# A study of the relative importance of student interactions for the attainment of laboratory-learning outcomes

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## 1. Introduction

Engineering laboratories, are currently conducted in various modes (Corter et al., 2011; Ma, & Nickerson, 2006). Those which involve real physical equipment, are face-to-face and remotely-operated laboratories. Face-to-face laboratories are the traditional and the most common mode for conducting laboratory experiments but may become impractical or too expensive to operate when the number of students is very large, due to their lack of flexibility in terms of time availability and scheduling. In contrast, technology supported remotely-operated laboratories provide greater flexibility of time and space, can be less expensive to operate and can potentially cater to larger student cohorts. The wider adoption and use of remotely-operated laboratories for educational purposes is currently limited possibly because of the difficulty of establishing a collaborative environment for students and instructors to interact during the laboratory work and also the physical separation between students and equipment. The present study therefore seeks to determine the relative importance of such interactions in traditional laboratory learning, as perceived by students and instructors, as a basis for the appropriate design of remote laboratories.

Previous studies have classified student interactions into three types: student-student (SS), student-instructor (SI), and student-equipment (SE) (Anderson, 2003; Miyazoe, 2012). Recent studies (Lal et al., 2018; Wei et al., 2018) have added a fourth type termed indirect interaction (IndInt). This 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. However, these interactions may be modified or even entirely absent in remote laboratories.

Attempts to establish opportunities for all four interactions to take place in remotely-operated laboratory have yet to be reported to the present authors' knowledge. However, some remote laboratories such as NetLab (Teng et al., 2016) have design features that allow students to collaborate during their laboratory work. Others have incorporated features that allow instructors to guide and observe students during the conduct of their laboratory experiment. The primary focus so far in the design of remote laboratories has been on providing students with convenient access to real equipment (Lindsay & Good, 2005).

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, 2008) in face-to-face laboratories from which recommendations for remotely-operated laboratory learning can be made. The study is centred on the views expressed by final-year undergraduate engineering students (Cicek et al., 2014, 2017) and also by their instructors. Final-year students was chosen because through their earlier study they would have developed a better 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) stipulates ten laboratory-learning outcomes for all students graduating with an accredited (at professional level) Bachelor of Engineering degree; 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.

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 a 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.

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 focus of the present study.

There are advocates for establishing remote-laboratory environments for students and instructors to conduct laboratory learning at the same level of effectiveness as achieved in the face-to-face laboratory mode; the proposition is that the remotely-operated laboratory could provide opportunities for appropriate collaboration and the attainment of essential skills. However, the direct significance of collaboration among students and instructors and the ease of access of equipment for its operation, with the actual attainment of the stipulated laboratory learning outcomes have not been studied yet.

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. The detailed discussion in Lindsay and Stumpers (2011) does address the design of remote laboratories to support students' attainment of Engineers Australia Stage One professional competencies. They show that remote laboratory deployment in combination with face-to-face laboratories can assist students in achieving all of the targeted learning outcomes. Various other comparisons have been conducted between face-to-face and remote laboratories for their effectiveness in students' attainment of learning outcomes (Lindsay & Good, 2005; 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 experiment in the respective laboratory modes. The distinct contribution of the present article is to relate the attainment of laboratory-learning outcomes with the interactions that take place within the laboratory activity.

## 3. Research questions

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

1. Which 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?
2. How can the results from (1) above be utilised to inform design for effective laboratory instructional practices in both face-to-face and remotely operated engineering laboratories?

## 4. Conceptual framework

The concept 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. Finally, students are awarded an engineering degree upon their attainment of those skills.

The structure depicted in Figure 1 equally applies to remotely-operated laboratories. Thus, understanding developed from the study of face-to-face laboratory work can support the future design of remotely-operated laboratories.

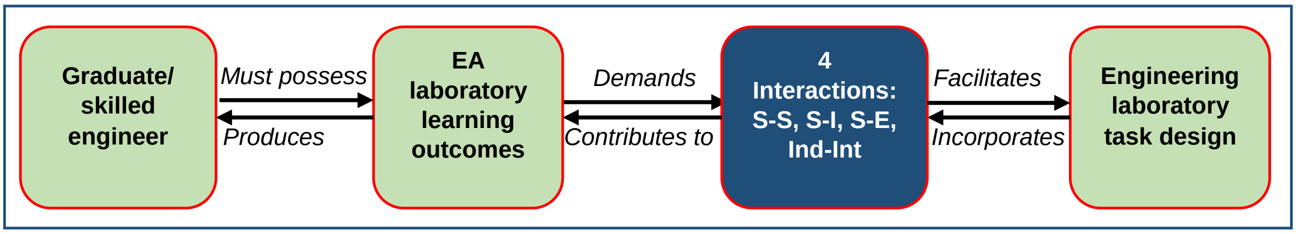


Figure 1: Interactions in engineering laboratory work contributing to the attainment of EA outcomes required to graduate as a skilled engineer. SS=Student-Student interaction, SI= Student-Instructor interaction. SE=Student-Equipment interaction, and IndInt=Indirect interaction

## 5. Research methodology

A quantitative study (Creswell, 2013) was conducted to answer the research questions posed in this study. An online survey questionnaire was designed and administered to all final-year (4th-year) students of an accredited Bachelor of Engineering and, as a separate cohort, their academic instructors in the School of Civil and Mechanical Engineering at an Australian University. The questionnaire developed and used is shown as Appendix A. Respondents were asked to rank each of the four interaction types from most important (1) to the least important (4) on the basis of its contribution to attaining each of the ten EA learning outcomes.

A total of 26 final-year students (from a student cohort of approximately 300) responded to the survey; these Engineering students had undertaken all of their practical work in the face-to-face laboratory mode during their degree study. The students did not have exposure to or experience of remote-laboratory work. Similarly, 22 instructors (from an academic staff cohort of approximately 40), with teaching experience in face-to-face laboratory mode responded to the survey. It is recognised that the results discussed in this study arise from small number of respondents. Thus, the purpose of the investigation reported in this study is to initiate an enquiry that has yet to receive sufficient attention in the Engineering-education community.

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

## 6. Results and discussion

### 6.1. Results

First, the correlation between students and instructors' responses was calculated and then graphical analysis was conducted. SPSS software was used to calculate the correlation coefficient between the responses received from students and instructors in the face-to-face laboratory. Calculation revealed a high correlation in the responses received from students and instructors ($r=0.87$, $p<0.01$). This indicates a significant alignment of in opinion received from students and instructors.

Figures 2(a) and (b) show the average of the ranking of the four interaction types in their contribution to the attainment of the 10 LOs drawn from the responses received from students and instructors respectively. The 10 learning outcomes (LO) in the figures are listed in the first column of the table in Appendix A. Each of the concentric rings represent a rank from 1 to 4, noting that 1 represents the greatest importance and 4 the least.

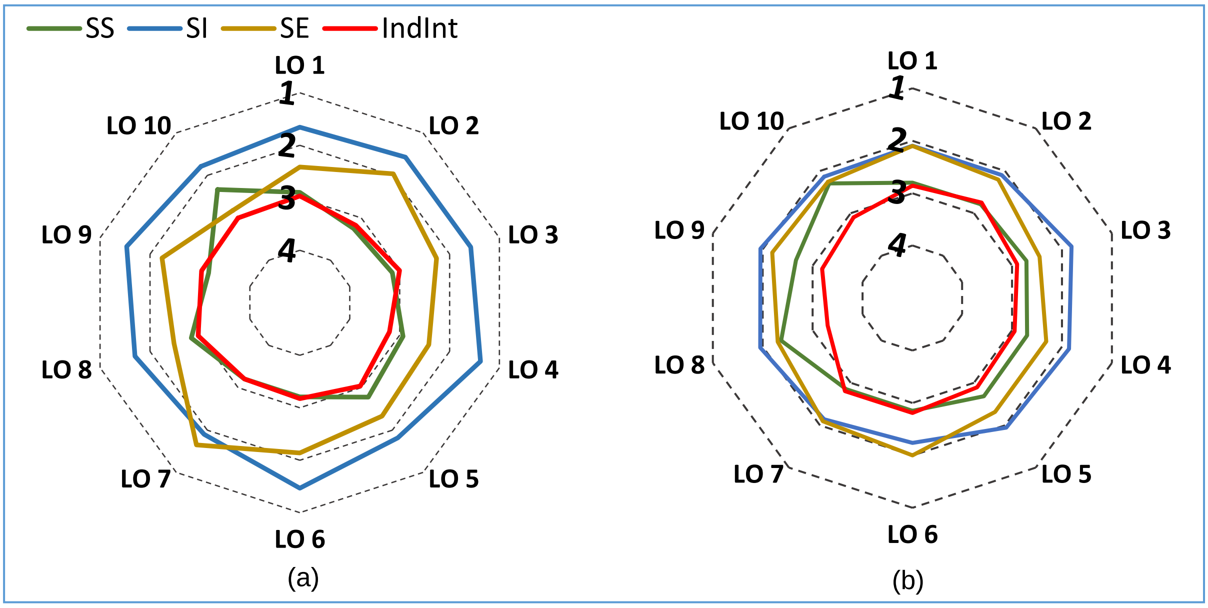


Figure 2: (a) Students (N=26) perceptions and (b) Instructors (N=22) perceptions of the relative importance of students' interactions in laboratory work towards attaining the EA laboratory-learning outcomes (LOs). SS=Student-Student interaction, SI= Student-Instructor interaction. SE=Student-Equipment interaction, and IndInt=Indirect interaction.

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 (SI) interaction. The second most important type of interaction was that of Student-Equipment (SE) interaction with an average rank that was mostly between rank 2 and 3, but peaked and averaged below 2 for the learning outcomes LO2 (safety) and LO7 (use of test rigs). The third most important type of interaction is that between students (SS). 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 interactions (IndInt) 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 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 (SI) interaction, indicating it to be the most important type of interaction of all. The average rankings for SI 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 (SS), Student-Instructor (SI) and Student-Equipment (SE) interactions all lie between 2 and 3 for all LOs with indirect interaction (IndInt) 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.

## 6.2. Discussion

### 6.2.1. The relative importance of interactions in face-to-face laboratories

Figures 2 (a) and 2(b) have shown that both students and instructors perceive 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 10 EA laboratory learning outcomes is seen in Figure 3.

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 interaction and 'Rank 4' represents the least important. This means that positive bars in Figure 3 indicate interactions that students perceived to be more valuable for the attainment of that LO while negative bars indicate the important ones from the instructors' perspective. Note that the sum of all bars within each LO result is zero.

For the purpose of the following discussion of Figure 3, the 10 laboratory learning outcomes are grouped into five broad experimental categories, namely: {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 {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 of the 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.

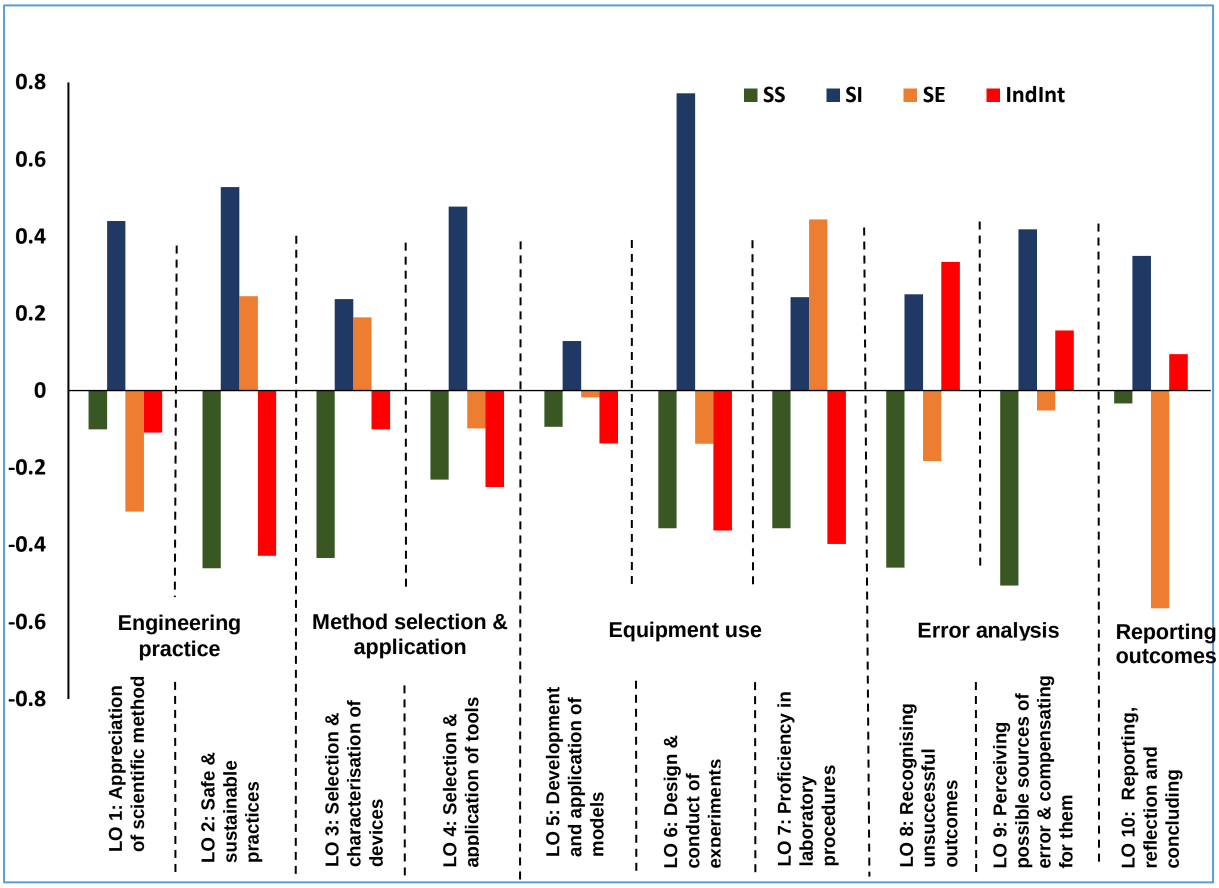


Figure 3: Difference of the average ranking observed in the students and instructors' response. Note: +ve difference represents students' ranking of interactions greater than instructors and –ve difference represents instructors' ranking of interactions greater than students. SS=Student-Student interaction, SI= Student-Instructor interaction. SE=Student-Equipment interaction, and IndInt=Indirect interaction.

In the attainment of 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 (LO 6) and matters related to laboratory procedures (LO 7). 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 more positive 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 {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 these to be developed 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. Overall, it seems that final-year students still expect instructors to lead their attainment of learning outcomes while instructors currently expect that such students, at their relatively advanced stage of educational development, should have become more independent learners and/or be able to learn through peer interactions.

### 6.2.2. Potential implications for remote laboratories

For proponents of remote laboratories, the above results from face-to-face laboratories pose challenges for creating a remote laboratory design which can effectively allow students to interact with instructors and gain the equivalent of a hands-on experience of equipment at a similarly effective level.

In remotely-operated laboratories, student-equipment interaction is evident and probably the most focused feature by designers of remote-laboratory systems. Recommendations for enhancing the design of remotely-operated laboratories generally come from the instructors themselves or academics researching engineering-education practice. However, the present findings for face-to-face laboratories suggest that it is crucial to take into account students' perceptions of what the types of interaction that they believe allows them to learn effectively through laboratory activities.

For the effective integration of remotely-operated laboratories alongside existing face-to-face laboratories in a laboratory teaching and learning program, it is important that efforts are made to create similar environments. This means enabling the important interactions that lead to the attainment of a set of mandated laboratory-learning outcomes which apply to both face-to-face and remotely-operated laboratory learning.

## 7. Conclusions

The present study of perceptions of the relative importance of student interactions for attaining the laboratory learning outcomes stipulated by Engineers Australia highlights some important matters that require careful consideration.

In answer to Research Question 1, a marked difference has been shown between student perceptions and those of their instructors for face-to-face laboratory learning. The main areas in which differences arise have been identified in terms of groups of laboratory learning outcomes. Overall though, final-year students value, or remain dependent upon, interactions with, or learning from, instructors and any opportunity 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' work in the laboratory. This then suggests that while instructors believe that peer interactions (direct and indirect) are an equally important means of attaining laboratory learning outcomes, this is in fact not occurring to the extent for which the laboratory activities have been designed.

In answer to Research Question 2, the beneficial adoption of remotely-operated laboratories may rely upon the consideration and incorporation of the types of interaction prioritised by students, namely student-instructor and student-equipment interaction, or their replacement via technological innovations, as their most effective means of attaining the laboratory learning outcomes.

## Disclosure Statement

The authors declare no conflicts of interest.

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## Appendix A: Survey questionnaire

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** (learning through discussions with other students) | **Student-Instructor interaction** (learning through discussions with laboratory instructors) | **Student-Equipment interaction** (learning through manipulation of equipment and from lab sheet instructions) | **Indirect Interaction** (learning through observation of or listening to other students and instructors interaction in the laboratory) |
| **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 | | | | |