Perceptions of the Relative Importance of Student Interactions for the Attainment of Engineering Laboratory-Learning Outcomes

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Abstract

Engineering degree programs include a significant amount of practical work for which national accrediting bodies stipulate a set of laboratory-learning outcomes. This paper sets out to understand how students' interactions in the laboratory contribute to the attainment of laboratory-learning outcomes. The investigation was conducted in the traditional face-to-face laboratory mode. Results from surveys of final-year students and instructors are reported. Students' and instructors' perspectives of the relative importance of four main types of student interaction to meet each of the Engineers Australia laboratory-learning outcomes are also presented. Students primarily expected to interact with instructors more than with students (directly or through observation of interactions) or equipment for their achievement of the learning outcomes, whereas instructors reported that all of the interactions are important to achieve the learning outcomes.

1. Introduction

Students graduating with an accredited bachelor degree in engineering are required to possess skills and expertise mandated by a national accrediting body. The engineering degree program and its constituent activities are designed to allow students to develop both personally and professionally thereby acquiring all of the competencies and graduate attributes stipulated by the accrediting body. Skills developed within the overall degree program include those related to laboratory activities. Engineering laboratories are currently conducted in various modes (Corter et al., 2011; Ma & Nickerson, 2006). The mode of conduct or delivery of laboratory activities can affect students' learning as well as their attainment of important laboratory learning outcomes (Lindsay & Good, 2005). Accordingly, the way that laboratory learning occurs through students' interactions is the focus of this paper.

Our earlier work (Lal et al., 2019) reported on the relative importance of student interactions in the attainment of the ten Engineers Australia (EA) laboratory learning outcomes (Engineers Australia 2013). The present paper is based on investigations conducted for face-to-face laboratory work with further analysis of the perceptions of students and instructors.

Previous studies have classified student interactions into three types: student-student (S-S), student-instructor (S-I), and student-equipment (S-E) (Anderson, 2003; Miyazoe, 2012). Recent studies (Lal et al., 2018; Wei et al., 2018, 2019) have added a fourth type termed indirect interaction (Ind-Int). Indirect interaction occurs when a student learns or is assumed to learn from the observation or listening in to other students' interactions either between themselves or with an instructor in the laboratory. Each interaction has its own significance for students' learning in the laboratory (Lal et al., 2018).

In face-to-face laboratories, the physical presence of students and instructors along with physical access to the equipment used provides opportunities for all four interactions to take place. For instance, instructors' guidance and demonstration of laboratory work is a student-instructor interaction. Similarly, students working together in groups permit student-student interactions. Students' operation of equipment to collect data is a student-equipment interaction. Finally, inter-group discussions and observations or a student listening to other students' questions being answered by an instructor demonstrate the existence of indirect-interactions.

The present study serves to understand further the relationship between student interactions in laboratory learning and the attainment of Engineers Australia's (EA) ten laboratory-learning outcomes (Engineers Australia, 2013) in face-to-face laboratories. The study is centred on the views expressed by final-year undergraduate engineering students (Cicek Ingram et al., 2014; Cicek Labossiere et al., 2014) and also by their instructors. The main aim of the study is to seek fourth-year students' perspectives when they were at the point of completion of all course requirements. This is done so as to allow them to summarise their experiences of the laboratory of the past four years. Final-year students who were near completion of their degree were chosen because through their earlier study they would have developed a good understanding of the EA laboratory-learning outcomes that are expected of them and, to some extent, would have attained some or all of those outcomes.

2. Engineers Australia (EA) laboratory-learning outcomes

Engineering laboratories, irrespective of the mode, are deemed important for students because they inculcate the scientific method used for investigation, develop the practical skills required of engineers, reinforce theoretical concepts learned in lectures, and their conduct provides the opportunities to develop and practise essential personal and professional skills. Engineers Australia (EA) (a signatory of Washington Accord) stipulates ten laboratory-learning outcomes for all students graduating with an accredited (at professional level) bachelor of engineering degree (Engineers Australia, 2013); these are listed in the first column of the table presented in Appendix A. In the sequential order presented by EA (as LO1 to LO10) these outcomes broadly represent the way that laboratory learning is designed to take place. The EA laboratory learning outcomes are very similar to those listed by other accrediting bodies, such as Accreditation Board for Engineering and Technology, Inc. (ABET) (ABET, 2017; Most & Deisenroth, 2003). However, team work and communication skills stipulated as laboratory learning outcomes in ABET are not part of EA laboratory learning outcomes (Feisel & Peterson, 2002; Most & Deisenroth, 2003).

Accordingly, an engineering graduate must possess a good understanding of the underlying theoretical concepts and also a sound knowledge of the scientific methods that govern laboratory work. Reflecting the nature of engineering work, an engineering student, through experimental work, must develop an understanding of the specifications of engineering devices, materials and also know how to characterise engineering systems. Students should also attain experience in equipment use to capture data and undertake its analysis with critical reflection so as to identify errors and explain their sources. Laboratory learning also includes the opportunity to develop the ability to create standardised reporting for the engineering laboratory work performed. Students working in laboratories, throughout their engineering studies, are assessed for their attainment of the aforementioned competencies.

Graduate learning outcomes and capabilities acknowledge independent-learning skills (Field & Duffy, 2014). They write that *"independent learning is a goal, not a starting point, and students, peers, academics, and tertiary institutions are all involved in the journey"*. Since laboratory work is a crucial part of an engineering-degree program, this means that the laboratory-learning outcomes stipulated by EA implicitly contribute to students becoming independent learners upon their graduation. The EA laboratory-learning outcomes are clearly enabled by the four types of student interactions that occur in the laboratory. Moreover, the ten laboratory learning outcomes, taken as a whole, prepare students with individual technical and evaluative skills that engender independence in the conduct of practical work so that after graduation they are able to work with confidence and minimal supervision in their place of work and continue to keep abreast of developments in the profession as independent learners.

A typical way to evaluate students' attainment of the EA laboratory learning outcomes is through a laboratory report or artefacts designed and/or manufactured as part of the laboratory assignment. However, the contribution of student interactions in the actual conduct of the laboratory activity to the attainment of the learning outcomes is less often considered. This is then the main focus of the present study.

Studies of the overall graduate competencies for engineering students have been conducted by Male et al. (2009, 2011) but without specific consideration for engineering laboratories. There are studies which have reported on the effectiveness of laboratories in the students' attainment of laboratory learning outcomes (Lindsay & Good, 2005; Lindsay & Stumpers, 2011; Nickerson et al., 2007; Ogot et al., 2003). However, these studies of attainment of laboratory learning outcomes are mainly based on students' perception of the ease of conduct of laboratory experiments. By contrast, the present paper relates the attainment of laboratory-learning outcomes with the student interactions that take place during the laboratory activity.

3. Research question

In light of the foregoing discussion, the present study is framed by the following research question:

> Which student interactions, from the viewpoint of students and their instructors, are important for their contribution to the attainment of each of the ten EA laboratory learning outcomes?

In Section 4 the conceptual framework for the entire study is outlined. We then structure the remainder of the paper in which the methods and results pertaining to the research question are presented in Section 5 Thereafter, Section 6 comprises a discussion of the overall findings and their contribution to existing research in the area of laboratory learning. Section 7 presents the limitations and scope of future research, while Section 8 contains its conclusions.

4. Conceptual framework

The conceptual framework for the study is summarised by Figure 1. This shows how the four interactions that occur during laboratory work are linked to: the design of engineering laboratory work, students' attainment of EA laboratory-learning outcomes and students' graduation as a skilled engineer. Thus, from left to right (arrows) in Figure 1, graduates of an EA accredited degree must have achieved the laboratory learning outcomes, the development of which is through active participation in the four interaction types that are promoted by the design of engineering laboratory activities. The sequence from right to left (also arrowed) shows that engineering laboratory design incorporates the four types of interactions discussed above. These interactions then contribute to attainment of laboratory learning outcomes stipulated by Engineers Australia. In this developmental learning process, both students and instructors play an important role. Instructors take the role of leaders while students remain as learners in the process.

The present study is focused upon the importance of four interactions that facilitate students' attainment of the ten EA laboratory learning outcomes. The study is conducted through a survey that investigates final-year students' and academic instructors' perceptions of the relative importance of the four types of student interactions in the attainment of EA laboratory learning outcomes.

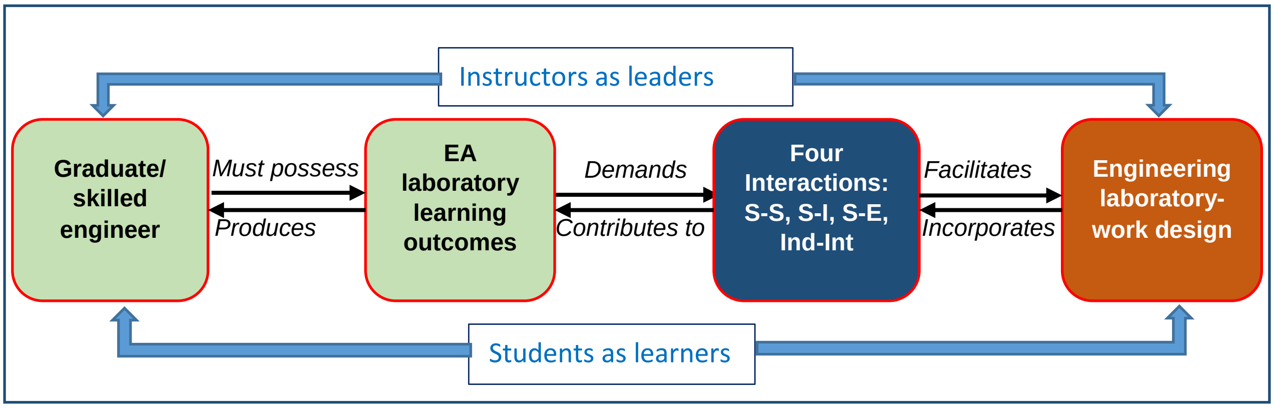


Figure 1: Interactions in engineering laboratory work and laboratory-work design contributing to the attainment of EA outcomes required of a graduate engineer. S-S=Student-Student interaction, S-I= Student-Instructor interaction. S-E=Student-Equipment interaction, and Ind-Int=Indirect interaction.

5. Identification of the relative importance of student interactions underpinning the attainment of laboratory-learning outcomes

5.1 Method

The quantitative study (Creswell, 2014) conducted to answer the research question aligns with the 'Four interactions', of the conceptual framework shown in Figure 1. An online survey questionnaire was designed and administered in an Australian University to all final-year (4th-year) students of an accredited bachelor of engineering in Civil, Mechanical or Mechatronics Engineering, who were nearing completion of their degree, and, as a separate cohort, to their academic instructors. The questionnaire developed and used is shown as Appendix A.

The survey instrument is a tabulated form with rows listing the ten EA laboratory learning outcomes and columns with four interaction types. Respondents were asked to assign a comparative rank to each of the four interaction types from most important (1) to the least important (4) on the basis of their contribution to attaining each of the ten EA laboratory-learning outcomes. For each row, a 'Skip' option was provided to respondents in order for them to opt out if they were unsure how to rank the interactions for that learning outcome (not shown in the questionnaire in Appendix A). A ranking system was chosen to encourage respondents to consider critically the relative importance of the interaction types. The survey was undertaken using an online platform with students and instructors invited to respond through email messages that also outlined the purpose of the survey.

A total of 29 final-year students (from a student cohort of approximately 300) responded to the survey which was conducted online. The low response rate suggests a bias towards more motivated students but it is unclear how motivation would impact upon interaction patterns in the laboratory, and as such it is impossible to control for the impact of this bias upon our results. Similarly, 22 instructors (from an academic-staff cohort of approximately 40), with teaching experience in the face-to-face laboratory mode responded to the survey.

Despite the low number of respondents, the results of the study provide insights as to how students and instructors view the relative importance of student interactions in the laboratory in the context of attaining the overall set of laboratory-learning outcomes expected by the professional body at the completion of a student's degree.

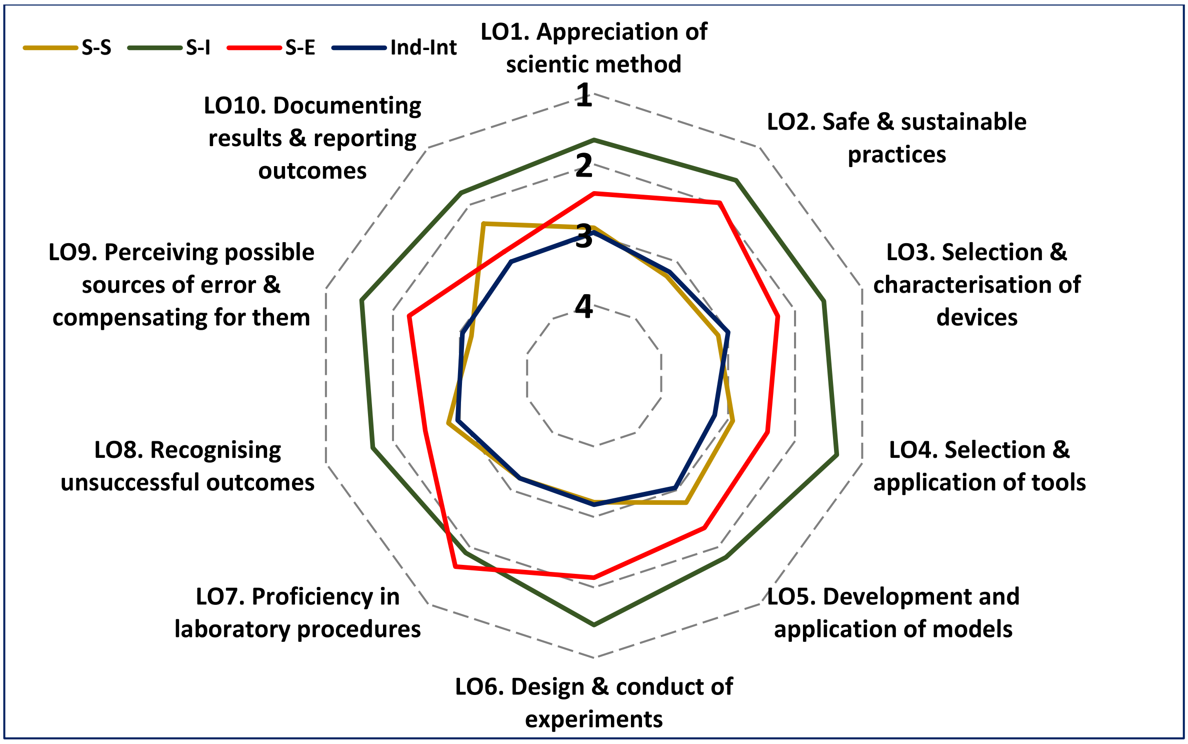
5.2 Results

5.2.1. Students and instructors' perception of the relative importance of interactions

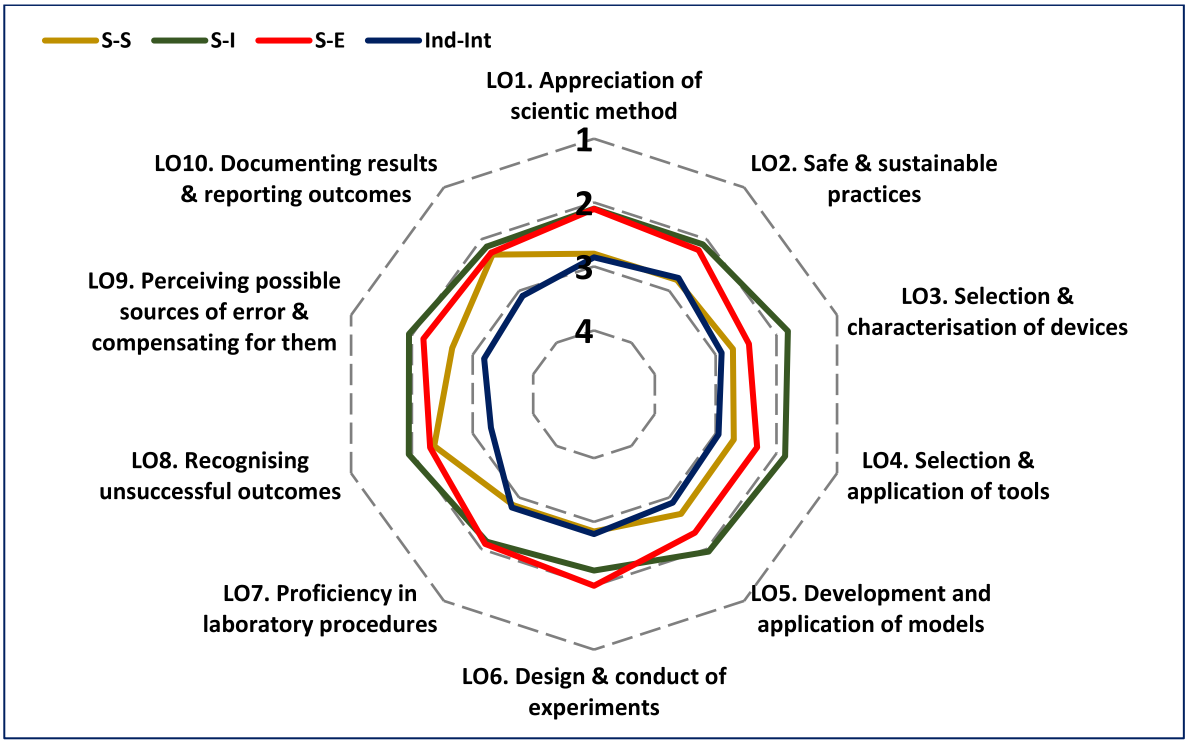
Figures 2(a) and (b) show the average of the ranking of the four interaction types in their contribution to the attainment of the ten learning outcomes drawn from the responses received from students and instructors respectively. The ten learning outcomes shown in Figure 2 are listed in full in the first column of the table in Appendix A.

Figure 2(a) shows that students report a marked importance for Student-Instructor interaction because for all learning outcomes the rank average was below 2 for Student-Instructor (S-I) interaction. The second most important type was Student-Equipment (S-E) interaction with an average rank that was mostly between the rank 2 and 3, but peaked and averaged below 2 for the learning outcomes LO2 (safety) and LO7 (proficiency in laboratory procedures). The third most important type of interaction is that between students (S-S). However, this interaction was deemed more important than student-equipment interaction only for LO10 (reporting results, critical reflection and drawing conclusions) with an average between 2 and 3. Finally, students believe that of least importance are indirect interaction (Ind-Int) as all rank averages for this category are greater than 3. Nevertheless, for many learning outcomes their importance is reported to be at a similar level as those of student-student interaction.

The average rankings plotted in Figure 2(b), received from instructors, shows similarity with the students' views plotted in Figure 2(a). The outermost results boundary is again the Student-Instructor (S-I) interaction, indicating it to be the most important type of interaction of all. The average rankings for S-I interactions peaked more visibly for LO3 (characterising engineering systems) and LO4 (selecting tools and technologies) each with an average rank of less than 2. As with the students' perceptions, instructors also ranked themselves important for LO8 and LO9 (both relating to error analysis) with an average rank of 2. What is clearly different between Figures 2(a) and (b) is that the Instructors' average ranking of Student-Student (S-S), Student-Instructor (S-I) and Student-Equipment (S-E) interactions all lie between 2 and 3 for all LOs with indirect interaction (Ind-Int) marginally lower. This indicates that instructors perceive all four types of interaction to be important contributors to the students' attainment of laboratory learning outcomes. A clear reflection of this is observed in the average ranking for LO10 (reporting results, critical reflection and drawing conclusions) where the average rankings for student-instructor, student-equipment, and student-student have almost identical average ranking of importance. Instructors ranked Student-Equipment slightly higher than the interaction with themselves for learning outcome LO6 (design and conduct of experiments) and at the same level as them for LO7 (proficiency in the use of procedures and equipment use). This might be expected given that instructors would expect the students to engage strongly with the equipment in order to gain command of its use.



(a)



(b)

Figure 2: Mean rankings of the four types of student interactions for attainment of the EA laboratory-learning outcomes as perceived by (a) Students (N=29) and (b) Instructors (N=22)

Note: S-S=Student-Student interaction, S-I= Student-Instructor interaction. S-E=Student-Equipment interaction, and Ind-Int=Indirect interaction. Each of the concentric rings represent a rank from 1 to 4, noting that 1 represents the highest importance and 4 the least.

5.2.2. On the difference between student and staff perceptions of the relative importance of interactions

Figures 2(a) and 2(b) have shown that both students and instructors perceive the Student-Instructor interaction to be the most valuable interaction in laboratory learning. However, the Student-Instructor interaction is perceived to be much more important by students than by their instructors. A clearer picture of the relative importance for interaction types expressed by students and instructors for attaining the ten EA laboratory learning outcomes is presented in Figure 3.

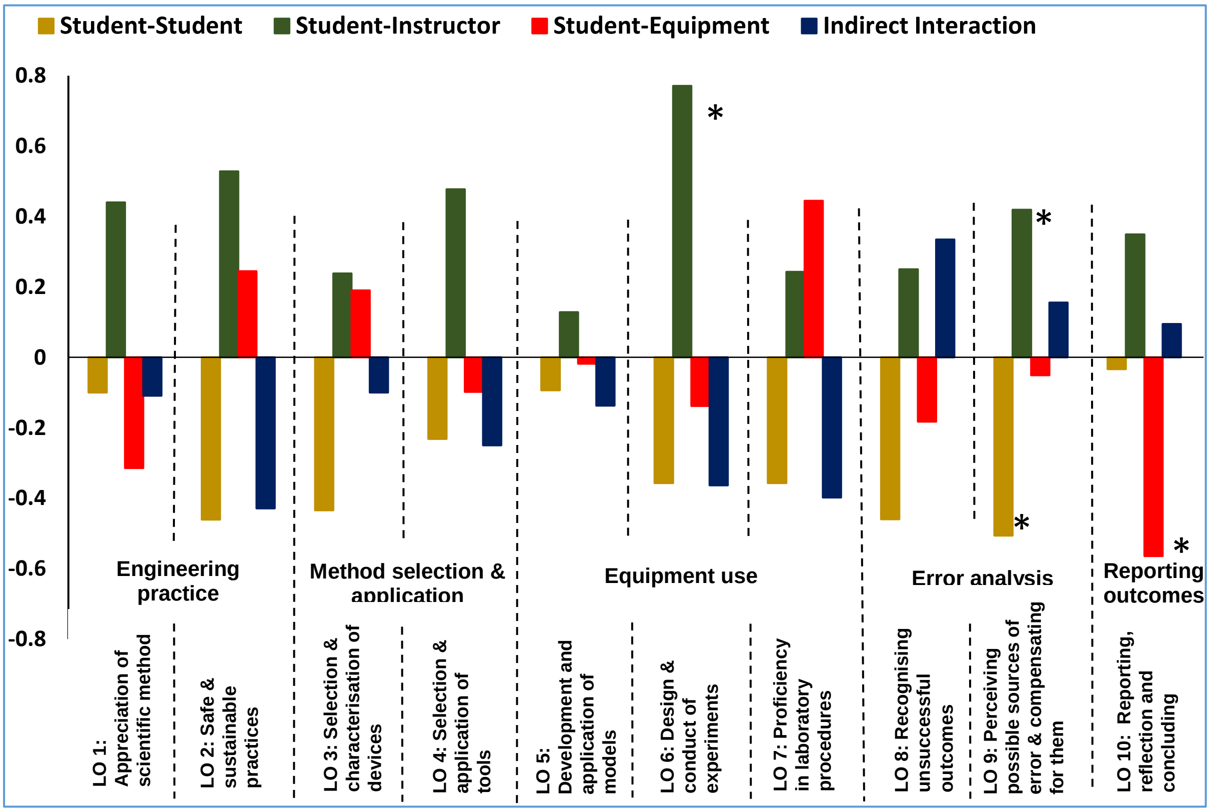


Figure 3: Difference in the average ranking from students' and instructors' responses: +ve difference indicates students' ranking of interactions higher than that of instructors and –ve difference indicates instructors' ranking of interactions higher than that of students.

Note: * -indicates that the difference in the distribution of responses between students and instructors are statistically significant at $p<0.10$.

Figure 3 emphasises the difference between student and instructor perceptions by plotting the difference in average ranking for each LO calculated by subtracting students' average ranking from instructors' average rank. It is important to note here that 'Rank 1' represents the most important of the four interactions and 'Rank 4' represents the least important. Note also that the sum of all bars within each LO result is zero, however, the ranking for each interaction can vary within the learning outcomes.

A series of Mann-Whitney U tests (Salkind, 2010) was performed to check for statistically significant differences in the distribution of responses received from students and instructors for the four interaction types for each learning outcome. The test revealed that there were four statistically significant differences in the responses with $p<0.10$; student-instructor interaction for LO6 ($U=187$, $z= - 2.466$, $p=0.01$), student-student and student-instructor interactions for LO9 ($U=203.5$, $z= -1.845$, $p=0.06$ and $U=220$, $z= -1.747$, $p=0.08$ respectively) and. student-equipment interaction for LO10 (U=180, z= -1.832, p= 0.06). While a general discussion of the differences between student and instructor responses follows, the responses that were statistically significant at $p<0.10$ are identified in Figure 3 with an asterisk mark (*).

For the purpose of the following discussion of Figure 3, the ten laboratory-learning outcomes are grouped into five broad experimental categories: {LO1, LO2} concern Engineering practice, {LO3, LO4} concern method selection and application, {LO5, LO6, LO7} concern equipment use, {LO8, LO9} concern error analysis, and {LO10} concerns reporting, reflection and concluding.

For 'Engineering practice' {LO1, LO2}, students ranked their interaction with instructors to be more important than did the actual instructors who indicated the importance of students' interaction with equipment to be more useful in gaining an appreciation of scientific method. Also noteworthy is that instructors perceive interactions with student peers inculcate safe and sustainable practices.

For attainment in the 'Method selection and application' group {LO3, LO4} students believed that interactions with instructors and equipment provide better support whereas instructors again believed that students' interactions with other students, either directly or through indirect interactions, were more suited to this purpose.

In the attainment in the 'Equipment use' group {LO5, LO6, LO7}, student and instructors were in close agreement regarding the development and application of models but reported very different views on the value of interactions regarding the design and conduct of experiments (LO6) and matters related to laboratory procedures (LO7). In these two LOs, students continue to look to their instructors for guidance whereas instructors believed that these were enabled by student interactions with their peers. Interestingly, students were clearer than instructors in asserting that their interactions with equipment enabled the development of proficiency in the use of equipment.

Skills required through the attainment of 'Error analysis' {LO8, LO9}, yield different emphases between student perception and those of their instructors. For this group, students clearly place greater importance on student-instructor interactions and indirect interaction. For the former they seek guidance from instructors while the latter suggests that their error analysis benefits from seeing what other students are doing and the questions that they ask instructors as to the 'correctness' of their results. Again, instructors expected students to acquire skills in error recognition and analysis by discussions with their peers, most probably by comparison of results obtained.

Finally, for the development of skills in documenting results, analysing the credibility of outcomes, critical reflection, developing robust conclusions and reporting outcomes {LO10} students also expected to be guided by instructors while instructors placed greater emphasis on their development through, a little surprisingly, by students' interactions with the equipment used. Students and instructors were in agreement over the role of peer interactions (both direct and indirect) in developing this LO.

The foregoing differences in student and instructor perceptions of the relative importance of interactions for attaining the laboratory learning outcomes highlights the need to re-consider the design of present face-to-face laboratory activities and other arrangements made for students to gain practical knowledge of engineering concepts.

6. Discussion of overall findings and contribution to research

The investigation addressing the research question has generated a mapping of the relative importance of the types of student-interactions that result in the attainment of the ten EA laboratory learning outcomes as perceived by these cohorts of students and instructors. For a number of these learning outcomes, differences in the rankings chosen by students and instructors suggest that there is a perception *gap* as to the importance of different interactions for laboratory learning. Overall, the findings are that

- Final-year bachelor of engineering students clearly prefer, or value more highly, interactions with instructors compared to the other interactions to attain most of the EA laboratory-learning outcomes; and
- Instructors believe that a range of students' interactions, either direct or indirect among themselves, alongside interaction with instructors are most useful in the attainment of the EA laboratory-learning outcomes.

Face-to-face laboratories tend to be the preferred mode in engineering because of the discipline's nature and purpose that ultimately results in the creation and operation of physical facilities, equipment and infrastructure. Student interactions play a vital role in students' attainment of the laboratory learning outcomes. However, the 'cook-book' approach in the design of many of these laboratories tends to make students more reliant on instructors. Problem-based (Gürses et al., 2007) and authentic real-life investigations included as part of the laboratory program do provide final-year students with opportunities to explore their learning capabilities, in particular through a laboratory-based final-year project, thereby reducing reliance on instructors by allowing students more independence and enhanced engagement since their choice of project typically aligns with their personal interests.

Statistical calculations revealed few interactions that have significant impact on students' attainment of some important laboratory-learning outcomes. Opportunity to interact with other students during the laboratory work supports students in gaining an understanding not just of the laboratory procedures but also in identifying the errors and faults that might alter the results obtained from the experiment. Hands-on manipulation of the equipment enhances students' ability to report, reflect and conclude their findings obtained from the laboratory work. However, actual knowledge of designing and conducting experiments during the laboratory work comes from the interactions between students and instructors.

Instructors are, and will always remain, a knowledge guide for students and ensure students follow the appropriate pathways to becoming a skilled graduate engineer. The overall findings of the present study also suggest that instructors could introduce change in their instructional practices and invest time to explore ways of re-designing laboratory programs. These changes can potentially create new learning opportunities that will develop a self-learning culture among students. This recommendation can serve as preparation for a career as a professional engineer attuned to self-management of lifelong learning.

Previous research on learning outcomes for engineering students focus more on the importance of those learning outcomes for graduating engineers (Male et al., 2009). Some studies have discussed the type of engineering laboratory courses that meet laboratory-learning outcomes (Most & Deisenroth, 2003) or the design and development of engineering laboratory-learning outcomes (Feisel & Rosa, 2005) or investigated student interactions for their effect on students' learning and their satisfaction with courses (Sher, 2009). However, the actual learning process involved in the students' attainment of the laboratory-learning outcomes have been rarely discussed. In the existing literature in the context of laboratory-learning outcomes, the present study specifically discusses the learning processes associated with the laboratory work, defined by the four student interactions, and the way these interactions impact upon students' attainment of engineering laboratory-learning outcomes. Further, along with three commonly known student interactions (student-student, student-instructor and student-equipment), this study also highlights the importance of indirect interactions in the attainment of laboratory-learning outcomes that have not been previously investigated. Indirect interactions have been shown to be important for students' learning in the laboratory (Lal et al., 2018). Finally, the present paper contributes a new research design for comparing the perspectives of students and instructors in any engineering laboratory setting that is across multiple engineering disciplines of any cohort size

7. Limitations of the study and scope of future research

The findings reported in this study are from a small cohort of students and instructors and is exclusively based on their experiences of face-to-face laboratories. Instructors and students were from just three disciplines of engineering, namely Civil, Mechanical, and Mechatronics Engineering. The applicability of these findings to other engineering disciplines and with larger number of student and instructor responses remains a focus for researchers who foresee applicability of the present results. Furthermore, it would be useful to conduct a similar investigation to obtain the views of students and instructors for modes other than the traditional face-to-face laboratory and include remotely-operated laboratories. Due to the low number of responses received both from students and instructors, further statistical calculations were not possible and hence, no other statistically significant conclusions could be drawn. Also, the conclusions reported from statistical analysis may have been stronger had there been a large number of responses.

Therefore, despite the limitations, the purpose of reporting the findings obtained from the investigation is to initiate a discussion which is deemed important for students learning in the laboratory and also for their attainment of the laboratory-learning outcomes required for them to graduate as a skilled engineer.

8. Conclusions

The present study was conducted with a small cohort of students and instructors. Therefore, the study of student and instructor perceptions of the relative importance of student interactions for attaining the laboratory-learning outcomes stipulated by Engineers Australia presents an indication of some important matters about laboratory learning that warrant careful consideration when designing laboratory experiments.

The relative importance of the four predominant student-interaction types have been mapped to the ten EA laboratory learning outcomes. In doing so, a marked difference was found between student perceptions and those of their instructors in face-to-face laboratory learning. The main differences have been identified in terms of groups of laboratory learning outcomes. Nevertheless, as learners, final-year students do value, or remain dependent upon, interactions with, or learning from, instructors, as leaders, and opportunities for hands-on manipulation of equipment more than the opportunity to interact with their peers and/or to be able to learn from observation of others' working in the laboratory. By contrast, instructors believe that peer interactions (direct and indirect) are an equally important means of learning but the student views suggest that this is not occurring to the extent for which the laboratory activities were designed.

At present, with small cohorts of student and instructor, this research has shown that a delicate balance needs to be taken between instructors actively directing laboratory learning and the need to allow students to have the opportunity to explore and self-learn through their laboratory work. The research findings have illustrated the viability of the research design for use with larger student cohorts for measuring the relationship of laboratory interactions with Engineers Australia laboratory-learning outcomes. With a larger cohort, it is recommended to implement a quasi-longitudinal study across the four years of engineering degree to ascertain any changes in students' and instructors' perspectives of the relative importance of four main types of student interactions taking.

Disclosure Statement

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Appendix A: Survey questionnaire to map interactions with EA laboratory learning outcomes

Reflecting on the overall laboratory experiences in your undergraduate engineering laboratories, for each of the 10 competencies, please rank (from 1 highest to 4 lowest) the importance of the interaction type to develop the competency described in column 1 of the table below.

EA laboratory learning outcomes	Interaction type			
	Student-Student interaction	**Student-Instructor interaction**	**Student-Equipment interaction**	**Indirect Interaction**
LO1. An appreciation of the scientific method, the need for rigour and a sound theoretical basis;				
LO2. a commitment to safe and sustainable practices;				
LO3. skills in the selection and characterisation of engineering systems, devices, components and materials;				
LO4. skills in the selection and application of appropriate engineering resources, tools and techniques;				
LO5. skills in the development and application of models;				
LO6. skills in the design and conduct of experiments and measurements;				
LO7. proficiency in appropriate laboratory procedures; the use of test rigs, instrumentation and test equipment;				
LO8. skills in recognising unsuccessful outcomes, diagnosis, fault finding and reengineering;				
LO9. Skills in perceiving possible sources of error, eliminating or compensating for them where possible, and quantifying their significance to the conclusions drawn;				
LO10. skills in documenting results, analysing credibility of outcomes, critical reflection, developing robust conclusions, reporting outcomes				

Note that the preamble above was used for the student survey. For the survey of academic staff (instructors), the preamble was: *"Reflecting on your* ***laboratory teaching experiences*** *in the undergraduate engineering laboratories, for each of the 10 competencies, please rank (from 1 highest to 4 lowest) the importance of the interaction type to develop the competency described in column 1 of the table below"*, but the table of the servery was identical to that above.