignments, which were marked out of 10 possible points. In detail, questions 1 and 2 of the questionnaire were designed to evaluate students' learning experience, particularly with respect to deep learning; questions 3, 4 and 5 were focused on evaluating students' perception of the learning environment; and question 6 aimed to evaluate students' overall impressions of the tutorial sessions. The results of questionnaires were stored on the course Blackboard® server, which allowed us to extract the questionnaire data while maintaining the privacy of students who participated in the study. To compensate for the limitation associated with the close-ended style of the in-semester questionnaires, end-of-semester student course evaluations overseen by the Teaching and Educational Development Institute (TEDI) at the University of Queensland were utilised for the present study. The TEDI end-of-semester course evaluation contained both quantifiable close-ended questions as well as open-ended questions.

Data Analyses

Collected data were analysed with respect to student learning as quantified by students' academic performance and responses to questionnaires, and the inter-relationship between students' perception of the learning experience and students' academic performance in lower- or higher-order of cognitive skills. A baseline assumption of this study is that students were not overly familiar with critical thinking and the application of new knowledge to solve problems at the beginning of the course. Essay assignment scores were treated as the potential mark of student learning outcomes as the

Table 1. Online student learning experience questionnaire used in AGRC1031 in 2014

Question	
Q1:	During the tutorials, did you apply what you learned in lectures/materials to form your answer/opinion?
Q2:	Did the peer assessment exercise improve your understanding of the subject?
Q3:	Did the peer assessment exercise encourage you to interact more with other students in the class?
Q4:	Did the tutors and lecturers engage with you to generate a good discussion?
Q5:	Were the tutorials a friendly environment in which you felt comfortable asking questions?
Q6:	Overall, was your experience in the tutorial sessions satisfactory?

assignments allowed unlimited access to the published literature and students were allocated a substantially greater length of time to complete essay assignments relative to the questions posed on the course final exam. Data from the online surveys were transformed to non-dimensional scores using a principal component analysis (PCA) (AlHagwi, Kuntze, & van der Molen, 2014). The two highest-scoring dimensions as calculated by PCA were designated principal components 1 and 2, respectively, and the scores of the principal components were treated as indicators of trends in student-learning experience and learning environment.

Differences in survey outcomes by modules were tested using a one-way ANOVA and mean values were compared using Tukey's honestly significant difference (HSD) test at a criteria of $p = .05$. The distribution of questionnaire responses and earned marks on the essay assignments were examined following transformation by multiplying the fraction of the distribution by individual scores; data transformation facilitated illustration of the distribution of students' experience and density of observations in a single dimension of scale. This method of transformation is frequently used to describe the performance of fertiliser granules or pharmaceuticals (e.g. Shoji, Gandeza, & Kimura, 1991). The transformed scores were then compared using Pearson's correlation test. Module effects on essay assignment marks were tested using a one-way ANOVA with Tukey's HSD test at $p = .05$. Statistical analyses were performed using Minitab v.16 (Minitab Pty Ltd, Sydney NSW).

To assess the impact of tutorial-session implementation on students' academic performance, the mean student score on the final course exam in 2012 and 2013 was compared with the final exam results obtained in 2014. The students' outcomes from 2012 and 2013 were combined for comparison to 2014 data because the course structures, including predominantly passive-style practical sessions, were the same in 2012 and 2013. To overcome differences in the distribution of marks between multiple-choice and short-answer questions on each final exam, data were transformed to per cent achievement of total possible marks in each section before performing statistical analyses. The present study assumed that students would become increasingly familiar with the application of new knowledge to solve problems or analyse a given scenario as the teaching term progressed. Further, all three tutorial modules possessed the same structure of small-group and PBL activities followed by instructor-facilitated discussion.

Results

Outcomes of PCA described a total of 56% of the overall trends observed within the survey results, with principal components 1 and 2 describing 32% and 24% of observed trends, respectively. Principal component 1 did not separate trends by module, which indicates that the most dominant trends in the outcomes of the student learning surveys were consistent regardless of the course module (Figure 2). In contrast, principal component 2 showed significant separation between the outcomes of module 1 from those of the other two modules. Further correlation analysis between the values of principal component 2 and ratings obtained on student

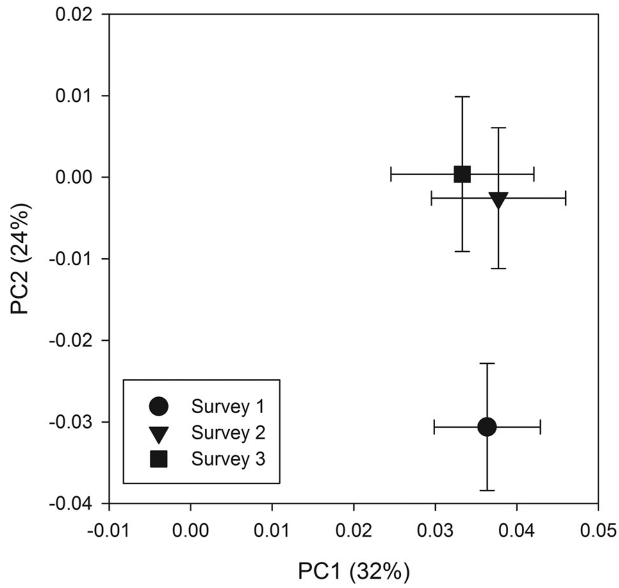

Figure 2. Results of principal component analysis of student learning survey results. Principal components 1 (PC1) and 2 (PC2) explain 32% and 24% of the variation in survey results, respectively. Each error bar indicates one standard deviation from the mean

questionnaires showed that principal component 2 was positively correlated with survey questions 2 and 3 ($p < .01$), which represented the learning experience and the learning environment with specific reference to peer-review activities. This result indicates that students in AGRC1031 were unfamiliar with or uncomfortable performing small-group peer-learning-type exercises at the beginning of the term. This result is consistent with the majority of university lectures being delivered using traditional passive lecture styles with minimal opportunity for students to participate in small-group peer-learning of PBL activities. The separation of module 1 tutorial sessions from the remaining course module tutorials by principal component 2 also indicates that students overcame any unfamiliarity or discomfort with peer-review activities prior to the module 2 tutorials (Figure 2).

Essay assignment scores significantly increased as the course progressed (Figure 3). The mean score for the module 1 critical-thinking essay assignment was the lowest of the three essay assignments at 7.9 out of 10. This is likely a reflection of students' general lack of experience applying new knowledge. The mean score for the module 2 critical-thinking essay was 6.3% higher than that for the module 1 essay, and the average score for the module 3 critical-thinking essay further increased by 9.5% relative to the module 2 essay mean score. The consistent increase in mean essay score from the module 1 to module 3 essay assignments clearly illustrates students' increasing proficiency applying new knowledge to critically analyse a given scenario.

The mean total score on the course final exam increased by 20% in 2014 compared to mean final exam scores in 2012 and 2013 (Figure 4(a)). The proportion of students

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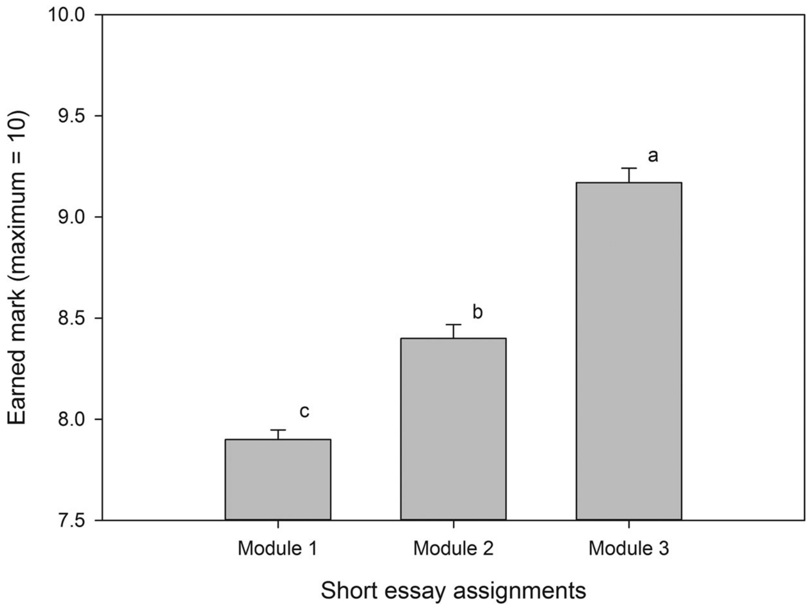

Figure 3. Mean student scores on each of three essay assignments. Error bars indicates one standard deviation from the mean. Different letters indicate statistically significant difference at $p = .05$ based on Tukey's HSD test

failing to achieve a passing mark of 50% or greater on the final exam decreased from 49% in 2012–2013 to 18% in 2014. In 2014, the mean score for the multiple-choice questions on the course final exam were 18% higher than in previous years (Figure 4(b)), whilst the mean score for the short-answer questions increased by 23% in 2014 compared to 2012–2013 (Figure 4(c)).

The first quartile of distribution of student scores on the 2014 final exam was 55%, which represents a 25% improvement compared to final exam results in 2012–2013; however, the distribution of exam scores was wider in 2014 relative to previous years. The first quartile mean final exam score increased by only 10% in 2014. In contrast, the third quartile final exam score increased by 30% in 2014 compared to 2012–2013. The wider distribution of final exam marks in 2014 indicates that the effects of implemented changes in tutorial sessions differed as a function of the students' relative performance within the cohort (e.g. first or fourth quartile distribution based on progressive assessment items). The substantially greater increase in third quartile final exam scores in 2014 relative to 2012–2013 is consistent with previous studies indicating that active learning in large courses typically increases exam marks of students with cumulative scores on progressive assessment in the lower half of the class, resulting in a significantly lower rate of student failure (Anderson et al., 2005; Freeman et al., 2014; Mats et al., 2012).

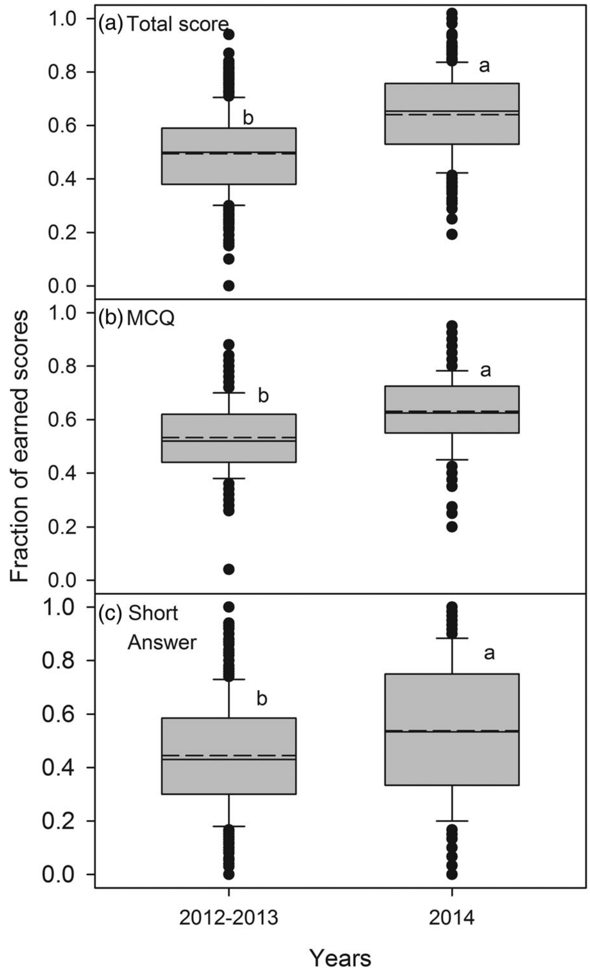

Figure 4. Students' performance on the course final exam: (a) total score; (b) multiple choice questions (MCQs); and (c) short answer questions. Different letters indicate statistically significant difference at $p = .05$ based on Tukey's HSD test

Discussion

Overall, the students' perceptions of the learning experience, learning environment and small-group PBL activities were largely positive throughout the term (Table 2). On average 76% of students responding to the surveys indicated that the learning activities undertaken in tutorial sessions was useful (score 6–11). This is similar to the results obtained by Sandall, Mamo, Speth, Lee, and Kettler (2014), who reported 82% positive feedback from students with respect to active-learning exercises. Students provided a great deal of positive feedback concerning the AGRC1031 active-learning tutorials in TEDI-administered course evaluations. Representative comments from students include 'The tutorials were very helpful and encouraged class discussion which helped to broaden my knowledge and see topics from different

Table 2. Summary of learning experience survey outcomes

	Module 1 ($n = 79$)			Module 2 ($n = 60$)			Module 3 ($n = 57$)		
Questions	Mean	Median	SD	Mean	Median	SD	Mean	Median	SD
1	8.4	9	2.2	7.3	7	2.2	7.5	8	2.2
2	7.1	7	2.6	7.0	7	2.4	7.5	7	2.5
3	7.3	8	2.5	7.2	7	2.2	7.5	8	2.8
4	8.6	9	2.4	8.6	9	2.0	8.5	9	2.4
5	8.4	9	2.7	8.2	8	2.4	8.2	9	2.8
6	8.5	9	2.4	7.7	8	2.6	8.3	9	2.5

Note: The possible range of score for each question was 1–11.

perspectives', and '[t]utorials were relatively engaging, allows students to take part in the activity than just passive lessons being taught'. In this regard, the active-learning education intervention successfully provided students with a high-quality learning experience and learning environment.

A particularly interesting result from the learning experience questionnaires related to question 6, which gauged students' overall impression of the course tutorials. The distribution of question 6 responses on the module 1 questionnaire was more strongly positive than the question 6 responses for modules 2 and 3. One plausible explanation is the 'wow factor' associated with a novel tutorial experience. Alternately, the slightly less positive responses to question 6 in modules 2 and 3 learning surveys may be a sign of questionnaire fatigue as mentioned by Hounsell (2009), as the same survey questions were used at the end of each course module.

Results of the present study indicate that a repeating format of small-group PBL activities and critical-thinking essay assignments can improve student learning outcomes in the short term, as indicated by academic performance. The observed increase in essay assignment scores as the course progressed (Figure 3) most likely resulted from repeated experiences applying new knowledge in tutorial sessions, easing the perceived challenge and improving students' proficiency with critical evaluation and expression of ideas using evidence-based logical support in essay assignments. The conduct of all tutorial sessions using the same format for each module allowed students to further develop higher-order cognitive skills, which was reflected in the mean 21% improvement in students' final course exam marks compared to the average of previous years' final exam marks. This observed improvement in AGRC1031 student scores is more than three times the 6% increase seen following implementation of active-learning exercises based on meta-analysis of 225 studies (Freeman et al., 2014). The essay assignments had a particularly positive impact on students' learning experience. Comments related to the essay assignments recorded in the TEDI-administered course survey included 'I found the essays challenging and rewarding (I loved the content we had to address for each)', and '[t]he essays were a large driver of content and very helpful in allowing the content to be understood'. The positive feedback from students regarding higher-order cognitive skills is similar to outcomes reported by Anderson et al. (2005).

The repeating small-group PBL activities improved students' capacity to critically assess scenarios or statements, as evidenced by both the improvements in essay assignment marks during the teaching term and the improved mean final exam scores compared to previous years. Hoffman, Hosokawa, Blake, Headrick, and Johnson (2006) demonstrated that when implementing a new teaching approach or environment at least three repetitions are required before differences in students' performance become apparent. Hoffman et al. (2006) treated all active-learning activities in a semester-long course as one activity and measured the effects on different student cohorts over multiple years, whereas the duration of active-learning activities in the present study was four weeks and was repeated using the same activity structure on a single student cohort within a single semester. Despite the difference in study formats, the results of the present study show a similar trend to Hoffman et al. (2006); the positive impacts of active-learning tutorial sessions on essay assignment performance lead to significantly improved student scores on the final course exam. More importantly, the repeating format of small-group PBL activities in the present study appeared to accelerate the improvement in learning outcomes relative to that reported by Hoffman et al. (2006).

The greatest effects of the short-term repeating small-group PBL activities were largely limited to students whose cumulative marks placed them within the middle of the distribution representing academic performance. In this study, students within the upper second and third quartile distributions exhibited overall course marks 20–30% better compared to the previous years' students. This result is similar to the findings of Anderson et al. (2005) and Mats et al. (2012), who demonstrated that the students whose performance placed them within the lower to middle portions of the score distribution obtained a significantly higher score on the course final exam material was delivered using a team-based learning method. The proportion of students who failed AGRC1031 was reduced from approximately 49% to 18%, which is consistent with the mean failure rate of 22% observed in a meta-analysis of STEM (science, technology, engineering and mathematics) education (Freeman et al., 2014). Evaluating improvements within the fourth quartile of students (top 25%) is challenging as these students are typically highly adaptable to different teaching styles, with a high level of motivation and interest in the subject matter. In addition, there is no course mark higher than grade 7 (≥85% achievement).

Overall, the small-group PBL activity format employed in tutorial sessions appeared to motivate students to employ higher-order cognitive skills, resulting in deeper learning to produce improved performance in assessments. The use of higher-order cognitive skills to facilitate deep learning improves the retention of fundamental information, such as new technical terms and theoretical concepts, as well as a contextual understanding of new knowledge. Enhanced retention of fundamental information was illustrated by the significantly higher scores for the multiple-choice questions on the course final exam in 2014 relative to that for the previous years (Figure 4(b)). There are several plausible explanations for this outcome based on

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situational and descriptive evidence that likely all contributed to the observed improvement in learning outcomes. First, there were three fewer 1-hour lectures delivered in 2014 than 2012–2013 as a result of removing course content that overlapped with other courses. Thus, students were expected to master marginally less course content for the final exam in 2014. Nevertheless, numerous new technical terms and concepts were presented in this first-year course and several students verbally expressed dismay concerning the quantity of new information during in-class discussions. The more likely explanation for the improved learning outcomes is the students' increased familiarity with new information as a result of discussion and interaction with other students centred on the application of new knowledge during course tutorial sessions. New information was concomitantly presented in course lectures and in tutorials, where key concepts were highlighted using small-group PBL activities. The process of teaching one another during peer-learning activities allowed students to exploit the inherent benefits of verbalisation and questioning as well as practice numerous meta-cognitive skills associated with information delivery (Hartman, 1990; Sternberg, 1985).

Conclusions

This study demonstrated that it is possible to enhance students' critical-thinking skills and for students to successfully apply these skills to analyse and evaluate new information within a relatively short period of time. The results reported herein showed a significant increase in student academic performance between the first and second essay assignments, the latter of which was assessed only 2 months following initial exposure to a small-group PBL tutorial environment. The consistent format of active learning tutorials throughout the teaching term coupled with a gradually increasing requirement for higher-order cognitive processing such as synthesising ideas, making inferences and analysing and evaluating alternatives likely contributed to the rapid improvement in students' academic performance. The outcomes of the present study support the concept that given opportunity and an appropriate learning environment, it is possible to facilitate students' development of higher-order cognitive skills as well as meta-cognitive skills in large, introductory courses. The small-group PBL activities undertaken during AGRC1031 tutorial sessions fostered the development of higher-order cognitive skills, equipping these students with essential skills to perform well in subsequent university science coursework and employment-related tasks.

The present study provides an example of how the action-learning approach described in Dilworth (2003) can be employed to systematically improve undergraduate course curricula and better prepare students for critical thinking, problem solving and decision-making tasks. The outcome of this study provides further evidence that implementation of action-learning methods such as small-group and PBL activities improve both student performance and students' perception of teaching quality in large introductory science courses, despite lecture materials strongly weighted towards lower-order cognitive processes such as memorisation. The implementation of repeated small-group PBL activities in tutorial sessions (approximately 60 students per session) permitted effective interactions among students in both small- and large-group exercises and between students and instructors. Although reducing the class size increased the resource and time commitment for the course, the improved learning outcomes demonstrate that the implementation of small-group PBL activities in tutorials was an effective use of teaching resources.

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No potential conflict of interest was reported by the authors.

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