DEVELOPING LABORATORY PROJECTS FOR A JOINT CHINESE/NZ MECHANICAL ENGINEERING PROGRAMME

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ABSTRACT

In engineering education, the underlying theory is developed in classroom lessons and its application in engineering is usually reinforced with laboratory experiments. Practical laboratory experiments that are performed in small groups or teams are common practice in most engineering programmes at a tertiary level around the world. In the Chinese education system, however, students often have little exposure to team-based assessments, and practical components are more observational that participatory. This paper reviews two project-based laboratory experiments that were developed for groups of 45 and 80 mechanical engineering students respectively in a Chinese University, as part of a collaborative degree program with Otago Polytechnic New Zealand. The first laboratory was part of strengths of materials course and was designed to reinforce understanding of strain gauges, which are passive transducers that convert a mechanical displacement due to applied force into a change of resistance. The second laboratory was developed for the thermodynamics and heat transfer course, where the students were required to conceive, design, construct and test a solar hot water system. Through developing more project-based and team-centred laboratories for larger classes, we discovered potential to integrate technical knowledge and logical problem-solving techniques with important aspects of group culture and language learning. We believe project-based and team-centred laboratory experiments run for larger classes in contexts like China can function as important steps towards more open-ended project-based and learner-centred learning. Further, building in language learning opportunities (LLOs) help to initiate students into the target language medium. Through the merging of a traditional laboratory with a CDIO-based project cycle and focus on language learning, we believe we can prepare students for successful learning in a project-based environment on a joint degree programme.

KEYWORDS

Project-Based Laboratories, Strain Gauges, Solar Water Heating, Project Groups, Language Learning Opportunities, Standards 2, 4, 5, 6, 7, 8.

INTRODUCTION

Outcome- or project-based learning (PBL) is a method of teaching that emphasises what learners can do once they are trained (Marwan Shamel, 2010). This is considered an essential feature of the CDIO initiative, where it provides the platform to implant essential graduate attributes and skills into an engineering program. Armstrong (2008) describes those attributes and skills which the new graduate must acquire at the completion of the engineering program. Along with a solid foundation in engineering principles, they are believed to be vital tools needed to handle the dynamism of the current world.

In our previous papers, we discussed the development and the implementation of a project-based learning (PBL) model for non-native English learners following the CDIO initiative (Weerakoon, Dunbar, & Findlay, 2014), (Weerakoon & Dunbar, 2017) (Weerakoon & Dunbar, 2018). We described a programme developed and taught in a language immersion situation in New Zealand which provided students with a better understanding of applying engineering knowledge into working examples, along with developing both engineering and English language and communication skills relevant to the real world. The above studies demonstrated that a motivation factor for students engaging in PBL is that it brings the learners' engineering knowledge closer to real life context and technology, and encourages them to be independent lifelong learners, critical thinkers, and good communicators.

We believed that many of the lessons and experience from that process should also be applicable when delivering courses in a non-immersion (English as a Foreign Language (EFL)) situation at university in China. We were conscious, however, of cultural and logistical challenges that were likely to arise when adapting this model to a new environment. This paper, therefore, outlines initial steps towards implementing PBL engineering laboratories that focus on developing integrated engineering, communication and language attributes in a Chinese university context.

Essentials of Engineering Laboratories in Engineering Education

Engineering is primarily devoted to harnessing and fine tuning the three essential resources - energy, materials and information - available for the making of all technology (Feisel, 2005). Feisel (2005) distinguished three basic types of engineering laboratories, including educational instructional laboratories which are often designed for undergraduate students and involve knowledge that is already known to practise engineers. A common goal of instructional laboratories in engineering programs is to relate fundamental theory to practice and to connect the real world into what would otherwise be theoretical education. Instructional laboratories are also at times considered to be a motivational factor to continue in the study of engineering since laboratories in many engineering programs are the only means by which students learn by doing things.

Engineering laboratories generally follow the introduction of the fundamental theory in classroom lessons and focus on reinforcing their application in engineering. However, there often seems to be a disconnect between those learning practices and full understanding of how this transformation process is achieved in the laboratories. To bridge this gap, the current study designed laboratories for two engineering courses - Thermodynamics and Heat Transfer and Strength of Materials - based on the CDIO model of conceiving, designing, and constructing the experiments prior to testing the laboratories to acquire the known knowledge.

One of the characteristics of many Chinese Engineering institutes is large class numbers, and undergraduate programs often lack facilities for student-centred laboratory experiences. In these institutes, engineering programs are mainly focussed on strengthening work on fundamental theory, and as a consequence, many undergraduate students have limited opportunities to develop skills on how theory connects to practical applications, lateral thinking and learning by doing. Laboratories are often 'observation'-based rather than experiential learning. We believe this also contributes to the disconnect between theory and practice that these students experience.

English Language Medium and Cultural Issues

The case study presented here is based on a joint programme between Otago Polytechnic and a Chinese university. In this collaborative programme, students study the first three years in China before coming to Otago Polytechnic for a final year. The medium of instruction in China for the engineering courses is English, although local teaching assistants (TAs) are available to help with communication issues. Students also have separate English language classes provided by the Chinese institute based on the Chinese College English curriculum. This curriculum, however, does not provide specific engineering-related support. We believe, therefore, that as far as possible engineering classes and especially laboratories need to provide opportunities for students to build confidence in using the English language for engineering communication purposes.

Observation of engineering classes on the joint programme delivered in China has shown that many, perhaps most, students struggle to understand large portions of lectures delivered in English. TAs, therefore, play an important role in translating engineering content. Students generally have more developed reading and writing skills than oral skills, but for engineers to practice, they need to develop good oral communication skills. Large classes limit the amount of language production that can occur in these classes, but team-based laboratories provide more opportunity for embedding communication and language learning opportunities.

Another aspect we considered prior to implementation was the impact that culture would have on the effectiveness of team-based and student-centred laboratories. We knew that Chinese students had seldom been exposed to group-based projects in an educational learning environment, but Chinese culture has long been identified as 'collectivist' (Hofstede, 2001). Team dynamics differ somewhat from those that we were familiar with in New Zealand (and from our experience with Japanese students on our previous projects), so we were uncertain what to expect. In particular, the large class sizes meant that we needed to work with a number of larger groups in limited space, and we were keen to observe the effectiveness of student-centred and project-based laboratories under these conditions.

DEVELOPMENT OF PROJECT-BASED LABORATORIES

For this pilot study designed to test the effectiveness of CDIO-based laboratories in the Chinese context, two laboratories were designed to meet part of the learning outcomes of the strength of materials course and a thermodynamics and heat transfer course as shown in Tables 1 and 2 below. The thermodynamics and heat transfer course consists of 60% internal assessments including assignments and practical laboratories, and a 40% final exam. The strength of the material course consists of 50% internal assessments including assignments and practical laboratories and 50% final exam.

Table 1 Learning outcomes and assessments for Thermodynamics and heat transfer

Learning outcomes	Assessment type	Weighting
1. Describe methods of energy production and their environmental effects	Assignment and exam	28.3%
2. Explain and apply the first and second laws of thermodynamics	Laboratory and exam	43.3%
3. Discuss the properties and characteristics of thermodynamic systems	Assignment and exam	28.3%

Table 2 learning outcomes and assessments for Strength of Materials

Learning outcomes	Assessment type	Weighting
1. Identify modes of failure in components	Assignment and laboratory	25%
2. Determine safe working stresses for components	Laboratory	10%
3. Analyse components in terms of principles of strength of materials	Exam and laboratory	65%

The strength of materials laboratory was designed for a class of 45 students from the 2016 intake and was delivered in 2017; the thermodynamics and heat transfer laboratory was delivered in 2018 to both the 2017 intake (80 students) and the 2016 intake (45 students). The thermodynamics and heat transfer laboratories were delivered separately to the two intakes during the 2018 winter months in the northern hemisphere.

Because the project-based learning laboratories were aimed at the course laboratories component which makes up only 20% or less of the overall course mark, the students completed the design and testing phases using out-of-class time and were provided with approximately six (06) hours of class time to complete their construction based on the design.

Task Design: The strength of Materials Laboratory

The development of the strength of materials laboratory was aimed at reinforcing the fundamental theory related to strain gauges. Strain gauges are passive transducers that convert a mechanical displacement due to applied force into a change of resistance. This is a fundamental theory addressed in the study of strength of materials. Generally, the concept of this conversion process is developed in classroom lessons, and its application in engineering is reinforced with laboratory experiments including bending, deflection and vibration. However, we have found there to be a disconnect between those learning practices and a full understanding of how this conversion process is achieved.

To bridge this gap, the laboratory was designed to allow students to conceive, design, construct and test a cantilever beam to measure mechanical displacement due to an applied load, and thus determine both the modulus of elasticity of the cantilever material and the deflection of the beam under various loads.

This is a well-defined design problem and designing the laboratory consisted of providing clear English language instructions relating to the strain gauge installation method at the appropriate location of the cantilever, soldering of the strain gauge terminals, and construction of the quarter bridge circuit to measure the change in resistance due to an applied force. The results could then be used to establish the modulus of elasticity of the materials and predict the deflection of the cantilever.

In this laboratory session, students were divided into six teams. The teams were expected to perform all laboratory outcomes including extracting experimental data for scientific calculation independent of other teams. Materials provided for cantilever testing were steel, brass or aluminium, a two wire 120-ohm strain gauge, terminal cables and metal surface preparation materials for strain gauge installation, and adhesives. A dial tester measured the deflection of the cantilever.

Task Design: Thermodynamics and Heat Transfer Laboratory

The development of this laboratory was aimed at harnessing the solar radiation energy and effective transfer of this energy to generate thermal heat using water as the medium. This was an open-ended design problem where students were tasked with conceiving, designing, constructing and testing to determine the effectiveness of the solar hot water heating system. The aim of the laboratory was to produce 10 litres of warm water raised to a minimum of 45 degrees during a typical winter period in the northern hemisphere (at roughly 40ºN) and to calculate the heat transfer effectiveness. Students were then expected to connect their learning to the theory learnt in class. Therefore, the laboratory instructions were primarily focussed on meeting the assessment outcome rather than the construction process or experimental procedure. The students were provided with the freedom to decide their own test procedure.
All teams were provided with the same resources to construct their hot water system:

- 12 mm internal diameter tube between 35m to 40m in length
- Materials to design the frame to accommodate 32m of tube length
- Transparent sheet to create a greenhouse effect
- Insulation sheet to rest the tube on top
- Various pipe fittings to circulate and collect water
- Thermocouple to measure water intake and outlet temperatures
- One radiometer to measure the incident solar radiation
- 500 ml measuring beaker

The team composition for the 2016 intake was the same as for the strength of materials laboratory. However, the 2017 intake had 80 students. The students were divided into 10 teams. Two teams were then joined together (to make five larger project groups) to conceive, design and construct the solar hot water panel. Because the two teams that made up each project group came from different classes, they conceived a common final design solution for the solar hot water panel outside classroom hours. Then, when construction commenced, the first team would hand over the construction responsibility to the second team at the end of each 90 minute laboratory session. The process continued until the whole panel was completed and ready for testing. Then the project groups were split into the original teams again and testing of the panel was carried out outdoors by each team separately. This model introduced added complexity with respect to interpersonal relations, negotiating a common goal, responsibilities and time management, and most importantly communication when the responsibility of handing over the construction was taking place, not only amongst individual team members, but also between teams in a group.

Since this was an open-ended problem, the students were given the flexibility to use waste or surplus materials which they could salvage besides the laboratory resources provided in order to fine tune the panel design to its solar energy harnessing effectiveness. The instructions for the laboratory were worded to clearly aim at meeting the laboratory outcomes using the resources provided rather than focusing on the construction process or the experimental procedure.

Construction Process: Strength of Materials Laboratory.

Figure 1a shows the steps associated with the installation of the strain gauge on the material surface. It consists of surface preparation - indicating the attachment location and cleaning of residue; application of adhesive tape and adhesive to attach the strain gauge; and holding until the strain gauge clasps the surface. The next step consisted of soldering the terminals, attaching the terminals to the strain gauge reader and subjecting the cantilever for a range of static loadings to measure the strain reading and deflection, as shown in Figure 1b.

a) Strain gauge Installation **b) Experiment setup**

Figure 1 Strength of material laboratory

Construction Process: Solar Hot Water Heating System

Figure 2 shows the steps broken down to construct the solar hot water panel. The first step involved constructing the frame to house the water circulating tube, followed by insulating the wall of the housing. One project group was provided with a coloured tube with 12 mm internal diameter tubes while all other project groups were provided with transparent 12mm internal diameter tubes. All project groups from both intakes (2017 and 2018) formed the same shape for the configuration of the water tube inside the housing. However, some project groups decided to attach sheets of salvaged black garbage bags between the insulation and the water tube. Some other groups painted the top surface of the transparent tube with mat black as shown in Figure 2b. The tube was secured to the wall of the housing, so that the tube would not collapse under the weight of the water during testing. The transparent sheet was laid over the housing to create the greenhouse effect. Finally, the pipe fittings were connected to circulate the water through the water mains.

i. Cutting to length ii. Connecting the angles iii. Completed housing

iv. Handing over v. Installing tube vi. Installing tube

Figure 2 constructing the solar hot water system

RESULTS

Strength of Materials Laboratory

This laboratory consisted of six teams. Two teams constructed the cantilever using the same material so that their results could be compared with each other and their proximity to theory measured. Five out of six teams met all the laboratory assessment outcomes. One team completed the construction, but their strain gauge did not work due to imperfection. This team used aluminium for the cantilever

As shown in Figure 3, both teams using the brass material estimated values of modulus of elasticity that were comparable with theory. The teams using steel and the one team using aluminium for the cantilever material estimated values of modulus of elasticity that were double that predicted by theory. A common experimental error observed with all three cantilevers was students not removing the masking tape clasped over the strain gauge prior to testing. This was only identified by the students when the calculations were completed. The brass teams exposed the strain gauge prior to testing. They were then able to explain to other teams the reason for their results being closer to theoretical calculations.

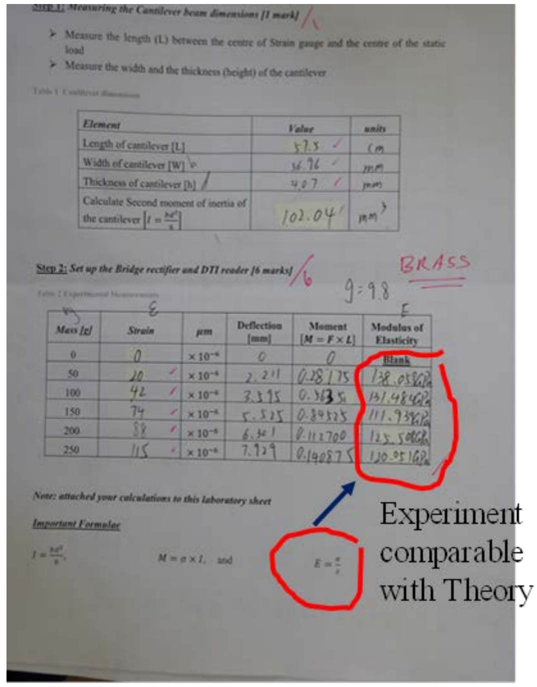

Figure 3 Experimental modulus of elasticity estimation for brass

Thermodynamics and Heat Transfer Laboratory

All teams from both intakes in 2016 and 2017 completed all of the requirements to meet the laboratory outcomes. However, the design arrangement for the tube configuration was the same for all teams or project groups. No team attempted to alter the tube configuration inside the housing. Figure 4 shows the testing of the panels outdoors, carried out by the 2017 intake. The students who understood the fundamental theory in heat transfer coped well with their design output by carrying out simple modifications to resources provided. As shown in Figure 4, their designs achieved over 60 degrees with outlet water temperature. The inlet temperature of water from the mains was about 18 degrees. Those panels achieved between 30 to 35 percentage efficiency in converting the total incident radiation to thermal heat. The panels that performed best were the ones that had a black sheet between the tube and the insulation, while the panels with transparent tube painted mat black performed better than those panels with wholly transparent tubes.

i. Testing outdoor ii. Collecting hot water iii. Measurements

iv. Outlet water temperature

Figure 4 Testing the hot water solar panels

DISCUSSION

Reflecting on mistakes

As we identified in a previous paper (Weerakoon & Dunbar 2017), mistakes in practical procedures often lead to learning for both students and teaching staff. There are many errors associated with strain gauge readings, including heat from the strain gauge, large changes in the temperature in both the test specimen and the strain gauge, faulty adhesive bond between the strain gauge and the test specimen, errors due to transverse sensitivity of the gauge, the circuitry between the gauge and the instrument and instrument itself. However, at molecular level strain is related to relative spacing between the atoms. Therefore, strain gauge has a finite stiffness. In this case, the students used masking tape to protect and reinforce the strain gauge during soldering. The teams using the brass cantilevers removed the masking tape after soldering and prior to testing the cantilever, thereby removing the additional stiffness from the strain gauge. However, other teams failed to remove the masking tape, providing the additional stiffness to the strain gauge. Consequently, with all other errors being within operational range for all teams, the additional stiffness restrained strain. Since the modulus of elasticity is the ratio of stress over strain, those teams obtained a relatively larger value for modulus of elasticity. However, had this being highlighted during the test, students may not have fully understood the role of their large experimental error, so a comparison between teams and team reflection added to the learning from this laboratory.

Understanding Counterintuitive Concepts

On a clear sky day, the direct incident solar radiations range between 700 to 900 W/m^2 around part of China where the case study was located. A basic heat transfer calculation will demonstrate the degree of potential solar energy that could be harnessed by the water inside the solar panels. However, prior to testing the solar hot water heating systems outdoors, the students had already judged that the temperature of the water inside the solar panel would not be heated. Although they understood the theoretical calculations, they appeared unable to apply this reasoning to establish the heat transfer mechanisms, and potential ability to harness this incident solar radiation. Before the test, when this was demonstrated in the classroom, this was contrary to their perception. However, after the test, their understanding of the heat transfer theory grew so that they could see the application of theory in a real context. This connection between theory and practical experiential observations is a key to deepening understanding. In feedback sessions, students were clear that the laboratories had impressed on them an understanding much deeper than that achieved from classroom calculations.

Team Dynamics and Communication

Generally, we found that teams worked well in a Chinese cultural context. One reason for the successful gelling of the teams may be that we implemented these laboratories with second year students who were already familiar with each other and had long developed and established relationships between the individual members. In collectivist cultures, this team 'bonding' can take longer than in individualist cultures, because team unity is based on relationships more than goals (Davis, 2001)
.

One innovation that was introduced for the larger number of students in the 2017 intake was the implementation of project groups, in which two teams from separate classes were combined to work on a single project. This was necessitated by the large numbers and lack of laboratory resources but proved to be particularly insightful in that we were able to identify opportunities to build in communicative attributes through the exchange of information at handover time. Students were observed to struggle with this handover, and subsequent mistakes were identified due to miscommunication. The importance of describing the development of a project and giving instructions and accurate steps needed to be reinforced. One way we believe may be effective in future is to show students how to develop checklists that they could use to ensure that all relevant information has been transferred accurately.

Although students had not been exposed to a group or a team projects much prior to their introduction for these courses, the feedback from evaluative interviews and focus group discussions with the students was overwhelmingly positive. Students felt motivated to be *actively involved* in the laboratories and expressed the desire to have more laboratories in future. They felt that they benefited from the opportunity to communicate in realistic team-based scenarios. They enjoyed the opportunity to try ideas in the design and construction phases and felt that they could understand the fundamental ideas more deeply after completing the projects.

Language learning opportunities

Although language learning outcomes are not measured directly in the engineering courses of this programme, we have observed that, without the increased opportunity to use language in a context-rich environment, language improvement is likely to be severely limited. During observations of the laboratories, and from subsequent feedback, it has become clear that in an EFL context, in particular, students need to be offered and guided towards opportunities to use the second language in context. We refer to these language learning opportunities (LLOs). In these first laboratories, we focused on the laboratory report writing and ensuring that students were introduced to the genre and language required for writing a simple laboratory report, which was a natural part of the laboratory process and a required part of the assessment. From our experience of these two laboratories, however, we believe there is ample opportunity to build in further language production and reception opportunities that will enhance language skills.

Although students have separate English language classes, embedding LLOs into engineering laboratories has several benefits. It provides a chance for oral production skills that tend to be overlooked in large lecture-based classrooms; students have a range of props and techniques (drawings or tools for example) that can be used to enhance communication and help put language into a real communicative context. Further, communicating with each other in small groups can help reduce the anxiety that is common in speaking in front of larger groups.

One major area for improvement identified for future is a need to develop mechanisms for monitoring and developing the take-up and effectiveness of LLOs. It is clear from our observations that some naturally occurring LLOs (for example, intra-group communication during design and construction) were taken up more readily than others. These LLOs must be identified and evaluated so that we can develop a working set so that student attention can be drawn to these opportunities, and so that they can be adapted and reused in future laboratories and practical classrooms, and their effectiveness in terms of overall communicative competence of students measured.

CONCLUSION

Previously we have written extensively about integrating project-based engineering and language learning in a New Zealand (English language immersion) context. In this paper, we have described initial steps to expand this process to an EFL context on a joint engineering programme in China. Operating overseas, and in an EFL environment created a new set of challenges, partly cultural, and partly logistical. However, we believe this paper demonstrates that the basic theory and practices that we developed for onshore delivery can be adapted to an offshore EFL context. In this context, careful consideration needs to be given to cultural factors including team development and the language of instruction. Feedback suggests that these project-based laboratories lead to both deeper and more motivated learning and that they also present a number of language learning opportunities. Further investigation and evaluation of these learning opportunities and learning outcomes will take place as students progress through the joint programme and arrive in a PBL environment in New Zealand, but we are confident that the introduction of these project-based and student-centred laboratories will help prepare students for this process of adaptation.

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