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A case study on the use of a multi-faceted team project for final-year mechanical engineering thesis students

Peter Woodfield[a], Ben Herring[a], Huiazong Li[a], Dzung Dao[a], Van Thanh Dau[a], Shoujin Sun[a], Stefanie Feih[a], Zia Javanbakht[a] and Maksym Rybachuk[a].
School of Engineering and Build Environment, Griffith University[a]
Corresponding Author Email: p.woodfield@griffith.edu.au

ABSTRACT

CONTEXT

Undergraduate engineering programs in Australia require a final year capstone thesis project. This study discusses advantages and limitations of a team-based final-year thesis.

PURPOSE OR GOAL

With growing numbers of students, it is important to consider ways through which learning objectives can be met by using a reduced number of hours assigned to supervision of engineering honours students. It is hypothesized that a differentiated group project may meet the required quality of learning without compromising on the originality and independence of the individuals' work expected from a thesis project.

APPROACH OR METHODOLOGY/METHODS

A study was conducted over a single trimester term at Griffith University with 32 students supervised by 9 academics in mechanical engineering discipline. Among these, 27 students were supervised by 8 academics using a traditional one-on-one student-supervisor mentoring on individual projects and, 1 academic supervised a team project with 7 students. Staff kept a weekly log indicating the numbers of hours invested in supervising students. Additionally, academics were surveyed on possible advantages and/or limitations of a team-project approach to managing final-year projects. The team project activity (with 7 students) was to research, design, build and test a miniature ducted turbine powered by compressed air. Differentiation between individual student projects within the team project was achieved by requiring each student to investigate a different type of ducted turbine.

OUTCOMES

8 out of 9 academics from the discipline participated in the study. On average, 8 academics spent 12.1 hours supervising an individual student project. The team project supervised by 1 academic required 8.8 hours per student. The minimum and the maximum hours spent on supervision 1 individual project were 2.0 and 34.5 hours, respectively. Externally managed industry-based projects required 8.8 hours, University centre - 13.7 hours and academic projects 17.0 hours per student. The team project resulted in 6 out of 7 students completing the thesis.

CONCLUSIONS/RECOMMENDATIONS/SUMMARY

The team project generated 6 substantially different theses works. Students benefited from the findings of other team members with respect to construction method, experimental technique and interpretation of results. The team project achieved a reduction in the supervision hours per student compared to the traditional 1-on-1 student-supervisor arrangement.

KEYWORDS

Capstone project; team-based; undergraduate engineering thesis.

Introduction

In undergraduate honours mechanical engineering programs there are typically three major components that correspond to integration of engineering knowledge – capstone design course(s), engineering professional practice/industry work experience and a final-year thesis. Capstone courses often contain design project work that can be done in a group (Merrett, 2022) and have the goal of practical application of engineering knowledge (Hamlin et al. 2014). Professional industry experience is typically, but not always, associated with engineering vacation employment. The final-year thesis is traditionally done as an individual project where students can demonstrate their research skills (Stappenbelt and Basu, 2019). For Mechanical Engineering at Griffith University, the final-year thesis is known as 'Industrial Affiliates Program (IAP) Thesis' with contributions towards all three of these aspects of integration and application of engineering knowledge. The objectives of IAP Thesis include being a capstone for the degree, providing an opportunity for students to acquire days towards professional practice requirements and serving as the main vehicle for demonstration of research skills required for the Australian Qualifications Framework (AQF) for a bachelor honours degree (AQF8). In recent years, senior management has encouraged staff to consider offering group-based projects to reduce the supervision workload. The educational implications of that advice is the motivation for this study.

Variations and alternative approaches to the traditional one-to-one student/supervisor model for thesis have been considered in other contexts. Dysthe et al. (2006) reported some merits of having multiple supervisors and interaction with peers in a research team for Master of Education thesis students. They reported positive experiences for the students involved and argue that 'that joint activity will improve research training'. For post-graduate research, Vehviläinen and Löfström (2016) cite several works that promote the idea to 'reconsider the agent of the supervision – from activity between individuals towards group-level as well as community-level activities'. These studies are more concerned with improving the supervision model for *postgraduate* students without considering any issues with overlaps in the dissertation topics among students. At a postgraduate level the individual student's work must be original and distinctly different from that of their peers in order to publish – so the problem of the topic having too much overlap with other students is not so likely to happen. Rather than the problem of receiving 'too much help' from peers, a more frequent concern expressed in the literature is having too much input from the supervisor in the one-to-one model (Cook 1980). For an undergraduate honours thesis, publication in the open literature is not essential so the guardian of 'failing to pass peer review due to insufficient originality' is not necessarily present. Therefore care must be taken to ensure that each student has a different facet to consider in a larger research team approach.

Learning Outcomes to Meet Expectations of EA and AQF8

To test if a group-based approach to undergraduate engineering thesis can meet accreditation requirements it is important to consider the competencies for graduates required by Engineers Australia together with the requirements specified by AQF. Here we map the target learning outcomes against EA stage 1 competencies and AQF8 learning outcomes. The learning outcomes set for 6002ENG IAP Thesis are as follows:

After successfully completing this course you should be able to:

1. *Describe a research question and apply a systematic approach to the planning, conduct, management and reporting of an engineering research project.*
2. *Conduct a literature review and describe a specialist body of knowledge and the current directions appropriate to an engineering research project.*
3. *Apply engineering methods, techniques, tools and resources to the solution of complex engineering problems.*
4. *Analyse and critically evaluate the research data, arguments and evidence appropriate to the engineering research project.*

5. *Describe the way in which contextual factors such as professional, environmental, economic and/or social issues influence the engineering research project and/or the engineering industry.*
6. *Effectively communicate the engineering research project in both a professional engineering research report and an engineering research seminar.*

Perhaps with LO5 as an exception, these align well with those identified by Cook (1980) for undergraduate thesis in science or related fields. They also match well with those listed by Stappenbelt and Basu (2019) for undergraduate engineering thesis. Cook (1980) places a slightly greater onus on the student through the use of expressions such as '*formulate an academically acceptable program*' instead of our '*describe … and apply*' in LO1. There appears to be nothing in the above learning objectives that precludes the use of a group project for thesis except for the notion that research requires a level of independence. The learning objectives map onto Engineers Australia Stage 1 Competencies (2019) as shown in Table 1.

Table 1: Mapping of learning outcomes to Stage 1 Competencies

E.A. Stage 1 Competency (abbreviated)		LO1	LO2	LO3	LO4	LO5	LO6
1. Knowledge and Skill Base	*1.1 Underpinning science and engineering fundamentals*		✓				
	1.2 Mathematics, numer. anal., stats, & info sciences.		✓				
	1.3 Specialist bodies of knowledge within the discipline.		✓				
	1.4 Discernment of research directions within discipline.		✓		✓		
	1.5 Knowledge of contextual factors.					✓	
	1.6 Understanding contemporary engineering practice		✓	✓	✓	✓	✓
2. Engineering Application Ability	*2.1 Application of eng. methods to complex problems*		✓	✓			
	2.2 Fluent application of eng. techniques, tools & res.						
	2.3 Application of systematic eng. synthesis & design						
	2.4 Application of systematic approaches to eng.projects.	✓					
3. Professional and Personal Attributes	*3.1 Ethical conduct and professional accountability.*					✓	
	3.2 Effective oral and written communication						✓
	3.3 Creative, innovative and proactive demeanour.			✓	✓		
	3.4 Professional use and management of information.						
	3.5 Orderly management of self, & professional conduct.	✓					
	3.6 Effective team membership and team leadership	✓					

In a similar manner the LOs map onto the AQF Level 8 (2013) outcomes listed in Table 2.

Table 2 Mapping of learning outcomes to AQF Level 8

AQF Level 8 Outcomes		LO1	LO2	LO3	LO4	LO5	LO6
Graduates of a Bachelor Honours Degree will have:							
Knowledge	*coherent and advanced knowledge of the underlying principles and concepts in one or more disciplines and knowledge of research principles and methods*	✓	✓	✓			
Skills	*cognitive skills to review, analyse, consolidate and synthesise knowledge to identify and provide solutions to complex problems with intellectual independence*		✓	✓	✓		✓

	cognitive and technical skills to demonstrate a broad understanding of a body of knowledge and theoretical concepts with advanced understanding in some areas		✓		✓		
	cognitive skills to exercise critical thinking and judgement in developing new understanding	✓			✓		
	technical skills to design and use research in a project	✓	✓		✓		
	communication skills to present a clear and coherent exposition of knowledge & ideas to a variety of audiences		✓		✓	✓	✓
Graduates of a Bachelor Honours Degree will ***demonstrate*** *the application of knowledge and skills:*							
Application of knowledge and skills	*with initiative and judgement in professional practice and/or scholarship*		✓	✓	✓		
	to adapt knowledge and skills in diverse contexts			✓	✓	✓	
	with responsibility and accountability for own learning and practice and in collaboration with others within broad parameters					✓	✓
	to plan and execute project work and/or a piece of research and scholarship ***with some independence****.*	✓			✓		

From Tables 1 and 2 it is clear that the LOs for IAP thesis map reasonably well with EA and AQF. In relation to the group project, the stage 1 competencies (Table 1) do not present any obvious obstacles, however it is clear from the AQF8 learning outcomes (Table 2) that the expectation is for the student to complete research *with some independence* within the timeframe of about one year to attain to an honours level qualification. Within a typical engineering honours program, the thesis is the main vehicle for this demonstration. This demonstration of independent research presents perhaps the greatest challenge for a group thesis project. Moreover, care must be taken to keep students “in the position of formulating their own ideas and making their own judgements, a key objective for most dissertations” (Cook, 1980) – (in relation to supervisors *guiding* rather than *instructing* thesis students). Similarly, Schefer-Wenzl and Miladinovic (2022) describe the thesis as the “move from guided learning in larger groups to self-organized learning with an individual topic” in their study related to undergraduate and postgraduate computer science.

Motivation for investigating the use of group projects for engineering thesis

With growth in student numbers there comes an increasing demand on academics to deliver thesis projects more efficiently without compromising on the learning outcomes. The traditional one-to-one approach can be taxing on the supervisor if more than 5 to 10 students are being supervised leading to poorer outcomes for the student. It is hypothesized that a group setting could improve the efficiency of delivery and the quality of the outcomes for the student if management of larger numbers of students is required from the academic. As noted above, the challenge is to ensure the student can still demonstrate independent research skills for AQF8.

Methodology

The approach used was to devise a group project with opportunities for students to individually demonstrate their research skills. Focus was given to tracking the time spent in supervision.

Data Collection

Data collection was done over a single trimester at Griffith University where 32 students were supervised by nine academics in mechanical engineering. 25 of the students were supervised using a traditional approach with one-on-one student-supervisor meetings on individual projects while one supervisor had a team project done by 7 students with weekly team meetings. Staff were asked to fill in a weekly log indicating the numbers of hours invested in supervising students. Staff were surveyed to obtain their views on the benefits/demerits of a team-approach to managing final-year projects. Student theses were each marked by two academics. Student designs were compared.

Student Project Outline

The group project was to research, design, build and test a miniature ducted turbine powered by compressed air as illustrated in Fig. 1. Differentiation between student projects within the group was achieved by requiring that each student investigated a different type of ducted turbine. Weekly group meetings were held with the students where the focus of the discussion was on progress reporting giving attention to common issues experienced by students. In relation to testing the turbine, students used similar methods which allowed for the sharing of ideas without compromising on the unique aspect of the project that each student individually had to investigate. Thus students could obtain the skills necessary to complete their own project. The available literature on this topic is sufficiently broad so that each student could conduct a solid literature review on their own turbine type. As a further measure to promote independent research, reviewing of individual student written work did not take place in the group setting. On occasions students requested individual meetings with the supervisor which were granted.

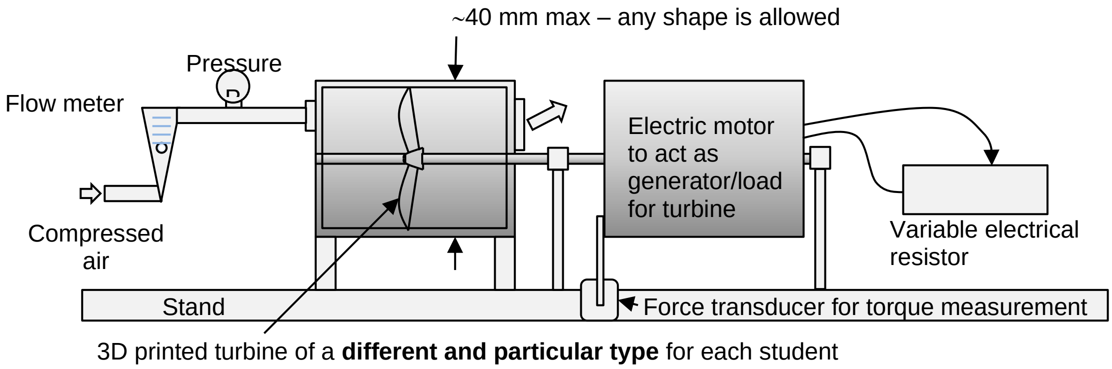


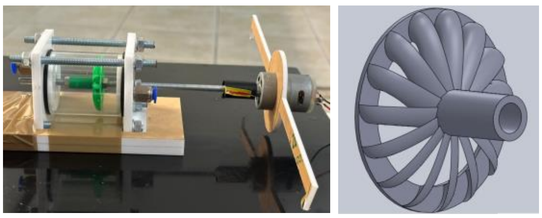
Figure 1: Project concept for group based thesis. Differentiation between students is achieved by insisting that each student investigates a different type of turbine

Results

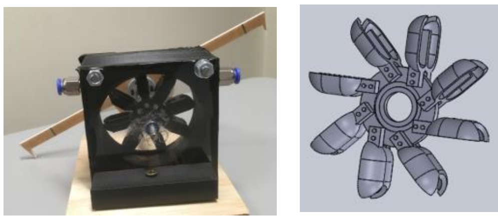
The findings of this investigation come from four sources: (i) the student designs; (ii) the student theses; (iii) the staff time log of supervision activities; and (iv) observations from supervisors.

Observable differences and similarities between student designs

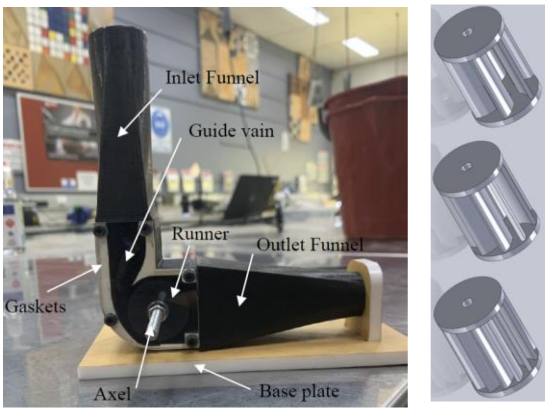
For the group project to be successful both in terms of learning outcomes and efficiency of delivery we hoped to be able to observe distinctly different designs in relation to the turbine type that share some common ideas in relation to the test set up and construction methods. This is the case as can be seen in Fig. 2 which shows core design outputs from the seven students who were on the team project. Quite clearly there are seven different turbine geometries shown in Fig. 2. All devices were able to operate successfully with maximum speeds ranging from a few hundred rpm in the lower performing devices to over 20000 rpm for the device with the smoothest operation. While there are distinct differences on the core turbine type, there are similarities in design method and features. Students 1, 4, 6 and 7 have a similar frame using threaded rods. Students 2, 3 and 5 used 3D printing to construct the turbine housing. Students 1, 2, 4 and 6 used a similar support structure for measuring the torque. Most students used similar bearings for the turbine shaft. Some used a threaded-rod shaft while others used a plane shaft. Thus the sharing of ideas in the group helped all students to achieve a working design. To explore the effect of design parameters on performance, most students 3D-printed variations of their core design as illustrated for Students, 3, 4 and 5 in Fig. 2 where different impeller designs are shown.



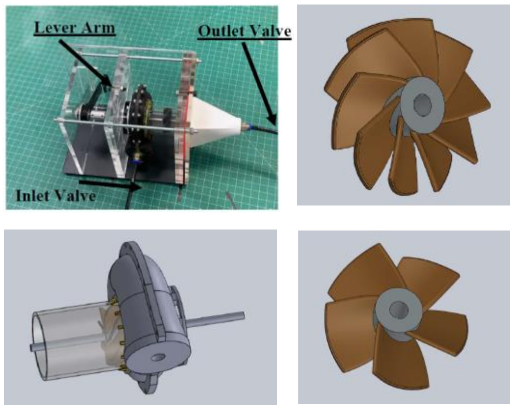
a) Student 1: Turgo turbine



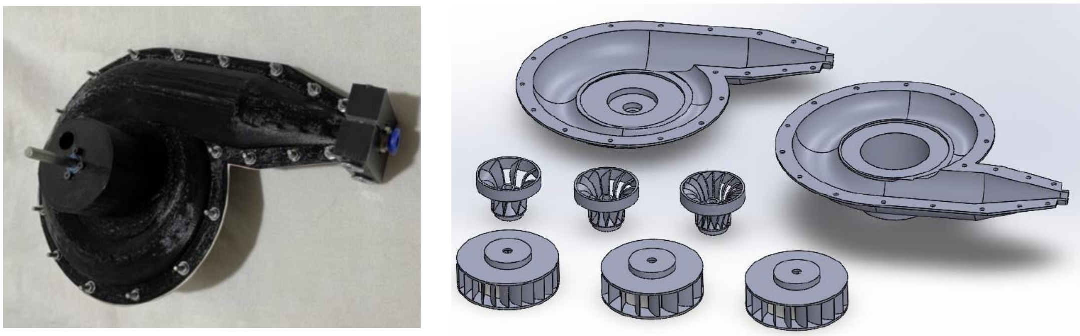
b) Student 2: Pelton turbine



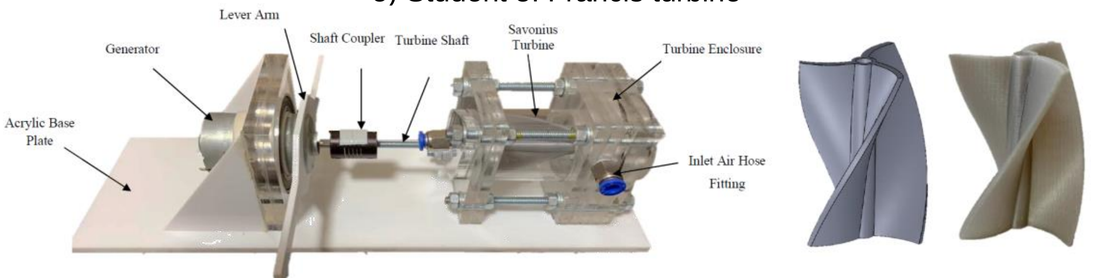
c) Student 3: Crossflow turbine



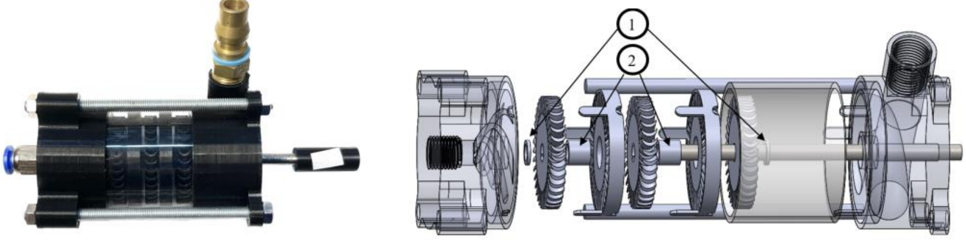
d) Student 4: Kaplan turbine



e) Student 5: Francis turbine



f) Student 6: Savonius turbine



g) Student 7: Multi-stage turbine

Figure 2: Student project designs developed and built by individual students in the team project

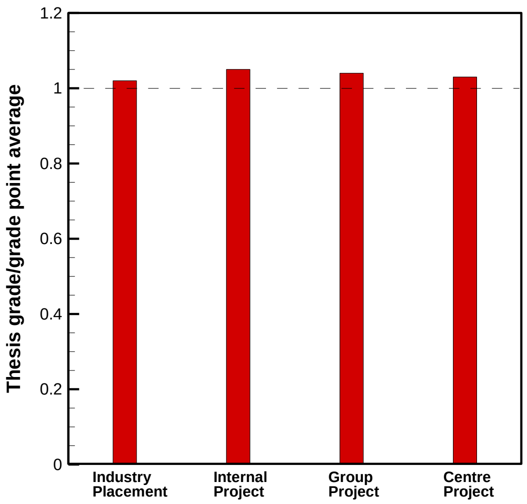
Similarities between submitted student theses and student performance

One of the main concerns with this approach is that students may depend on the group rather than taking initiative to produce their own individual research work. Of the seven students, one dropped out and six submitted final theses. Students were instructed to only report results that they collected themselves in their theses. The six submitted theses had a similar structure with a fairly strong emphasis on design. Literature reviews were unique however, each focusing on their own particular turbine. No data was shared so it seems reasonable to conclude that no student passed IAP thesis based on the success of another. In terms of performance, each student's thesis grade was divided by the student's grade point average (GPA). The average ratio of thesis mark to GPA for the 6 completed group projects was 1.04 indicating that the performance on the thesis project was commensurate with the students' performance in prior coursework (Fig. 3a).

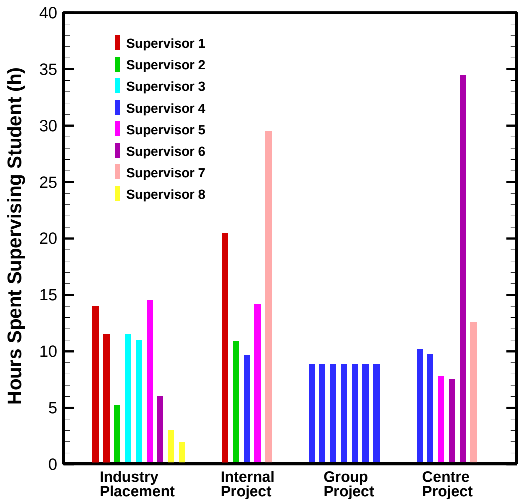
Supervision hours

Fig. 3b presents the overall results recorded from the log of supervision activities during the trimester. The projects are categorized according to (i) industry placement, (ii) internal project, (iii) group project and (iv) centre project. Griffith University divides internal projects into two categories (research projects and industry-connected projects), however, these have been combined in Fig. 3b. For the industry projects, students are located at the industry workplace. The group project took place on campus but it included a visit to a local industry partner who has an interest in this topic. Centre projects take place at research centres on campus.

It is clear from Fig. 3b that there is a wide variation in the number of hours dedicated to supervision of a single final-year thesis student. The minimum number was two hours by Supervisor 8 for an industry placement. If the input from the academic is small on an industry placement it often means that the student works independently or has very good support from the industry supervisor. The most time dedicated to an individual student project was 35 hours for one of the research centre projects by Supervisor 6. The same academic supervised another student which required only about 7.5 hours. This shows that differences between students and the project itself can have a major bearing on the number of hours required for supervision. In the case of the group project, the total supervision time was 61.9 hours which comes to about 8.8 hours per student for the trimester. Noting that the thesis is completed in one trimester, these numbers are not too far from Cook's (1980) student contact time of "10-15 hours within the academic year with an additional 5 hours required for reading draft scripts".



a) Average normalized student performances



b) Supervision hours

Figure 3: Performance & Supervision hours by project type and supervisor (Note: the group project took a total of 61.9 hours. For direct comparison, this is divided by 7 to give the hours per student)

The group project is one of the 'more efficient' performers in relation to hours per student but obviously there are cases where individual projects of other types required fewer hours of supervision. On average the group project required 28% less time than the average project time of all the other projects. However, if compared against the other projects that were also supervised by Supervisor 4, the reduction per student is 11%.

The supervision log also included a breakdown on the type of supervision activity as shown in Figs 4a and 4b. From Fig. 4a it is interesting that the projects which required a large amount of supervision time also have a large amount of training/induction time. This is really clear on the case of the centre project student with 35 hours of supervision time. Evidently for such projects the students were not as well prepared for their particular projects and hence required considerable training input from the supervisor in order to succeed at the project.

Fig. 4b averages the results from Fig. 4a to show the overall trends more clearly. Interestingly for all projects except external placements, the average time in student meetings is 50% or less. The lowest percentage for meeting time was for the group project where just 37% of the total was spent in meetings. This should be expected since the savings per student arise through meeting in a group. The reason it was not even lower than 37% was that Supervisor 4 allowed time for students to meet 1-to-1 on request. Percentagewise, the group project required more preparation time (27% of total) than the other projects to ensure its success. Across all project types, 1/8th to 1/4 of supervision time was spent in giving feedback on student work. Fig. 4b also shows that the average hours per student for the industry placements was similar to that of the group project.

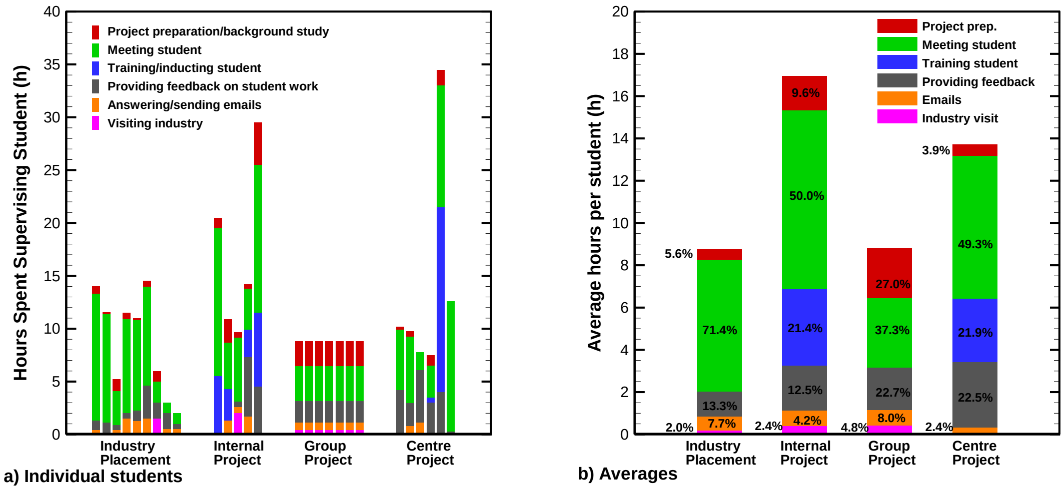


Figure 4: Supervision hours by supervision activity

Views, observations and perceptions of academic supervisors

The academics who participated in this study were collectively asked for their views on the use of group work in an engineering thesis. The following points were noted:

- The project must clearly indicate individual contributions of the students.
- It should show the extent and impact of individual projects to the team outcomes.
- Each student must have a different aspect of the project to consider.
- There should be elements of cohesiveness or inclusiveness embedded into the project.
- It should be designed to avoid free-loading
- It must be done in a way that is parallel (synchronistic collaboration)
- The project should still work for each student if other members fail
- Consideration should be given to avoid negative synergy
- It is not the preferred way to deliver an engineering thesis

Limitations of this study

The main limitation of this study is the small sample size. Only one group project delivered by one academic was tested. Moreover, by comparing the 'centre project' case in Figs. 4a and 4b it is clear that a single student project where the student needs extra training can have a significant influence on the average results for that type of project. While the results from this work can only be considered as a case study, they do highlight important considerations and show that it is possible to deliver a successful group project for engineering thesis.

Conclusions

The team project was successfully delivered with six substantially different theses written. Students benefited from the findings of other team members in relation to successful construction to achieve a working device, experimental technique and interpretation of results. The team project achieved a reduction in the supervision time per student compared with the average time for the traditional individual student-supervisor arrangement. For this type of project to meet the AQF8 requirements, care must be given to ensure that each student has the opportunity to demonstrate independent research skills.

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