The Development of Student Research Skills in Second Year Plant Biology

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Abstract

In 2011, students in Agricultural Sciences and Viticulture & Oenology were first provided with opportunities to develop research skills in plant biology through the course *Foundations in Plant Science II*. Students worked in small groups and completed an open-ended research project under the guidance of an academic mentor. Each group of students were given the freedom to plan and manage an experiment; collect, analyse and interpret data independently and to present their results both orally and in writing. Students reported that the group project was a positive experience where they were able to develop skills in scientific report writing. In 2012, students were challenged by aspects of the research project including experimental design and identifying published papers to support their hypotheses. In 2013, when we provided more support and structure using on-line and in-class tutorials, students were better able to work in groups, source appropriate literature and analyse data using statistics as their confidence in research and questioning ideas had improved.

Introduction

One of our greatest challenges as educators is to encourage students to adopt life-long learning habits (Madhuri & Broussard, 2008). In applied disciplines, such as the agricultural sciences, the ability to develop research skills and apply knowledge to problem solving in real-life situations is integral to their success as a graduate (McSweeney & Rayner, 2011).
In order to engage with their discipline in a meaningful way, students need to have their research skills explicitly developed (Willison & O'Regan, 2007) and be aware they can contest knowledge. Research is one of the best ways to do this (Healey, 2005). Promoting a change from transmission and assimilation of knowledge to the development of research skills in students can be difficult because both student and academic place more emphasis on content knowledge rather than the process whereby knowledge is created (Willison & O'Regan, 2007). In addition, many students are not well prepared for research at university with often poor information literacy (Weiner, 2010) and quantitative skills (Matthews, Belward, Coady, Rylands & Simbag, 2012). Research requires the access, evaluation and application of information, and quantitative skills are needed for experimental design and interpretation of data. As early as possible in the undergraduate degree, students should experience research-based or inquiry-oriented learning approaches that enable information literacy and quantitative skill development, regardless of discipline.

Inquiry-oriented learning is more academically rewarding and exciting (Reisberg, 1998; Mears, 2013) and is useful for subsequent studies and employment (Willison, 2012). Students simultaneously gain a deeper understanding of their discipline and improve their thinking as a scientist through research (Seymour, Hunter, Laursen & Deantoni, 2004). More specifically, inquiry-oriented learning in a scientific laboratory setting leads to improved student learning outcomes compared to 'recipe-based' laboratory classes (Boud, Dunn & Hegarty-Hazel, 1989). Inquiry based learning allows students to be inventive and imaginative making them 'think outside the box' (Kirkup, 2013). In addition, academics find their commitment to teaching increases with the development of students' research skills (Wright & Boggs, 2002) and teaching efficacy is enhanced, enabling more regular feedback and clarification of the main learning outcomes (Willison, 2012).

Although inquiry-oriented and project-based learning has been used successfully to improve student engagement and learning in the sciences it requires very clear scaffolding of the activities (DebBurman, 2002; Willison, 2012; Wright & Boggs, 2012). Research by its very nature is open-ended which can increase the cognitive load thereby causing problems in learning (Sweller, 1994). Students need to learn how to participate in the process to be successful (Wright & Boggs, 2012). Process skill development through scaffolding is therefore an essential component of helping students to manage the increased cognitive load and consequently, their research skills (DebBurman, 2002).

Structuring the learning environment so that peers can assist learning can further improve the inquiry-oriented learning experience. Project-based learning in groups has been shown to enhance student learning. Students learn communication, critical thinking and problem solving skills through teamwork (Pan & Allison, 2010). Collaborative learning also has a positive effect on cognitive structuring because it allows individuals to elaborate their thinking to other team members (O'Donnell, 2006). In these experiences, students strengthen connections between previous learning and current activities (Wittrock, 1990). Providing scaffolded and well-defined tasks also influences student discourse by allowing teachers to intervene and provide instruction in communication, explaining or reasoning skills (Webb, 2009).

The aim of this study was to determine if independent, student-centred learning was appropriate for a second year undergraduate plant biology course, *Foundations in Plant Science II*, and to explore whether scaffolding research skill development could improve student learning outcomes. The course was designed as a second year plant biology course to provide students in Agricultural Sciences and Viticulture & Oenology with the necessary plant biology background in their degrees and to develop research skills in experimental science. In 2011, students working in small groups completed an independent research project under the informal guidance of an academic mentor. Students were given the freedom to plan and manage an experiment; collect, analyse and interpret data independently; and to present results in class. Formal and anecdotal student evaluations suggested students, however, struggled with 'the enormity of the task', lacked an appreciation of why they were doing the project and wanted more information about requirements. In 2012, we provided students with more information on the requirements and purpose of the project including the expected learning outcomes. We also sought feedback from the 2012 cohort of students about the project and their perceptions of their abilities through surveys. In response to the results of the surveys, in 2013 we provided directed scaffolding, in the form of in-class tutorials and on-line activities, to ensure research skill development and improve the student learning experience.

Methods

The research project and its components

In 2011, students (n=45) worked in small self-selected groups to complete an independent research project across eight to ten weeks of the semester with limited guidance from academic teaching staff. Students were given the freedom to plan and manage an experiment; collect, analyse and interpret data independently; and to present results in class.

In 2012, students (n=49) were introduced to mentors and research topic areas in week 2 of the semester. Mentors were selected as academics who were already involved in lecture or practical classes and had 2 to 3 groups of students. Students formed groups of four to five students and selected a topic area and were given a timeline and a set of expectations. Each group developed a one-page research proposal with their main aim and experimental design. This was submitted to their mentor for comment before the mid-semester break. Mentors provided immediate feedback on the number of replicates, concentrations of compounds, species of plants and other information. After feedback from the mentor, students set up experiments, collected and analysed data in an independent manner. Mentors were available at the practical sessions or by prior agreement outside of practical session time. Students presented the results from their group project as an oral presentation in the last week of semester (week 12, worth 10% of the final course grade) and submitted a report (worth 10% of the final course grade). Their individual mark for the research project was determined by moderating the group mark by the self and peer assessment of the performance in group work which was subtracted from the class average using the formula:

Individual mark for report = Group mark for report X (100 - (average group work performance for class – individual group work performance)).

For example, if the group mark for the report was 65% , the class average was 90% for performance in group work performance and the student received an individual mark of 85% from their peers and themselves then their final individual mark for the report was equal to 95% of the group mark or 61.75% [65 X (100 – (90-85)].

In 2013, a similar format was followed except that:

1) students (n=41) were provided with in-class tutorials and on-line activities (via an interactive package created using Articulate Storyline) on the nature of scientific papers, designing experiments, formulating hypotheses, the research process, statistical analysis techniques and working in a group effectively;

2) students used scientific papers to justify their experimental design in the research proposal;

3) the allocation of marks changed with the research proposal worth 5%, the oral presentation 5% and the group report 10%;

4) grading rubrics were provided to students for each component of the project;

5) the final student mark was calculated using a measure of their engagement with the online material (the formula described above was modified to Individual mark for report = Group mark for report X [100 - (average group work performance for class – 0.95.individual group work performance)] for the students who did not engage with the online material or quizzes);

6) students had a 30 minute consultation with a biometrician on data analysis and were provided with written recommendations;

7) students started the research later in week 3 of the semester;

8) there were two less practical sessions available for data collection; and;

9) students were randomly allocated to groups.

Survey of the student learning experience and perception of research skill ability
Students were surveyed about the learning experience using a 5-point Likert-type scale (strongly disagree, disagree, neutral, agree and strongly agree). Students were asked to respond to statements about whether adequate information and sufficient guidance was provided, whether scientific papers helped generate hypotheses, whether sufficient time was allowed for the project and if the self or peer assessment was useful.

In 2013, additional scaffolding was provided allowing students to consult with a biometrician and resources were provided by on-line and in class tutorials. To evaluate these strategies, students were also surveyed about whether the online activities, the tutorial on statistical analyses and consultation with a biometrician were useful. In these surveys students were also able to provide open-ended comments.

To determine the development of research skills, students were also surveyed about their perception of the research project and the development of research skills before and after the research project. Students responded to a 5-point Likert-type scale (very poor, poor, average, good, excellent) and were asked to rate their ability in writing reports, formulating questions/hypotheses, devising scientific experiments, oral communication, time management, finding scientific papers, and critiquing scientific papers. In 2013, we also asked them to rate their ability to interpret data and contribute to a group.

Students were also surveyed in 2011 and 2013 using formal student evaluation of learning and teaching (SELT). Only those questions directly relevant to the research project were reported here. Results from both surveys were statistically analysed using chi-square tests (Clason & Dormody, 1990; Boone & Boone, 2012). Ethics approval for the project was granted by The University of Adelaide's Research Ethics Committee (Approval number H-2012-034).

Results and Discussion

In general, students positively responded to the research project and indicated that it was the best part of the course *Foundations in Plant Science II* (Table 1). There were some negative comments from students, but this was less than 5% of students, who indicated they either wanted to spend more time doing the research project or that they did not like working in a group.

It has been suggested that students require more time to process and analyse data in open ended research investigations compared to pre-designed laboratory experiences which have a pre-determined outcome. In open ended situations, students need longer to cope with the detail-oriented nature of research particularly if they are new to research (Cartrette & Melroe-Lehrman, 2012). Being second year undergraduates already, our students have mostly been provided with pre-designed laboratory experiences which occur in a given timeframe where the expected outcomes of experiments are known. This type of learning could lead to the common misconception that research is a solitary but smooth, problem-free process in a 'closed' system where outcomes are easily predictable and do not require further analysis (Cartrette & Melroe-Lehrman, 2012). In addition, the cognitive and process-related skills needed to work collaboratively on a detail-oriented task, such as the group research project, are more difficult to develop (Webb, 2009).

A small number of the agricultural science students indicated in surveys that they were not interested in plant biology. These same students did not engage with the online tutorials and according to self and peer assessment, did not contribute as much to the group work. Where an individual's interest lies has been previously suggested to affect the development of their process skills and to determine whether they engage with and contribute to the collaborative research process (Roth & Roychoudhury, 1993). The success of the co-construction of knowledge and decision-making by groups, however, is also known to rely on the different personality types present in the group (Barron, 2003). A lack of coordination and participation by group members can result when individuals focus on their own ideas and when there are perceived differences such as culture, age, gender or intelligence in the group (Barron, 2003). The students that most often complained about working in the research groups were the high academic achievers. Differences in academic abilities can lead to emotional uncertainty and/or anxiety of accountability (Sweet & Pelton-Sweet, 2008). Conversely, social loafing ('a free ride') by less-talented students can occur (Salomon & Globerson, 1989). These differences in personality types and their ensuing behaviours can be resolved through the development of a complex and open-ended problem with appropriate scaffolding which encourages collaborative dialogue (Webb, 2009).

Student comments, in both years, indicated that they valued the opportunity to assess how each member of the group contributed through peer assessment. This occurred regardless of whether students had chosen their own group (as in 2012) or were allocated to a group (as in 2013). Interestingly, the peer and self-assessments were more positive in 2013 than in 2012 suggesting that the extra scaffolding provided in 2013 helped with group functioning. Unsurprisingly, mentors observed that those groups that functioned better were those where all members contributed.

Over 50% of the cohort in 2012 and 2013 indicated they agreed or strongly agreed with the statements that: adequate information was given at the start of the project, sufficient guidance was provided throughout the project, scientific papers helped generate hypotheses, sufficient time was available and peer/self-assessment was useful (Figure 1). In 2012, however, more than 10% of students indicated they needed more guidance. Our observation was that students struggled with three processes: the development of their hypotheses using appropriate scientific papers, the interpretation of data in a biologically meaningful way and statistical analysis. The lack of quantitative skills of undergraduates may hinder attempts to introduce inquiry-based learning (Reyner, 2012). Even though students had done a statistical course in first year, they were unable to use statistical analysis. Such an inability to apply statistical skills in a real world example has been described in other studies (Colon-Berlingeri & Burrowes, 2011; Reyner, 2012). Similarly, undergraduate students lacked information literacy skills. This has been described by others as an ongoing concern. Although students are very good at finding information in this 'Google-age' they do not know how to evaluate information (Salisbury & Karasmanis, 2011). Scaffolded opportunities to develop information literacy skills in context, can improve student performance (Matthews et al., 2012; Reyner, 2012; Salisbury & Karasmanis, 2011). In our study, close to 50% of the 2013 cohort indicated the scaffolding provided (online tutorials, statistical analysis tutorial and consultation with a biometrician) was useful.

Compared to the year before, all groups in 2013 analysed their data and reported the biological context in an oral presentation and group report. This suggests that the extra scaffolding enabled a higher order of learning that ensured students were better able to apply what they had learnt to their research, as expected (Goldstein & Flynn, 2011). When the student data from 2012 and 2013 was compared only two parameters were significantly different. In 2013, a significantly greater proportion of students agreed that the information given in the practicals was useful (73.2% compared with 59.2% in 2012, $P < 0.001$) while significantly more students indicated there was not enough time (48.8% compared with 12.2% in 2012, $P < 0.001$). This was probably a result of having less time due to timetabling with public holidays and the nature of the activity as previously discussed.

The impact of the greater scaffolding of the research project was reflected in the formal evaluations of the course (Table 2) which improved between 2011 and 2013. The average grades achieved by the cohorts also increased from 2012 to 2013. In 2012, the average grade for the oral presentation was 63.3% and the group report was 67.4% (an averaged total of 64.7% for the research project). In 2013, the average grade for the report was 73.4%, 71% for the proposal and 76% for the oral presentation (overall mark of 73.5% on average for the research project). The higher marks in 2013 reflect the increased use of data analysis, improved interpretation and presentation of results, greater use of references and an articulation of further possible research. The grading of the proposal also appeared to help students to consider the literature further.

Regardless of year, students' perceptions of their ability in writing reports, formulating questions, devising experiments and delivering oral presentations significantly improved because of the research project (Figure 2). Students indicated their ability to work in a group also significantly increased (only asked in 2013).

In 2012, after the project was completed, all students reported their ability to find scientific papers was average or above and an increase in 17% of students indicated they were 'good' at finding scientific papers, although the shift was not statistically significant ($P = 0.17$) and there was no increase in the 'excellent' rating.

A similar pattern was observed when students were asked about their ability to criticise scientific papers. Greater than 90% of students in 2012 had a positive perception of their literacy skills which was inflated as observed by other studies (Salisbury & Karasmanis, 2011). A greater number of students in 2013 than in 2012 reported that they lacked skills in finding and critiquing scientific papers both before and after the project. After the project, an increase in the number of students that thought they were 'excellent' at finding scientific papers and 'good' at critiquing scientific papers was also observed.

In addition, students stated in the open-ended comments that although the in-class sessions and on-line tutorial provided them with a greater awareness of what they needed to do to develop their literacy skills, many students found that it was easier to 'just ask the mentor' and that there was insufficient time to improve.

Student perception of their time management skills did not significantly change over time. In 2013, the percentage of students who regarded their ability to manage time as 'excellent' did decline from 19% before the project to 7% after the project. In this year, however, there were more significant time pressures than in 2012. Students were also provided with additional resources to interpret data, including opportunities to consult with a biometrician. Students reported their ability to interpret data was significantly lower after the project, even though students were given additional resources and performed better in the assessment. The student comments in the survey indicated their conception of interpretation changed after completion of the project. Many students commented that they did not know how to use statistics and they needed practice to increase their confidence. The integration and application of the quantitative skills in the research project provides students with opportunities for higher order learning (Goldstein & Flynn, 2011) that can be used in subsequent courses.

Lessons Learnt and Conclusion

Although we acknowledge that the differences in student responses may be because of the inherent differences in cohorts, the improved performance of the 2013 cohort suggests that providing scaffolding is necessary. Guidance by a mentor, time to develop ideas and group work strategies, and access to information all were important factors in ensuring success in the research project. We provided scaffolding based on student perceptions and mentors' observations of where students struggled in the previous two years. A pre-test of some of these skills may be a more rigorous method for academics to determine where scaffolding is needed (Georgiou, Sharma, O'Byrne, Sefton & McInnes, 2009) and to provide students with a more realistic guide of their research skills. Alternatively, students could directly assess their own progress by using the research skills development framework developed by Willison and O'Regan (2007). This method has been successful in a number of other undergraduate biology-related courses in Australia (Willison, 2012). Regardless, we aim to continue providing improved resources to students both in-class and online. This may also include the involvement of the biometrician earlier in the research project, particularly during the experimental design stage of the project. To improve engagement, we also need to consider greater rewards, such as mark-incentives, for the use of resources as has been used by other research projects (Wright & Boggs, 2002; DebBurman, 2002). Students generally believe in 'economy versus effort' and our studies as well as others have shown that inquiry-oriented learning needs time (Mears, 2013). Therefore, we need to reconsider the time allocated to the project as well as whether the effort required, for students and staff equates to the 20% assessment value of the project.

In general, the group approach used in the research project worked well. There were, however, concerns about working in groups from our more academically-gifted students. There were also observations that some students did not engage well. To address these issues we could integrate more team building strategies in the future which would help engage more with those that are not as interested in plant biology.

It is well known that students do not automatically collaborate in group work (Schmitz & Winskel, 2008). When students realise the unique contributions that each individual can make the group is more likely to function well (Kim & Tan, 2013). Other strategies for building effective groups include providing greater structure in the task by assigning roles to individuals (whether cognitive or otherwise); providing training in reciprocal questioning, explanation prompting and group processing (discussion of and improvement of group interactions); aligning the assessment to cognitive contribution and/or greater mentor intervention (Webb, 2009). Continued evaluation and focus groups with students will assist with improving group work in the research project in *Foundations in Plant Science II*.

In conclusion, students in *Foundations in Plant Science II* improved in experimental design, analysing data, accessing and critiquing the literature and questioning. These skills will be useful as they progress through their degrees ensuring better preparedness for more specialised plant biology classes and postgraduate programs.

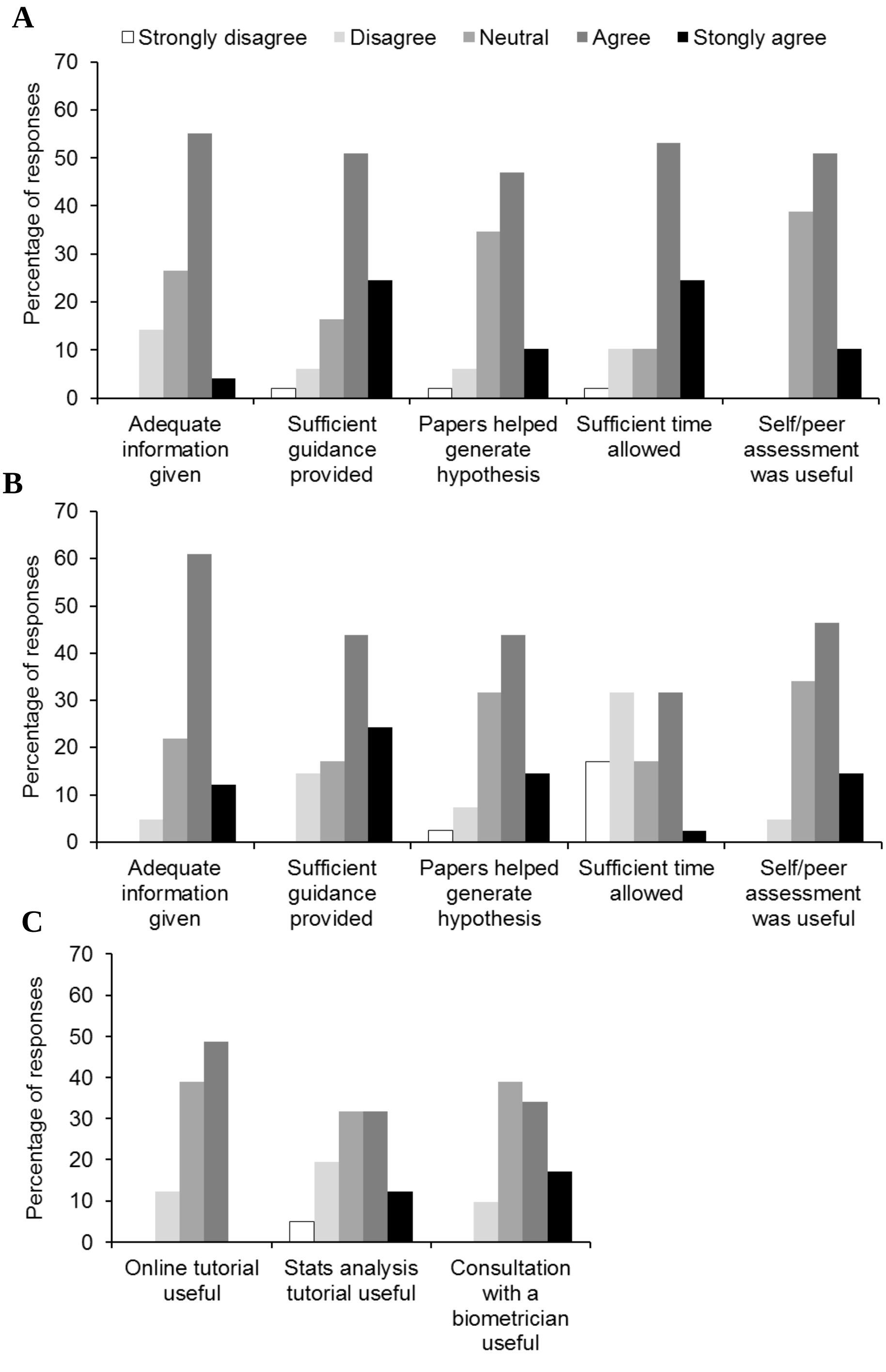

Figure 1. Student's opinions of the research project in *Foundations in Plant Science.* Students were surveyed at the end of the project in 2012 (A) and 2013 (B) using a Likert-type scale that asked to what extent they agreed with the statements that: adequate information was given at the start of the project, sufficient guidance provided throughout the project, scientific papers helped them to generate the hypothesis, sufficient time was available and peer/self-assessment was useful. In 2013, students were also asked to rate whether the online tutorial about research design, the statistical analysis tutorial and consultation with a biometrician was useful (C). n=49 in 2012 and n=41 in 2013.

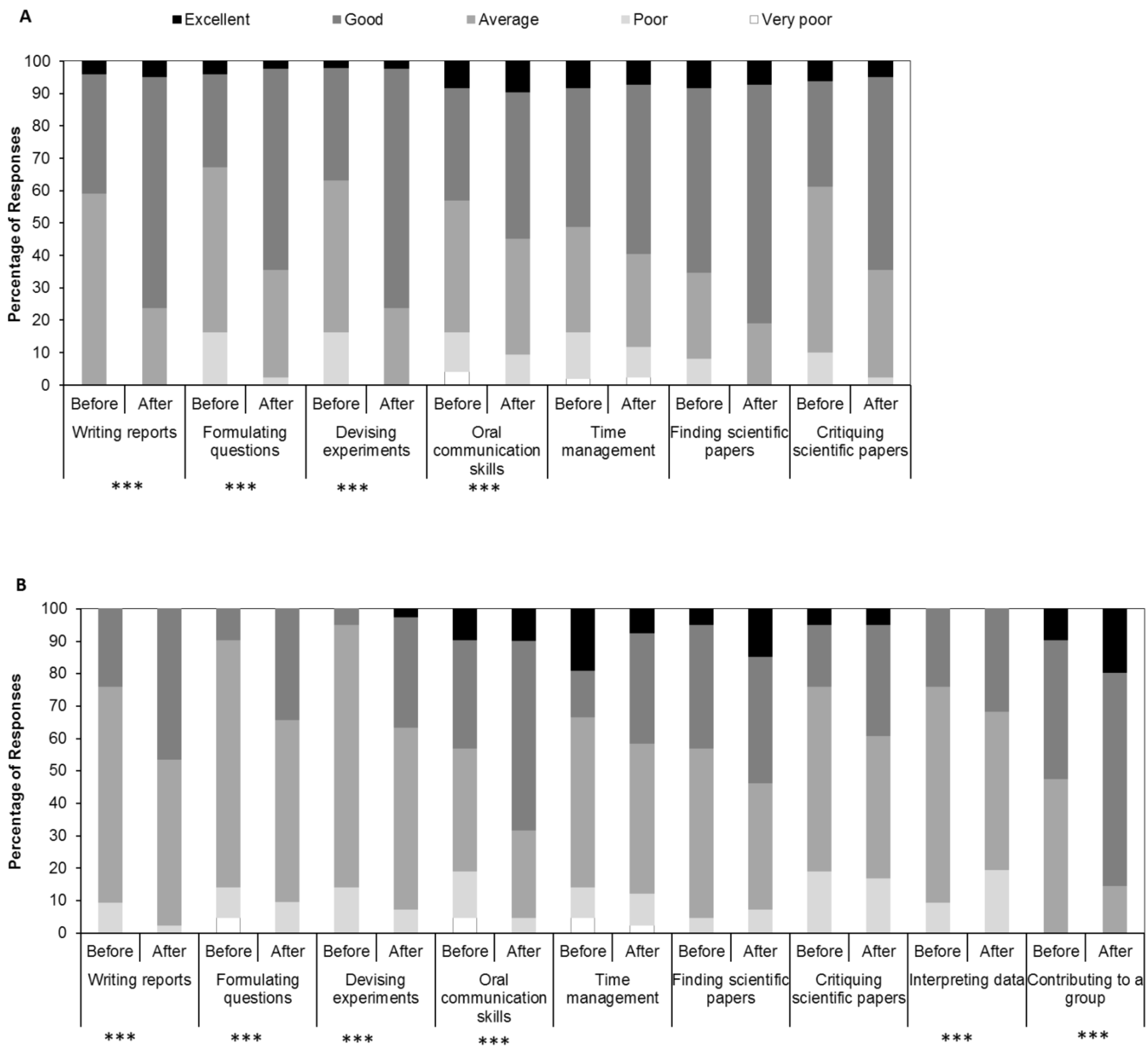

Figure 2. Rating by students of their skills before and after the research project in *Foundations in Plant Science.* Students were surveyed before and after the project in 2012 (A) and 2013 (B) using a Likert-type scale. n=49 in 2012 and n=41 in 2013. *** indicates statistical difference at $P < 0.05$ using Chi-square analysis.

Table 1. Student Evaluations of Learning and Teaching (SELT) when asked 'What was the best part of the course and why?' SELTs were issued in 2011 and 2013.

Research project
Developing own project and choosing own topic
The project allowed us to apply knowledge to real life situations
Group project good for creating experience and creating context
Designing own experiment
The project - develop experiment skill, communication, problem solving
Forces you to use knowledge gained in lectures and apply to real life situations/experiments

Table 2. Formal evaluation of Foundations in Plant Science (via Student Evaluation of Learning and Teaching; SELT). The mean score ± S.D. for those SELT questions relevant to the research project component of the course Foundations in Plant Science. Maximum score is 7.0.

SELT question	2011	2013
Workload is appropriate	4.7±0.8	5.4±1.0
Appropriate strategies are used to engage students	4.9±1.3	5.0±1.1
Helps students develop thinking skills (e.g. problem solving)	4.9±1.5	5.3±0.9
Overall quality of course	4.8±1.4	5.3±1.0
No. of responses	*37*	*40*

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