The Use of Peer-Assisted Learning to Enhance Foundation Biology Students' Understanding of Evolution

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Abstract

Peer-assisted learning (PAL) promotes improved skills across a variety of disciplines, and may enhance students' understanding of conceptually difficult ideas. The effect of group size in promoting learning of such concepts, either in quantitative or qualitative terms, is also an area of interest. This study aimed to investigate the comparative value that foundation biology students placed on paired versus quad PAL activities, and both their perceived and actual understanding of plant and animal evolution, following such activities. The activities were structured and scaffolded over a four week period, with paired groups (dyads) merging into quads, and with students being surveyed over that period. Students reported that discussions with their lab partners helped improve their understanding of plant and animal evolution, and the majority valued quad over dyad PAL. Additionally, the PAL intervention had a positive impact on students' examination results, compared to the previous year's baseline cohort. Our findings indicate that in the design of group learning activities, particularly those related to threshold concepts, educators should give due consideration to several factors. These are group size, activity scaffolding and sequencing, and the structure and types of post-activity questions that seek to catalyse reflection, discussion and the development of deep knowledge.

Background

Learning has both individual and social contexts, and although an individual phenomenon, it can be promoted through various catalysts. These include students' interest, aspiration, and past experiences (Kuh, Cruce, Shoup, Kinzie, & Gonyea, 2008), and the environments and people that influence these, such as family, friends and peers (James, 2012). While some students are independent learners, a considerable body of literature has shown the value of social and collaborative learning in promoting more accurate understanding generally and in particular for difficult concepts, across a range of science disciplines (Barkley, Cross, & Major, 2014; Jeong & Chi, 1997). Social learning can be defined as collaborative, supplemental or peer-assisted learning (PAL), which in broad terms is the acquisition of knowledge and/or refinement of skills through active assistance among students in a group (Topping & Ehly, 1998). The benefits of PAL in enhancing more accurate learning have been reported across a range of disciplines (Kieran & O'Neill, 2009; Springer, Stanne, & Donovan, 1999; Topping, 2001), and it has been shown to have considerable value for less capable students (Huynh, Jacho-Chavez, & Self, 2012). PAL also promotes generic skills (McMaster, Fuchs, & Fuchs, 2006), including problem-solving (Johnson & Johnson, 1990; Slavin, 1992). Further, peer collaboration through engaging in explanation enhances student learning (Astin, 1993; Springer, Stanne, & Donovan, 1999), and overall group learning (Webb, Troper, & Fall, 1995). The approach of using small, cooperative learning groups can be very effective in large enrolment, foundation year subjects, as students feel less anxious and are more prepared to voice their ideas (Allen & Tanner, 2005).

Social learning may also have value in promoting students' understanding of threshold concepts, which can be defined as new and previously inaccessible ways of thinking about something (Meyer & Land, 2003). Such concepts are often abstract in nature, can be difficult to teach, and may consequently be difficult for students to understand. However, a correct understanding of such concepts can be transformative in that it may provide an effective pathway to related, higher order and more conceptually difficult concepts (Taylor, 2006). The traditional approach to teaching threshold concepts in many science disciplines has relied largely on surface learning or memorisation of facts and content (e.g. Atherton, Hadfield, & Meyers, 2008), without the development of deeper understanding and higher order learning skills, which are longer lasting and thus the more preferred outcome of learning. This calls for the development of new ways of teaching and understanding threshold concepts, including the possible use of techniques such as peer-peer interaction.

An example of a biological threshold concept is evolution, which is a common component of senior secondary and undergraduate foundation biology curricula. A correct understanding of evolution and its mechanisms is necessary for subsequent studies in fields such as ecology, genetics, and molecular biology (Beldade, Mateus, & Keller, 2011). In fact, Shtulman and Calabi (2012) argue that students' "acceptance of evolution is crucial to the long-term advancement of scientific literacy and scientific reasoning" (p.58). Entwistle (2008) argues that an understanding of evolution is transformative in the way that students observe biology, and thus requires a sophisticated integration of knowledge within the discipline. Despite this, Lawson, Alkhoury, Benford, Clark, and Falconer (2000) consider students' conceptual framing of evolution to be hypothetical, as its teaching uses "exemplars that cannot in practice be observed due to limits on the normal observational time frame" (p.996). Perhaps because of this, and despite the importance of correctly understanding evolution, a high proportion of students exhibit gaps or misconceptions about it, both before commencing university and upon graduation (Burke da Silva, 2012; Nelson, 2012). Such deficits commonly relate to natural selection (Gregory, 2009), genetic drift (Andrews et al., 2012), macroevolution (Catley & Novick, 2009) and tree-thinking (Baum, Smith, & Donovan, 2005).

Enhancing students' understanding of conceptually-difficult concepts can be achieved using a range of strategies, including animation (Lee & Yeap, 2009), simulation (Treen, Atanasova, Pitt, & Johnson, 2016), student-generated videos (Kuchel, Stevens, Wilson, & Cokley, 2014), intensive, scaffolded workshops (Male & Baillie, 2011), and PAL (Topping, 2001, 2005). The use of PAL for such has been explored in science disciplines such as chemistry (Lewis & Lewis, 2005; Tien, Roth, & Kampmeier, 2002) and physics (Barkley, Cross, & Major, 2014). In the biological and biomedical sciences, the effectiveness of PAL has been investigated for complex concepts in anatomy and physiology (Hughes, 2011), microbiology (Tariq, 2005), in broad curricula such as first year biology (Downs & Wilson, 2015) and in clinical medicine (Field, Burke, McAllister, & Lloyd, 2007). However, little research appears to have been carried out into the use of PAL to enhance students' understanding of evolution. Another area related to PAL is the potential effect of group size as a determinant of student learning: for example, Bacon (2005) commented on the unresolved nature of the effect of group size on peer learning. A crucial question that links these two areas therefore is: what group size maximises the effectiveness of PAL activities on student learning, particularly with respect to difficult threshold concepts such as evolution?

As a consequence of the above-described issues and questions, this study broadly aimed to investigate the effectiveness of PAL in enhancing foundation year biology students' understanding of evolution. More specifically, the study aimed to (i) compare student preference for either small (dyad) or large (quad) PAL group size; (ii) determine whether PAL improved students' perceived and actual understanding of plant and animal evolution; (iii) determine whether there was a differential effect of the PAL intervention on less capable compared to more capable students, based on ATAR (Australian students' tertiary admission rankings: Dobson & Skuja, 2005).

Methods

Study participants were students at Monash University (Clayton campus) undertaking a foundation year biology unit (herein 'BIO1011') over 12 weeks from March to May, 2011 ($n_{initial}$ =993). PAL was introduced as a structured and iterated component over four weeks (7-10) of the semester (Figure 1). Over this period, the curriculum had a blended structure, with prescribed textbook readings set as pre-class learning for subsequent lectures and practical activities (Figure 1). Students also undertook a weekly pre-lecture formative assessment, which tested their understanding of the prescribed readings and their preparedness for the corresponding lecture. This combination of resources and assessment prepared students for the practical activities, and had the additional benefit of addressing differences in prior learning among students, since approximately 40% of them had not undertaken senior secondary biology studies.

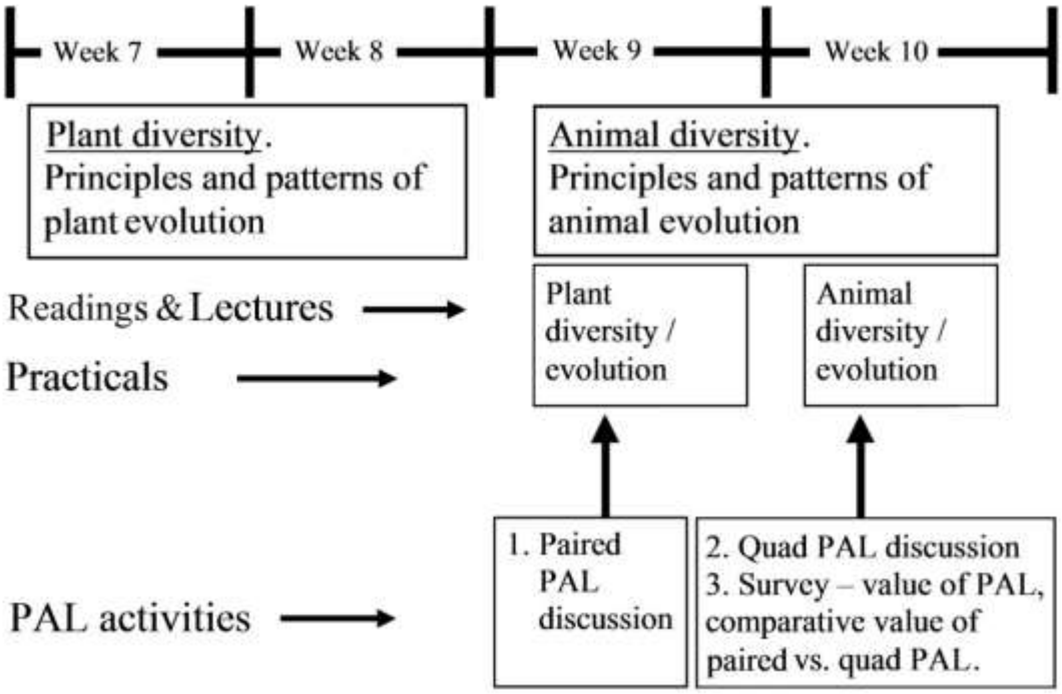

Figure 1: Timeline of foundation year biology (BIO1011) evolution lectures and readings, together with associated practical and PAL activities.

During week 9 of semester, students undertook a practical activity on the evolution of terrestrial plants, and then participated in a paired PAL task where they were asked to discuss and formulate answers to five open-ended questions about plant evolution (Table 1A). This first PAL activity was carried out in pairs for reasons of simplicity and familiarity, as students had previously worked as pairs (dyads). In week 10, the dyads coalesced to form quads (groups of four), based purely on geographical location in the laboratory, thus preventing bias in group formation by eliminating the opportunity for students to choose to be with their friends or acquaintances. After a practical activity on the evolution of marine and terrestrial animals, each quad was asked to discuss and formulate answers to four open-ended questions about animal diversity and evolution (Table 1B). The primary aim of each PAL activity was to provide students with opportunities to ask contextual questions, engage in discussion and through these, resolve misconceptions, without tutor moderation or intervention.

On completion of the quad PAL activity, students were surveyed about their perceptions of (i) the value of PAL in enhancing their understanding of evolution, and (ii) the differential value of dyad versus quad peer groups in mitigating such understanding. Student responses to survey questions were based on a five-point Likert scale, from strongly disagree (1) to strongly agree (5). Incomplete surveys were excluded from consideration. The survey was administered under Monash University Human Ethics permit CF10/1517 – 2010000819. All analyses were undertaken using Microsoft Excel™.

Table 1: Foundation year biology (BIO1011) open-ended questions associated with post-practical PAL activities

A. Plant Evolution
1. Briefly summarize your present understanding of evolution (use these plant groups you studied today as a basis if it will help).
2. Present four major steps in the evolution of land plants, from ‘bryophytes’ through to ‘angiosperms’.
3. What aspects of plant evolution do you find puzzling or problematic?
4. What questions about plant evolution remain unanswered?
5. What are the three most important things about plant evolution that you would tell someone?
B. Animal Evolution
1. Discuss what you know about evolution (consider your lectures, readings and pracs).
2. How would you explain how animals have evolved?
3. Are there aspects of animal evolution (or evolution in general) that you find puzzling or problematic?
4. What are the three most important things about the evolution of animals that you would tell someone?

In order to determine the potential positive impact of this PAL intervention on students’ actual understanding of plant and animal evolution, exam results of the 2010 cohort for BIO1011 (prior to the intervention) were compared to those of the 2011 cohort (post-intervention) for six relevant multiple choice questions. The 2010 cohort was used as a baseline, and standardized to exclude students who did not undertake the two laboratory practicals (n=917). The 2011 cohort was standardized to omit repeating students, and the exam results of all students who missed the PAL intervention or did not participate in the survey were likewise excluded from analyses (n_{final}=820). The PAL-assessed cohort consisted of 319 males and 501 females of roughly comparable age, with <5% being mature-age students.

A T-test of the ATARs for each of the 2010 and 2011 cohorts indicated no significant difference between them (T=0.35, p=0.57), thus demonstrating their academic equivalency. All conditions were equal between the two cohorts, apart from the PAL activities in weeks 9 and 10 of the 2011 teaching semester. These conditions included the blended structure of the curriculum and the exam questions for 2010 and 2011, which were identical in terms of wording and sequence (Table 2). The six exam questions related specifically to processes, content and/or concepts covered in the post-practical dyad and quad PAL discussions (Table 1). Students in both cohorts did not have access to any prior year exam papers.

Table 2: Foundation year biology (BIO1011) exam questions associated with post-practical PAL activities

Question	Distractors
1. Of the following plant groups, which one comprises species that are NOT vascular?	Gymnosperms; Mosses; Ferns; Angiosperms
2. Double fertilisation is a unique feature of:	Ferns; Bryophytes; Gymnosperms; Angiosperms
3. Plant spores germinate and give rise to:	Sporophytes; Gametes; Gametophytes; Zygotes
4. Which one of the following statements regarding the evolution of terrestrial animals is MOST correct?	Amphibians were able to exploit the surface of the earth because they evolved an air-breathing lung; Land vertebrates evolved from fish that could support their body weight on their arms and legs; The development of a water proof skin is known to occur in the first reptiles; The first reptiles, defined as having an amniotic egg, can be identified in the fossil record because they have an amniotic egg
5. The ultimate source of variation in traits among individuals in a population is:	Genetic mutation; Changes in the environment; Differences in reproductive success; Sexual reproduction
6. Two frog species (A, B) have ranges that are mostly separate, but overlap slightly. Species A males from populations outside the area of overlap have a mating call similar to that of species B males from outside the area of overlap. But males of the two species from the area of overlap have mating calls that are much more distinct from each other. This differentiation of calls is an example of:	Hybridization; pre-zygotic reproductive isolation; post-zygotic reproductive isolation; parthenogenesis

To test the potential differential effect of the PAL intervention on less capable compared to more capable students, we compared the mean percentage increase from 2010 to 2011 in correct answers for these six questions, for each of the lowest and highest ATAR quartiles (n_{2010}=220, n_{2011}=188). Student ATARs calculated by the Victorian Tertiary Admissions Centre were extracted from university records. There was no significant difference in mean ATAR between the 2010 and 2011 cohorts for lowest quartile students (T=0.3, p=0.26). There was a small, but significant difference for highest quartile students (T=0.9, p=0.04), with mean ATARs being 95.9 ± 0.2 and 95.5 ± 0.15 for the 2010 and 2011 cohorts respectively.

Results

Post-practical dyad and quad group PAL discussions

Students highly valued the effectiveness of post-practical discussions, with regard to their perceived understanding of plant and animal evolution. When asked for their response regarding, "To what extent do you agree with the following statement? 'Discussions with my lab partner(s) helped improve my understanding of plant and animal evolution'", 75.4% of students agreed or strongly agreed in relation to plant evolution. Similarly, 75.8% of students agreed or strongly agreed in relation to animal evolution. There were no significant differences in the levels of Likert-scale agreement comparing plant and animal evolution (3.97 $\pm$ 0.03 versus 4.00 $\pm$ 0.03). For plant evolution, 6.4% of the students disagreed or strong disagreed with the statement, and 18.2% were neutral. For animal evolution, these values were 5.5% and 18.7% respectively.

Similar results were found regarding the relative importance of group size on its perceived value in enhancing students' understanding plant and animal evolution. When asked for their response to the question, "To what extent do you agree with the following statement? 'Larger group (4-5) discussions were more beneficial to my understanding of evolution than with my lab partner(s) (2-3)'", 74.9% of students agreed or strongly agreed in relation to plant evolution, and 75.3% for animal evolution. Again, there were no significant differences in the levels of agreement when comparing plant and animal evolution (4.03 $\pm$ 0.03 versus 4.06 $\pm$ 0.03). For plant evolution, 5.8% of the students disagreed or strong disagreed with the statement and 19.3% were neutral. For animal evolution, it was 5.3% and 19.4% respectively.

Effect of the PAL intervention on students' actual understanding of plant and animal evolution

There was an improvement in students' performance for five of the six BIO1011 exam questions that related specifically to the PAL intervention, comparing the 2010 and 2011 cohorts (Figure 2). Q1 (plant vascularization) and Q2 (plant fertilization) had a high percentage of correct answers for both the 2010 and 2011 cohorts, with net increases of 1.0% and 5.0% correct answers respectively. Although the overall percentage correct answers were lower than for Qs 1 and 2, there were similar increases of 1.1%, 4.1% and 5.3% respectively for Q3 (plant germination), Q5 (animal reproduction) and Q6 (animal differentiation), comparing the 2010 and 2011 cohorts (Figure 2). For Q4 (animal diversity), which had the lowest percentage of correct answers of all six questions, there was a *decrease* of 8.5% for correct answers from 2010 to 2011 (Figure 2). The overall percentage increase of correct answers from 2010 to 2011 for the three plant evolution and the three animal evolution exam questions was 7.1% and 0.9%, respectively. For all six exam questions as a whole, there was a rise in correct answers from 53.5% to 54.8%.

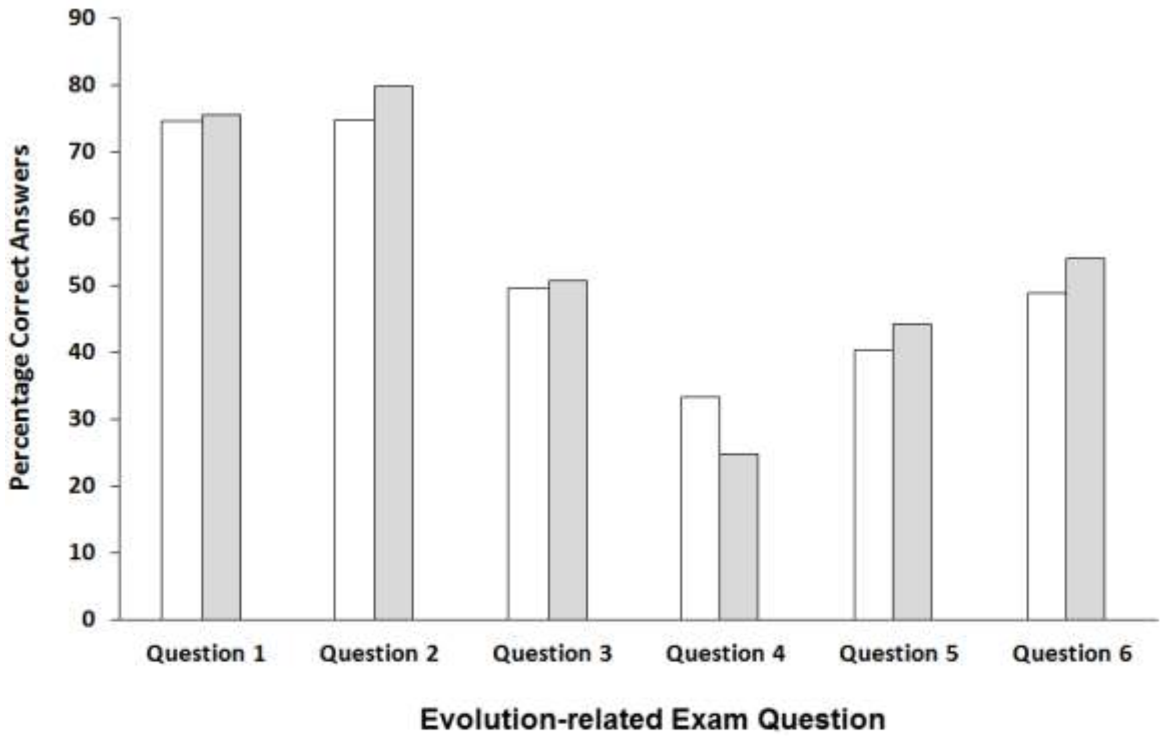

Figure 2: Comparison of student academic performance on six evolution-related exam questions for BIO1011, in 2010 and 2011. White columns indicate percentage correct answers for 2010 exam questions (n=917), grey columns the corresponding results for 2011 (n=820). Exam question number is as indicated per Table 2.

The average percentage increases in correct exam question answers from 2010 to 2011, for the lowest versus highest ATAR quartiles, were 4.8 ± 2.1% and 2.5 ± 1.1% respectively (mean ± standard error). The difference between them was not statistically significant (T = 0.75, p = 0.08). In terms of individual exam questions, for the lowest quartile, there was a 0.6% *decrease* in correct answers for Q1, a 9.9% increase for Q2, a 1.8% *decrease* for Q3, a 4.8% increase for Q4, a 6.8% increase for Q5, and a 9.9% increase for Q6 (Figure 3A). For the highest quartile, there was a 0.9% increase in correct answers for Q1, a 3.2% increase for Q2, a 4.3% increase for Q3, a 0.8% *decrease* for Q4, a 6.4% increase for Q5, and 1.0% increase for Q6 (Figure 3B). For the lowest quartile students, the overall percentage increase in correct answers from 2010 to 2011 for the three plant evolution and the three animal evolution exam questions was 7.5% and 14.7%, respectively. For the highest quartile students, these increases were 8.5% and 6.5% respectively. The overall aggregate percentage increase for the six exam questions was 29% for the lowest quartile students, and 15% for the highest quartile ones (Figures 3A and 3B).

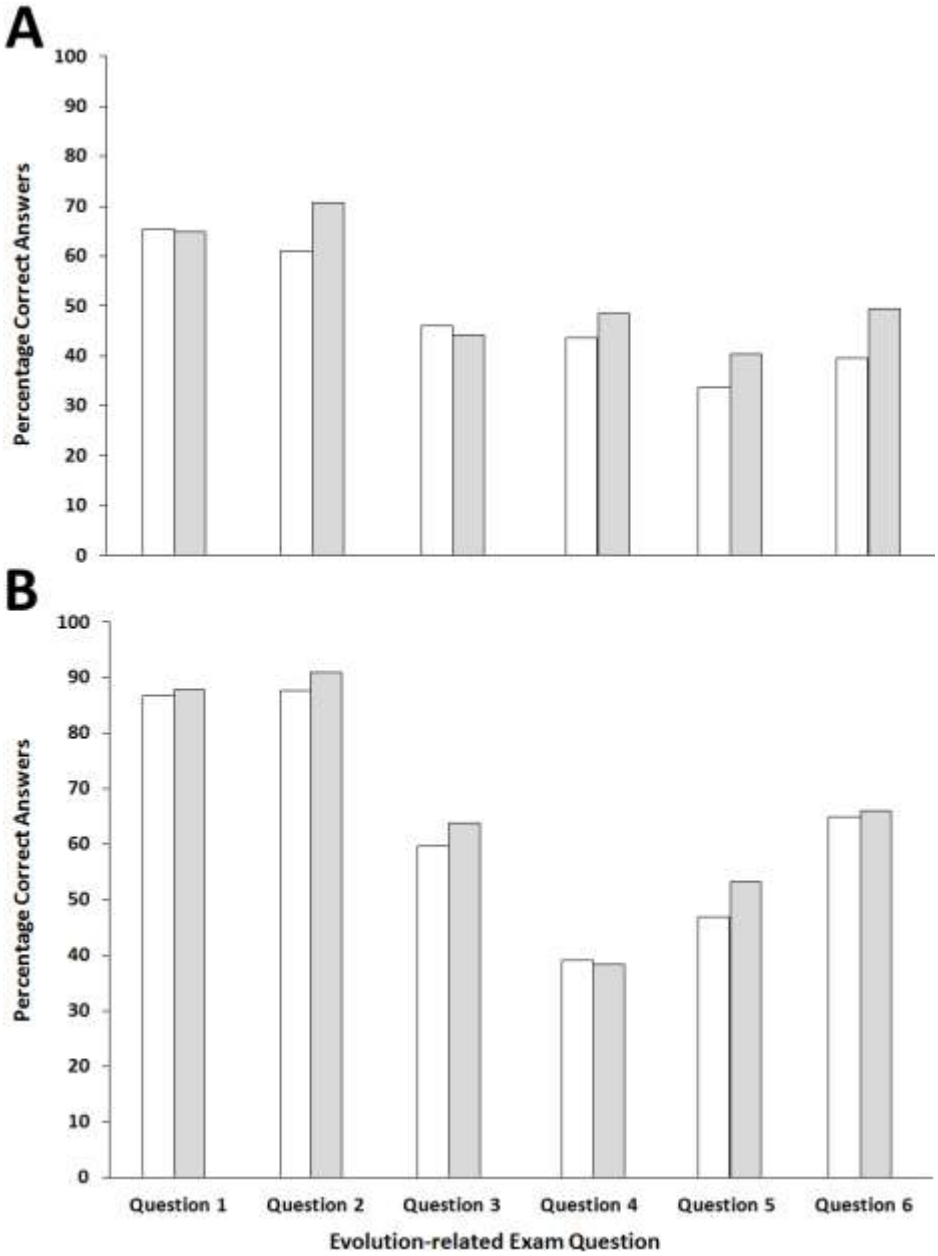

Figure 3: Comparison of (A) lowest quartile and (B) highest quartile ATAR students' academic performance on six evolution-related exam questions for BIO1011, for each of 2010 (n=220) and 2011 (n=188). All other indications are as for Figure 2.

Discussion

Students' perceived understanding of plant and animal evolution

Given that the considerable majority (~75%) of students reported an improved understanding of plant and animal evolution as a consequence of their discussions, we conclude that our PAL intervention supports other evidence regarding the positive effect of PAL and its alignment with the zone of proximal development (ZPD: Vygotsky, 1978). The ZPD states that more capable peers collaborate on specific curricular elements, and through this enhance their own understanding as well as that of the broader PAL group. The positive impact of the ZPD on biology undergraduates' learning has previously been reported by Wass, Harland and Mercer (2011) for critical thinking, and Harland (2003) for problem-based learning.

For the approximately 25% of students who did not believe the PAL intervention improved their understanding of plant and animal evolution had improved after the PAL intervention, there are two possible explanations. The first is that these students may have believed that they already had an accurate understanding of these aspects of evolution. In this case, such students may have previously studied evolution-related concepts in their senior secondary biology studies. The alternative explanation is that PAL discussions did not enhance these students' understanding of evolution, either due to prior knowledge, or lack thereof. For the latter group, further opportunities to refine and enhance their understanding of plant and animal evolution may be required, perhaps through additional PAL or targeted tutorial assistance.

The differential effect of group size on learning

Our results demonstrate the importance of PAL group size in promoting students' perceived understanding of evolution. On the one hand, group size must be large enough to enable sufficient diversity of ideas (Benson, Noesgaard, & Drummond-Young, 2001), but not so large that it inhibits group cohesion or the readiness of less confident students to provide an opinion or to discuss what they know. Our results are consistent with those of Treen, Atanasova, Pitt, and Johnson (2016), who reported that student performance increased in line with group size up to a maximum of five members. This is also supported by Kooloos et al. (2011), who reported that students favoured groups of five as being most effective for their participation. Beyond this, where a group comprises seven or more members, meaningful participation decreases, as members have difficulty in evaluating input (Hare, Blumberg, Davies, & Kent, 1994). Larger groups are also likely to become intimidating to individual contributions, and inhibit candid expression and interchange of knowledge and understanding (Kooloos et al., 2011). Although students strongly agreed that quad discussions were more valuable than dyad discussions in terms of their understanding of evolution, they were not asked to justify their response. We recognize this as a shortcoming of the study design and recommend that it be included in future research, given its potential value to make more informed inferences from such surveys.

At the lower end of group size, dyads are less likely to have at least one knowledgeable member, and a pair may thus flounder in articulating or resolving threshold concepts such as evolution. However, notwithstanding this, or the apparent broad consensus that a group size of 4-5 students is optimal, differences in subject discipline and/or the nature of the interaction among members may affect optimum group size, with dyads being more effective under certain circumstances. For example, Uribe (2002) found dyads to be the ideal group size for computer science students collaborating in an online task, which is consistent with the findings of Lou, Abrami, and d'Apollonia (2001) for this discipline. Regardless of the discipline or nature of the interaction, an ability to work effectively and productively in teams is highly valued by STEM employers (Rayner & Papakonstantinou, 2015), which demands that educators carefully examine group size in order to best align student learning with development of their teamwork skills.

We recognise a limitation in the design of the study to assess the potential impact of group size and prior learning. Ideally, the 2011 student cohort should have been stratified so that comparison of the perceived value of dyad and quad PAL discussions could have been undertaken in both weeks 9 *and* 10. However, this was not possible due to the potential inequity generated by different group sizes in each week. We hope that future research investigating the potential effect of PAL group size on students' understanding of threshold concepts will be able to overcome such design constraints.

Students' academic success relating to plant and animal evolution

In this study, the provision of appropriate content (e.g. lectures and readings), followed by small-scale assessments, subsequently reinforced by contextual hands-on practicals including peer discussions, was designed to refine and enhance student understanding of evolutionary processes and mechanisms. This approach of preparing students with readings and formative assessments has been shown to enhance learning outcomes, through improved performance on subsequent summative tests and exams (Rayner, 2008). The use of contexts in this way thus incorporated not only physical components, such as fossils or living or preserved plants and animals, but also had a social domain, through interactions and information-sharing among learners. It endorses the contention of Brown, Collins and Duguid (1989) that most learning is social, and it is the actual interactions among individuals that generates knowledge.

The observed improvement in students' actual understanding of most aspects of plant and animal evolution is encouraging, and addresses calls (e.g. Burke da Silva, 2012) for the integration of such modes of learning, where students construct and refine their knowledge through the asking of questions, identification of knowledge gaps, and peer-peer discussion. Our results are consistent with those of Minhas, Ghosh, & Swanzy (2012), who suggested that integrating active and passive forms of learning may have a greater impact than either method on its own. Therefore, our observed improvement in students' understanding of evolution may be related to their individual preferences about learning (Wehrwein, Lujan, & DiCarlo, 2007).

In regard to the overall cohort's decrease in performance for exam Q4 (evolution of terrestrial animals), it is possible that the lectures, readings and formative assessments were insufficient for students to develop a correct understanding of it. It is also possible that concepts relevant to this question were not adequately covered in the practical, and that misconceptions thus persisted and were perhaps even promulgated via post-practical discussions. As Nehm and Reilly (2007) have indicated, misconceptions about aspects of evolution may persist in the longer term, despite the known positive impact of active, collaborative learning approaches such as that evaluated in this study. Further, the evolutionary processes underlying this question are inherently difficult to understand, and students may require targeted tutorials or other interventions in order for them to develop a more accurate and deeper understanding of it. One final possibility is that the absence of tutor input in post-practical PAL discussions may have generated misconceptions about the evolution of terrestrial animals. Thus, there might be value in incorporating tutor or instructor input, via either post-practical discussions, or in an online forum related to this material.

The trend for less capable students to gain more from the PAL intervention compared to those who were more capable, while not statistically significant, suggests that the former group *may* gain proportionally more value from PAL. Our suggestion is consistent with other, albeit limited, research showing a greater benefit of PAL on less capable or knowledgeable students in a cohort (Huynh et al., 2012; Romero, 2009). Nevertheless, these limited findings, together an apparent broader lack of scholarly literature, call for further research on this topic. The decrease in percentage correct answers from 2010 to 2011 for Q1 (plant vascularization) and Q3 (plant germination) for the lowest quartile signposts which facets of evolution might be the focus of the targeted tutorials and interventions suggested above.

Conclusions

This paper investigated the impact of peer-assisted learning (PAL) on enhancing foundation year biology students' understanding of the threshold concept of evolution. We found that the majority of students preferred quad over dyad PAL, that the considerable majority perceived that PAL enhanced their understanding of evolution, and that the PAL intervention generally improved students' understanding of plant and animal evolution, as measured by their performance on relevant exam questions. The possibility that less capable students gain more from PAL than more capable students is both interesting and worthy of further research. Our findings emphasize the importance of appropriate curriculum design to maximise the value of group work on individual student learning, particularly for conceptually-difficult topics. Important factors to consider in designing PAL interventions thus include group size, the scaffolding and sequencing of learning activities, and the structure and types of post-practical questions that provide catalysts for reflection, discussion and refinement of student knowledge and understanding.

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