Didactic strategies for final year projects

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Abstract

PURPOSE
Capstone final year projects (FYP) are a core part of every engineering degree. They provide the student with a sufficiently open-ended problem that requires the student to apply his/her knowledge in an integrative and solution-focused manner. This in contrast to the piecemeal approach to knowledge development that occurs in conventional courses that are focussed on one subject only, and the conventional assessment tasks where the solution is known and the student merely has to rediscover it. In a FYP neither of those conditions hold. Consequently the FYP is a challenging learning experience for the student. It is also an opportunity for the student to learn and apply the type of attributes that the profession expects (as per the Washington and other accords) at the relevant level of complexity. Nonetheless it requires a deliberate course design to draw out these attributes, including a careful consideration of problem-complexity when setting up projects, and finding ways to include the graduate attributes holistically.

APPROACH
This paper takes a case study approach.

OUTCOMES
It shows, with respect to a successful FYP course, how the profession's expected graduate attributes can be interlocked into the learning outcomes in such a way as to frame a set of expectations around student performance. Course descriptors emphasise explicit learning outcomes, often in overly simplistic Bloomsian taxonomies. In contrast the implicit learning outcomes, and the didactic strategies that support them, are not evident on the course descriptor, yet add greatly to the quality of the student's work and their readiness for a professional career.

CONCLUSIONS
Consequently it is possible, with attention to didactic strategy, to design a FYP course to be not only a capstone experience that integrates existing knowledge, but also a transition to professional practice.

KEYWORDS

Washington Accord; graduate attributes; pedagogy

1 Introduction

Engineering degree programmes invariably have a final year project (FYP). Although the Washington Accord (IEM, 2013) does not prescribe how this course is arranged, there is generally a need to include design and other problem-solving learning. Such a course provides the student with a sufficiently open-ended problem that requires the student to apply his/her knowledge in an integrative and solution-focused manner. This in contrast to the piecemeal approach to knowledge development that occurs in conventional courses that are focussed on one subject only, and the conventional assessment tasks where the solution is known and the student merely has to rediscover it. In a FYP neither of those conditions hold. Consequently the FYP is a challenging learning experience for the student. It is also an opportunity for the student to learn and apply the type of attributes that the profession expects (as per the Washington and other accords) at the relevant level of complexity.

Nonetheless it requires a deliberate course design to draw out these attributes, including a careful consideration of problem-complexity when setting up projects, and finding ways to include the graduate attributes holistically. This paper shows, with respect to a successful FYP course, how the profession's expected graduate attributes can be interlocked into the learning outcomes in such a way as to frame a set of expectations around student performance.

2 Background

Literature

The FYP course is ubiquitous in engineering programmes. A large proportion of the courses reported in the literature are design courses: students design, build, and test something. The ‘thing’ is typically a problem set by the university as an elaborate form of an assignment (Anwar & Marchetti, 2000; Dong & Dave, 2008; S. Laguette, 2007; Li, Zielinski, & Gebali, 2012; Tan, Fleming, Connor, & Wilson, 2006). They are typically focused on solving some problem, usually a complex one (S. W. Laguette, 2012), by a synthesis approach (Pacella & Bayles, 2010). However such FYP projects have been criticised for lacking consistency in project formulation (Idowu, 2004).

In some areas there has been a growing awareness that a course that only develops design skills is not fully preparing the student for the working environment (Ruwanpura & Brown, 2006). For example, chemical engineering projects were found not to have much content on health & safety or the environment, and there has been a push to remedy this (Kentish & Shallcross, 2006). Thus there have been attempts to include elements of the professional soft-skill learning outcomes into the project. In some cases this has been by the inclusion of taught material (Sheppard, Dominick, & Blicharz, 2008; Stanfill, Rigby, & Milch, 2014), and in other cases integrated into the nature of the project (Garcia-Otero & Sheybani, 2010; Goldberg, 2007). Material considered here includes teams, society, ethics, environmental, intellectual property, project management, communication, among others.

In some cases the type of project constraints that an external client might impose have been replicated internally by the student groups (Moore & Berry, 1999).The issue of what In some cases, only relatively rarely, external industry mentors are reported to have been involved in guiding the students, though the projects themselves were not necessarily of external origin (Karimi, Eftekhar, Manteufel, & Singh, 2003). In some cases these arrangements have extended to industry financial support (S. Laguette, 2008).

Some programmes are reported to be truly outward facing, i.e. the problem is provided by an external industry client (Asiabanpour & Subbareddy, 2007; Bryan, 2013; De Vere, 2008; Maxim & Akingbehin, 2006; Mechefske, 2001; Nagel, Nagel, Pappas, & Pierrakos, 2012; Strong, 2012). In these situations the clients may provide financial sponsorship as well as mentorship roles to the students (Laiho, Savage, & Widmann, 2010). A minority of programmes emphasise research and development (R&D) as opposed to design per se

(Attarzadeh, Barbieri, & Ramos, 2010; Shekar, 2012). This is an important point, because jurisdictions like New Zealand require 4-yr engineering degrees, which are honours inclusive, to include a research component. Most of these couses have a temporal development of students' skills and self-efficacy. In a few cases this progression has been empirically tested (Smith, Siddique, & Mistree, 2014).

Known areas of difficulty with project courses

Assessment of design courses is a known difficulty, because of the subjectivity of the assessor (Estell & Hurtig, 2006; Hashim & Hashim, 2010; S. W. Laguette, 2012; Stansbury & Towhidnejad, 2009).

What the engineering profession might expect in a FYP course has been partially explored in some situations. For example, there are reports of FYP courses being generally consistent with accreditation requirements, e.g. those of ABET (Genis, Danley, Rosen, & Racz, 2010). However the literature seldom, if ever, shows FYP courses that were design *a priori* with the profession's graduate attributes in mind.

3 Purpose and approach

The purpose of this work was to explore how to create a more explicit alignment between the International Engineering Alliance (IEA) graduate attributes for engineers, and the learning outcomes of a FYP course. The situation under examination is a New Zealand university, and the context is primarily mechanical engineering and mechatronics engineering. The results are presented as a case-study.

Context

The course under consideration is a final year capstone project, where students work in small teams for a whole year on an industry defined and sponsored problem. The problems are open-ended and complex, not contrived in any way, and the solution is not known beforehand (there may not even be a solution). There are no pre-existing solutions paths, no standard recipes to follow. Students apply research and design, select their own tools and find their own solution, and are assessed accordingly. The projects have a R&D emphasis, as opposed to being only design. The work is done in teams of nominally four students, and each team has its own project different to all the others. Students have choice about which project they join.

Approach

Learning outcomes were rewritten to align with the IEA graduate attributes. Then the assessments were also aligned therewith.

Taking the

4 Results

4.1 Complex problem solving

In conventional course design, the learning outcomes follow a rote pattern, using overly simplistic Bloomsian taxonomies ('anyalse', 'create' vs. 'understand', 'remember'). Such contrivances encourage superficial course design and do not create an integrated learning experience for the student. A great deal of additional didactic design has to be exerted to make these learning outcomes effective.

On the other hand, the Washington Accord graduate attributes are relatively abstract and the application to course design is not straightforward. The approach was to take an existing FYP course, and re-align it with the IEA graduate attributes.

The key starting point was to adopt the IEA concept of engineering COMPLEXITY, and contextualise it for the course. This is a useful way to frame the entire course, and encourages a holistic approach to course design. As will be shown, this extends into the assessment too.

Students tend to think that *complexity* in engineering problems comes from mathematical complexity. This is one form of complexity, but actually the form least likely to be encountered in professional practice. The other more common forms of complexity arise from the multiple contexts to the problem. These other dimensions can include not only the technical complexity but also the user/customer/client, and the need to accommodate financial, societal, environmental, health & safety, and legal considerations. These are usually conflicting (mutually exclusive), and hence further complexity arises. A high-level representation of this complexity, as it arises in an industry-lead project situation, is shown in Figure 1.

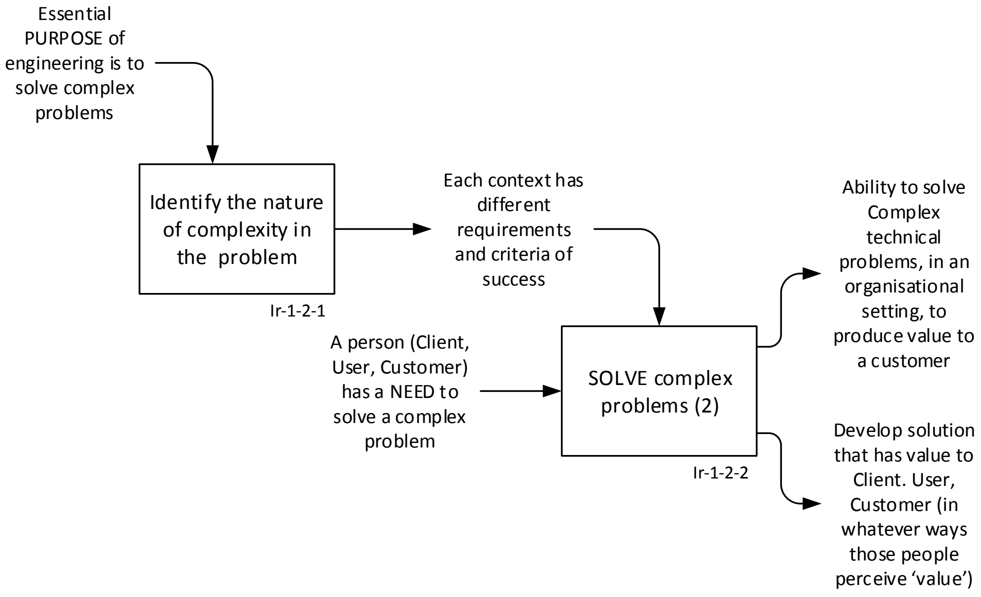
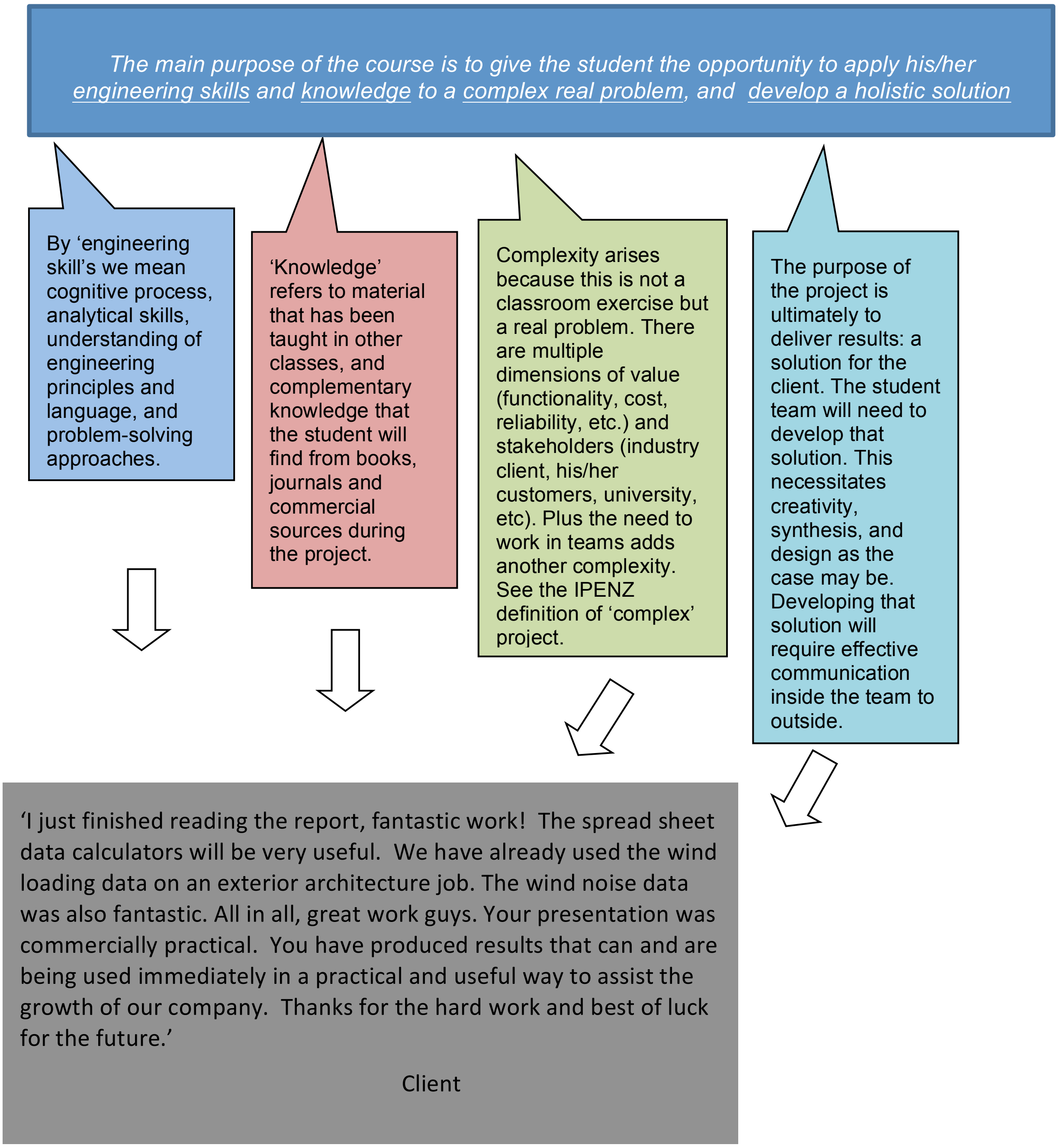


Figure 1: Complexity arises in industry-lead project situations.

At a more detailed level, the engineering profession has a DEFINITION OF COMPLEXITY. It is important because (a) it determines, via the accreditation process, the course content for the various engineering qualifications, and (b) it defines the level of skill required for professional registration. Complex problem solving is a key idea in the International Engineering Alliance (IEA) graduate attributes, see Appendix A. This is an ideal framework for final year projects, and the appendix shows how such a course may be aligned therewith. A more concrete representation of the concept is given in Figure 2.

Furthermore, in New Zealand there is a specific cultural association with engineering complex-problem solving being cognitively similar to the unravelling of knots, hence the Maori term *wetepanga* for engineer. This is a very helpful concept, and New Zealand is fortunate in having this idea.

These associations, both the abstract and the specific, help both students and supervisors grasp what is meant by engineering complexity. This is important, because each team's project is different, each student has a unique work-stream, and academic supervisors have intimate knowledge only of the few projects they supervise. Having a common understanding of complexity is vital for the quality of the assessment process.



The main purpose of the course is to give the student the opportunity to apply his/her engineering skills and knowledge to a complex real problem, and develop a holistic solution

By ‘engineering skill’s we mean cognitive process, analytical skills, understanding of engineering principles and language, and problem-solving approaches.

‘Knowledge’ refers to material that has been taught in other classes, and complementary knowledge that the student will find from books, journals and commercial sources during the project.

Complexity arises because this is not a classroom exercise but a real problem. There are multiple dimensions of value (functionality, cost, reliability, etc.) and stakeholders (industry client, his/her customers, university, etc). Plus the need to work in teams adds another complexity. See the IPENZ definition of ‘complex’ project.

The purpose of the project is ultimately to deliver results: a solution for the client. The student team will need to develop that solution. This necessitates creativity, synthesis, and design as the case may be. Developing that solution will require effective communication inside the team to outside.

‘I just finished reading the report, fantastic work! The spread sheet data calculators will be very useful. We have already used the wind loading data on an exterior architecture job. The wind noise data was also fantastic. All in all, great work guys. Your presentation was commercially practical. You have produced results that can and are being used immediately in a practical and useful way to assist the growth of our company. Thanks for the hard work and best of luck for the future.’

Client

‘This is by far the most useful course I had at university. In my first job, I hit the ground running. I knew what they wanted, what I needed to do, and how to communicate.’ *Student*

Figure 2: High-level statement of purpose

4.2 Alignment with profession's graduate attributes

The attributes that the profession seeks are defined by an international agreement (IEM) called the Washington Accord (4yr BE degrees), Sydney Accord (3yr BEngTech), and Dublin Accord (2yr Diplomas) (IEM, 2013). While engineering degrees do have a lot of engineering science in them, they are not primarily a science degree but a professional degree. The final year R&D project addresses the other aspects of the graduate attributes not covered in the science education, and it develops skills to handle complex problems involving people ('stakeholders') and their different needs. This course is explicitly aligned to the IEM graduate attributes, as per Appendix B.

Though the course is presented as a technical problem-solving challenge, it also has important deeper objectives. These are more tacit, and involve the development of skills that are needed for effective professional practice. They include the ability to work in teams, communication, client interaction, professionalism in presentation of results, identification of stakeholders, etc. Professional working practice is thus learned tacitly in the context of a realistic engineering problem. The integrative aspects of the final year project experience are emphasized. Professional development in areas of leadership, team dynamics, interpersonal relationships, technical communications, and project management are particularly emphasised via the programme structure, oral presentations, and the assessment criteria).

4.3 Delivery

Process through the year

An overview of the programme follows, see also Figure 3. Four students are allocated to a team, along with an academic supervisor and a technician. The allocation process is detailed in Appendix C. The technician allocations are important to get right as they can complement any gaps in the range of skills of the students. Also, many projects require testing and instrumentation, and good electronics technicians are invaluable even in a purely mechanical engineering project. The team then meets the client (1) and elaborate on the need. We let the students do this. It is much better that they hear it directly from the client, who can then see for him/herself how well the students understand the situation, rather than us attempt an exhaustive capture of the client's needs at the outset. This also reduces the barrier to client participation in the programme, as only a one page problem descriptor is required initially.

This addresses the issue raised in the literature, that:

> 'The students and teams should be held accountable in providing a formal definition of expected Project Completion outcomes and should provide objective evidence of problems solution and project completion. ' (S. W. Laguette, 2012)

In this course the students set their own outcomes, based on their curiosity and appetite for work, and are assessed accordingly. Thereafter the students go away and do two things: (a) Background investigation of commercial and academic literature, and (b) Project planning and working out an approach. Separate lectures help them with methods for doing all this, and the supervisors guide the specific application of these principles to the situation under examination. The students, with their supervisor, are permitted to adjust the scope, since we often find that industry clients tend to see the whole problem (e.g. a new product), whereas the students may only be able to get the solution to the first stage (e.g. a working prototype).

The students then write a proposal back to the client (2). This includes Definition of scope, intended approach, resource requirements, budget, Gantt chart. It is graded by multiple markers (supervisor, course director, tutorial assistant marker) so the students are given a lot of feedback, The feedback comes from different perspectives, and the students find this confusing at first. We help them understand that a report has multiple audiences, all of whom need to be satisfied.

The rest of the year is taken up with the students performing the work (3). There are regular meetings with supervisor (weekly) and with client (monthly). We find that students are imperfect in their project-planning ability, and are optimistic about how long things will take. Also, we realise that projects take different directions as they unfold. Consequently the students may make changes to scope if necessary, in discussion with their client. There is a Mid-year Progress report and presentation/ This is graded by supervisor, academic marker, and course director, to again give multiple perspectives of feedback for the students. This also helps moderate the marks. Students also get feedback from their verbal presentations, since each student is required to give feedback on a certain number of other presentations. The feedback forms are the same as the marking criteria, so this also helps think explicitly about the criteria. Also, this is consistent with the professional engineering responsibility to be able to review other engineer's work in a manner of constructive criticism.

At the end of the year students close out on the project (4). They produce a final report, give a verbal presentation, create a poster, and handover any physical artefacts to the client. They are assessed on outcomes. They have to write a Team contribution statement – this is to get them to think explicitly about what they each did, and who else contributed. We find that they need help to perceive that the supervisor and technicians have helped the project to its outcomes. In this way we emphasise the team component to projects. There is also a major individual assessment, this is styled as an appraisal. Also, students have to tidy up their workspace and close-down the project resources.

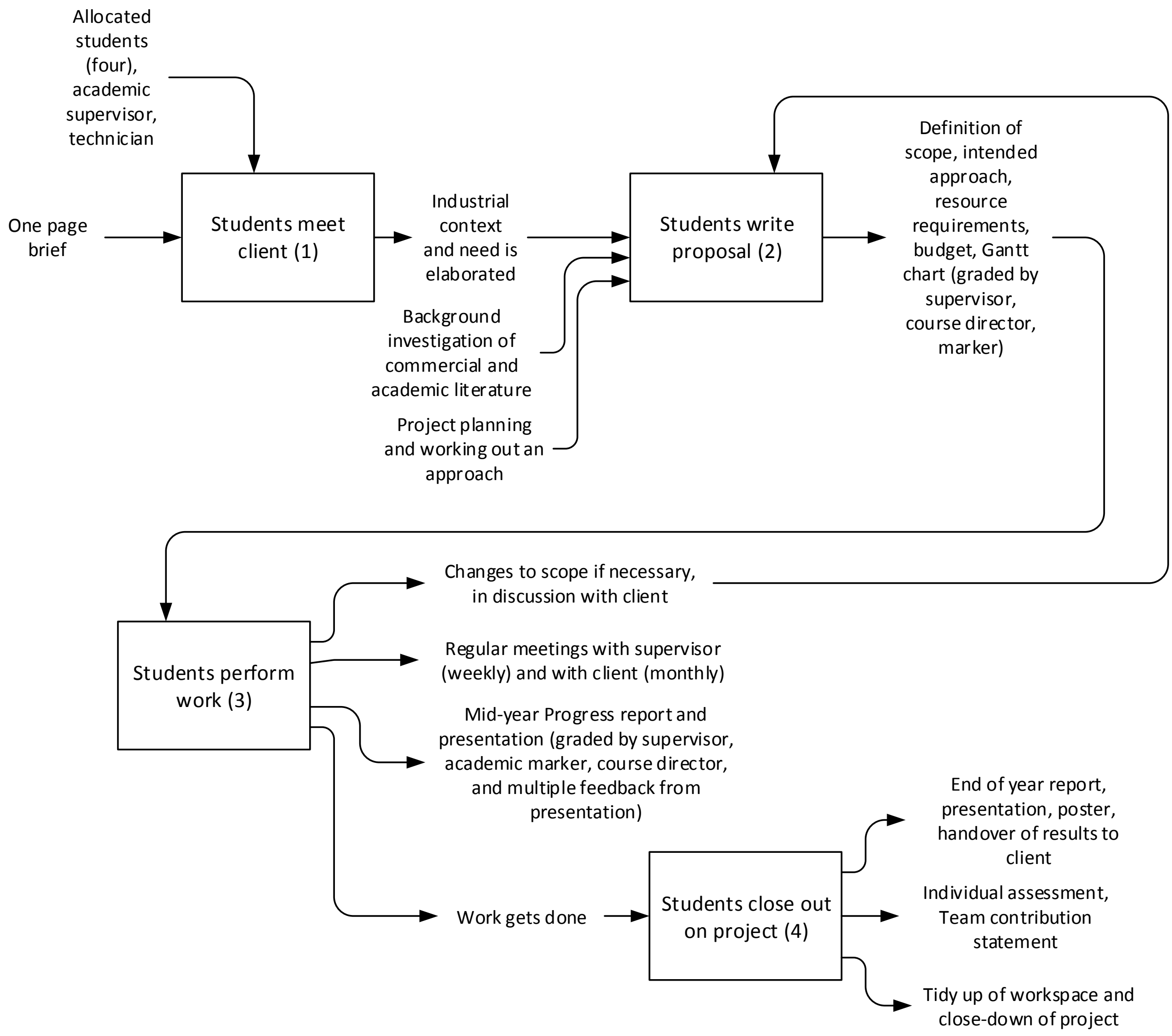


Figure 3: Processes for the year

A number of professional related topics are covered in the FYP programme including intellectual property and confidentiality statements, health & safety inductions to facilities, introduction to journal literature and bibliographic management software, tutorial on the use of project management software.

Soft skills

Students are encouraged to take a structured and systematic approach to their project. It can be useful to help them structure their work and begin with the end in mind. Their productivity is low in the first half of the year while they are forming relationships within their team. They are anxious that their technology may fail, so they tend to over-analyse things, and we have to encourage them to active experimentation. They learn more about the problem if they can take some action, fail early and often in small ways. Students are also given training on how to conduct a meeting, and each is expected to chair the weekly meeting at least once, and likewise serve as minute secretary. This gives them appreciation for these roles, even if it is not something that they want to be doing in the future.

Areas where students need specific help

In the project formulation, as seen in the proposal, it is evident that students often struggle with:

1. Lack of specificity of PURPOSE. They are too vague about the criteria by which success would be determined.
2. Failure to identify (and hence plan for) the complexity in the project. Project plans are thus too naive and optimistic. What are the technical challenges? What about other forms of complexity?

Students need help developing methods to find the research/practitioner literature. There is so much information out there, that they need systematic methods for finding what is relevant, as opposed to hoping that just browsing the web will find something.

4.4 Assessment strategies

The above activities are all done in teams. All members of the team share the mark for submitted reports. In addition, each student is individually assessed, and so the final mark for the course is a combination of team (50%) and individual marks (50%).

Situations sometimes arise where members of the team are not equally committed to the course. In which case they still all get the same team marks, and will be pulled-down or lifted-up by the contributions of others. It is relevant to note that students have an initial choice of *project* but not of *team-members.* This is realistic compared to industry working arrangements. However it does expose the students to some risk, because their mark is not entirely determined by themselves. This risk is explained to students at the outset. It is our experience that one in about twenty projects will have problems in this regard, usually because one or more students do not want to do anything more than the bare minimum. The solution is for the student who wants to get ahead, to work with the supervisor to undertake additional work and boost the individual mark component. This generally seems to solve the problem of mismatched grade expectations.

Individual assessment

The individual assessments occur at the end of each term, and take the form of an individual appraisal discussion between the student and supervisor. This assessment rubric is aligned to the Washington Accord graduate profile, as shown in Appendix D.

Team assessment

The team assessment is based on their written report, verbal presentation, and poster. This assessment is aligned to the Washington Accord graduate profile, as shown in Appendix D. It also explicitly uses the complexity terminology. As each project has a different topic, not all the IEA competencies are relevant in each case, and this is accommodated.

The literature identifies the difficulty of making robust assessment of design related work, primarily due to the variability between different assessors (Estell & Hurtig, 2006). The present course is designed to minimise this risk by using the same IEA-derived assessment terminology through the many assessments on the course. Both staff and students thereby get accustomed to the expectations. The fact that these have a solid foundation in the Accord, as opposed to being an ad-hoc construct of the course director, makes this a non-contentious form of assessment. The multiple opportunities for feedback, that arise from using a consistent rubric, give the student opportunity to improve, as envisaged by (Stansbury & Towhidnejad, 2009).

4.5 Does this actually work?

It is difficult to get an objective assessment of any course design, a limitation that applies to all the FYP interventions described in the literature. The programme designed with this scheme has been successful, where success is measured as:

1. Satisfaction of industry clients and students.
2. Regular production of patents and novel intellectual property.
3. Several journal publications arise from student work each year.

4. The course was commended at accreditation, with the profession specifically identifying its strengths in communication, teamwork, multidisciplinary and industry involvement.
5. Projects have won national awards. Specifically, project teams from this programme won first place in the IPENZ Ray Meyer Medal for Excellence in Student Design five times in the last seven years.

5 Discussion

Outcomes

The results show that it is feasible to create a close alignment between a final year R&D project course and the IEA Washington Accord. Thus the profession's expected graduate attributes can be interlocked into the learning outcomes in such a way as to frame a set of expectations around student performance. This is advantageous for several reasons:

First, students receive a consistent message of expectations. This is important as it gives them a consistent framework of feedback, within which they may change their behaviour.

Second, the creation of assessment rubrics is straightforward. In turn this encourages consistency of marking. It is our experience that supervisors tend to mark their students more generously than do assessors not involved with the project. There are probably several reasons for this including supervisors having a natural goodwill towards their students, and the fact that they are more familiar with the students' work. Having robust assessment strategies aids in the moderation and avoids unnecessary conflict between the supervisors and the assessors. We find that in most cases the three marks for a piece of student work are within a 10 percentage point range, often more narrow still, and we consider that acceptable

Third, with this way of doing things, all the necessary evidence for accreditation is already explicitly collected. This is important, as the FYP course is one area that is bound to attract scrutiny in any accreditation process. Being able to show an explicit alignment between the didactic design of the course and the IEA graduate attributes is a good way of doing due diligence to the requirements. It also means that the programme continues in the spirit of the accreditation, as opposed to being a document that is drawn up for the accreditation visit and then lapses.

Fourth, the course explicitly and implicitly works on developing graduate attributes in readiness for a professional engineering career. It develops problem solving self-efficacy and a variety of soft-skills. This is to the advantage of graduates in their careers and to the benefit of their future employers.

Conclusions

Consequently it is possible, with attention to didactic strategy, to design a FYP course to be not only a capstone experience that integrates existing knowledge, but also a transition to professional practice.

Copyright statement

A Appendix: Definition of complex problems

Table A1: Definition of complex problems in this course (IEM, 2013).

IEM Definitions: Engineering problems which cannot be resolved without in-depth engineering knowledge and having some or all of the following characteristics:	Application to this course
Involve wide-ranging or conflicting technical, engineering and other issues	The projects arise from industry, and with that comes all the messiness of the other considerations: customers, commercial, production, safety, etc.
Have no obvious solution and require abstract thinking, originality in analysis to formulate suitable models	The projects have no fixed solution path determined beforehand. Many projects have no obvious solution, and some projects turn out to have no solution at all.
Requires in-depth knowledge that allows a fundamentals-based first principles analytical approach	All projects have some element of first-principle engineering science or mathematics involved. The nature and proportion varies with the projects.
Involve infrequently encountered issues	The projects are typically back-burner issues for industry. We deliberately advise industry clients not to suggest topics that are on their commercial or R&D critical path. Consequently the projects that we do receive tend to be something that the client does not know a lot about either, so this adds to the complexity.
Are outside problems encompassed by standards and codes of practice for professional engineering	Students are expected to identify any standards that are applicable, and this is particularly important for health and safety testing regimes for specific products. Nonetheless most of the student work involves engineering beyond the standards. This is because of the nature of the projects that industry provide.
Involve diverse groups of stakeholders with widely varying needs	Every project has at least three stakeholders: the client, academic supervisor, and course director. All of these have to be satisfied. There are also other stakeholders namely the university appointed technician, and the second degree stakeholders of the client (e.g. the client's customers).
Have significant consequences in a range of contexts	Every project is different but they all have consequences to the client if the work is incorrect.
Are high level problems possibly including many component parts or sub-problems	The projects all have multiple workstreams. This is because we only accept projects that have sufficient work for four students. Also, the projects invariably require *different* workstreams. We identify these right from the beginning on the BRIEF. We also actively encourage students to select a sub-problem and make a contribution there, and we explicitly assess this.

B Appendix: Graduate competencies

Table B1: Graduate competencies required for Engineers at the end of a 4yr study programme, as per the Washington Accord (IEM, 2013), paraphrased and emphasis added.

		GRADUATE ATTRIBUTES for Washington Accord degree (paraphrased)	Where in the Course is this covered?
1.	**Engineering Knowledge :** Breadth and depth of education and type of knowledge, both theoretical and practical**.**	Knowledge: Have a systematic, theory-based understanding of the natural sciences, conceptually-based mathematics, mathematical methods, numerical analysis, statistics, computer and information science, engineering fundamentals, engineering specialist knowledge, and accepted practices. This knowledge is expected to cover the discipline as a whole (as opposed to being limited to a sub-discipline), and much of it is expected to be at the forefront of the discipline. Apply this knowledge to the analysis, modelling, and solution of complex engineering problems.	These subjects are not taught in this course, but students are expected to bring this knowledge to their projects as necessary. This course emphasises holistic and integrative use of engineering knowledge. This means that where we would expect, for a given topic, to see certain engineering knowledge applied, we expect students to identify this themselves (and help them to do so). We also expect students to move out of the safety of deterministic answers to engineering science problems, to the messy reality where they have to identify which methodology is appropriate in the situation, and find the input variables. Thus we recognise the value of engineering sciences as taught in specialist courses, but our emphasis here is on the contextualisation of those sciences to the problem at hand.
2.	**Problem Analysis:** Complexity of analysis	Identify, formulate, research literature and analyse complex engineering problems reaching substantiated conclusions using first principles of mathematics, natural sciences and engineering sciences.	Each project starts with a one-page brief, and a discussion between the student team and the client. From this students are expected to analyse the problem and develop a proposed solution path (the PROPOSAL) with the resource implications identified.
3.	**Design/ development of solutions:** Breadth and uniqueness of engineering problems i.e. the extent to which problems are original and to which solutions have previously been identified or codified	Design solutions for *complex* engineering problems and *design* systems, components or processes that meet specified needs with appropriate consideration for public health and safety, cultural, societal, and environmental considerations.	While every project is unique, they all require the development of a solution to a problem. All projects therefore involve a design activity, though the nature and importance depends on the project.
4.	**Investigation:** Breadth and depth of investigation and experimentation	Conduct investigations of complex problems using research-based knowledge (research literature) and research methods including design of experiments, analysis and interpretation of data, and synthesis of information to provide valid conclusions.	Students are also expected to investigate the background to the problem, by accessing commercial and academic literature, and include this in their PROPOSAL and later reports. A thorough approach to citations and acknowledgement of sources (including images) is expected, as is access to the journal literature. However we do not

			expect the students to make a novel intellectual contribution, but rather to be well-informed by the existing research literature. We have specifically strengthened the applied research component within this course, in response to the changing IEM requirements around applied research. This is also consistent with the requirements for a research component within an honours-level degree.
5.	**Modern Tool Usage:** Level of understanding of the appropriateness of the tool	Create, select and apply appropriate techniques, resources, and modern engineering and IT tools, including prediction and modelling, to complex engineering activities, with an understanding of the limitations.	Typical tools used by projects include computer aided design (CAD), computation (MATLAB), finite element analysis, data acquisition (Labview), as required.
6,	**The Engineer and Society:** Level of knowledge and responsibility	Comprehend the role of engineering in society and identified issues in engineering practice in the discipline: ethics and the professional responsibility of an engineer to public safety; the impacts of engineering activity: economic, social, cultural, environmental and sustainability Apply reasoning informed by contextual knowledge to assess societal, health, safety, legal and cultural issues and the consequent responsibilities relevant to professional engineering practice and solutions to complex engineering problems.	Each project has an objective which is determined by the client. This client is typically seeking to satisfy a customer at another degree of separation. Students are thereby exposed indirectly to the broader issues regarding customer requirements, and responsible operation of the technology within society. In addition, students are required to sign confidentiality agreements, thus introducing them explicitly to one area of legal responsibility in professional practice. This material is not formally taught.
7.	**Environment and Sustainability:** Type of solutions.	Understand and evaluate the sustainability and impact of professional engineering work in the solution of complex engineering problems in societal and environmental contexts.	Relevant to some projects, in which case they are expected to consider the issues. Is not formally taught.
8.	**Ethics:** Understanding and level of practice	Apply ethical principles and commit to professional ethics and responsibilities and norms of engineering practice.	Basic awareness is developed. Some projects have to take it further (particularly relevant where work-streams involve testing on people, or surveys).
9.	**Individual and Team work :** Role in and diversity of team	Function effectively as an individual, and as a member or leader in diverse teams and in multi-disciplinary settings.	**The TEAM work is an important feature of this course. It is effortful for us to arrange, and we acknowledge that sometimes the team functions distract the students from technical accomplishments. Nonetheless we believe this is an essential learning outcome.** Although the course is overtly about providing a technical solution, i.e. that is the deliverable at the end, the teamwork process of getting there is an important

			feature of the course. This is achieved by the team nature of the projects, and the assessments (half the marks are allocated to team outcomes). The course specifically teaches students how to conduct meetings and work in teams, and sets expectations for team work. This is a very deliberate part of the tacit learning outcomes for this course. The course also expects each student to make an individual contribution, one to the team and one to the technical activities. At the end of the course the team is required to write a CONTRIBUTION STATEMENT (see final report), and each student is required to write an individual statement (which is framed as a reference). This is done to force students to consciously consider, in retrospect, how the team achieved its outcomes. It also prepares them for a future where they will have to write references for subordinates.
10,	**Communication :** Level of communication according to type of activities performed	Communicate effectively on complex engineering activities with the engineering community and with society at large, such as being able to comprehend and write effective reports and design documentation, make effective presentations, and give and receive clear instructions.	**COMMUNICATION is strongly emphasised throughout the course. Students are given a structured environment in which to develop the skills in various forms of communication.** The communication implications are emphasised in this course, as evident in the assessment criteria. Students are required to give three oral presentations (one in class as a practice, a mid-year progress report, and a final presentation at year-end), draw up a poster, and write three major reports (PROPOSAL, PROGRESS REPORT, and FINAL REPORT). In all cases the emphasis is on communicating to a technically literate audience. Students are given instructional lectures on each of these. They are also given detailed feedback on their written work, especially the earlier work. Communication is explicitly assessed in the marking criteria.
11.	**Project Management and Finance:** Level of management required for differing types of activity	Demonstrate knowledge and understanding of engineering and management principles and apply these to one's own work, as a member and leader in a team, to manage projects and in multidisciplinary environments.	Project management is covered in taught material (Gantt chart, work-breakdown-structure, proposal, progress reporting, closure), a tutorial (MS Project software), and assessed in the PROPOSAL. Teams are also required to identify the resource requirements for their project, including the financial requirements (see PROPOSAL) and to report ton that subsequently. All teams are given a small nominal starting budget and exposed to the institutional purchasing processes (order numbers and approval, etc.) . Some projects with a large build component have relatively large budgets assigned by their Client, and these students get more exposure to the whole finance and procurement processes 9and

			issues). However we do not actively teach the theory of finance in this course: it is more an emphasis on the application.
12.	**Life long learning:** Preparation for and depth of continuing learning.	Recognize the need for, and have the preparation and ability to engage in independent and life-long learning in the broadest context of technological change.	This course deliberately positions each student in a challenging situation. We do this by providing *complex* project topics. (We decline projects that are insufficiently complex). This helps the student realise that successful completion of the course does not merely require the application of existing knowledge, but the learning of new knowledge and perhaps also new skills. We emphasise this, especially at the start of the course. We also emphasise the way this course bridges into professional practice. In doing so we deliberately introduce to the student the possibility, which might not have been so clear before, that real engineering almost always involves learning something new, and that this is not something to be feared. Also, by helping students achieve a project that is often somewhat intimidating at first, we build their self-efficacy. In this context self-efficacy is the ability to say to oneself, 'I have never done this before, and I do not know the exact solution beforehand, but I know that I have the skills, knowledge and motivation to be able to find a solution if one exists and if not then at least do something to move the problem closer to a solution'.

Learning objectives

Engineering Practice

- Learn to apply engineering fundamentals to real problems
- Learn to foster creativity and problem solving through applying multidisciplinary aspects of engineering
- Exercise engineering knowledge and skills gained from prior coursework

Research

- Carry out applied research including experimental design
- Investigate and summarise current literature
- Perform engineering analyses to guide and justify design decisions
- Execute design and testing according to best engineering practice
- Write proposals, reports, memos, make impromptu and formal oral presentations, and prepare poster presentations for a general audience

Project Management

- Develop organisational, project management, research, and interpersonal (team) skills

Communication

- Learn to communicate effectively, clearly, and professionally in a variety of situations, e.g. with Supervisor and Client
- Learn to understand client's aims, analyse and critically evaluate ideas
- Acquire skill in working with others as a member of a team
- Develop skills in communicating technical information orally and in writing
- Practice teamwork, project management, and personal time management

Professional development

- Be responsible for independent, individual accomplishment
- Learn to organize your own work toward achieving professional engineering outcomes
- Learn about professional practice and ethics

C Appendix: Operational methods

This capstone R&D courses is operational labour-intensive, but we believe the results are worthwhile. There are a number of things that can be done to stream-line the operations, and take away some of the problems. The following are our local experiences, and we share them as we have found they have worked well for us, though there can of course be no guarantee they will work in every situation.

Allocation of students to projects

This is a notoriously difficult part of such a course, especially as students have so much at stake. There is the risk that students can be very dissatisfied with the outcomes, and this seriously limits their early productivity. Also, any changes to team composition are disruptive to team formation.

We have tried a number of approaches and the one that works best for us is as follows, see Figure C1. First, we find the projects (1). For each we produce a one-page brief, and identify the different types of key skills each project will need. The student then selects candidate projects (2), and identifies what key skills he/she would bring to the project, see Table C2. Importantly, we get students to *score* all the projects (1…5 where 5 is the most attractive), rather than *rank* them. Thus a student might have three projects with score '5', and several more with score '4'. The reasons for this are obvious: to increase the number of acceptable choices for students, thereby making the optimisation easier for the course director. Students are then allocated to projects (3), with the first being to ensure that all the key skills needed by the project are covered, with students who have a high interest in the work. Grade point average (GPA) is only the third consideration when all else is equal.

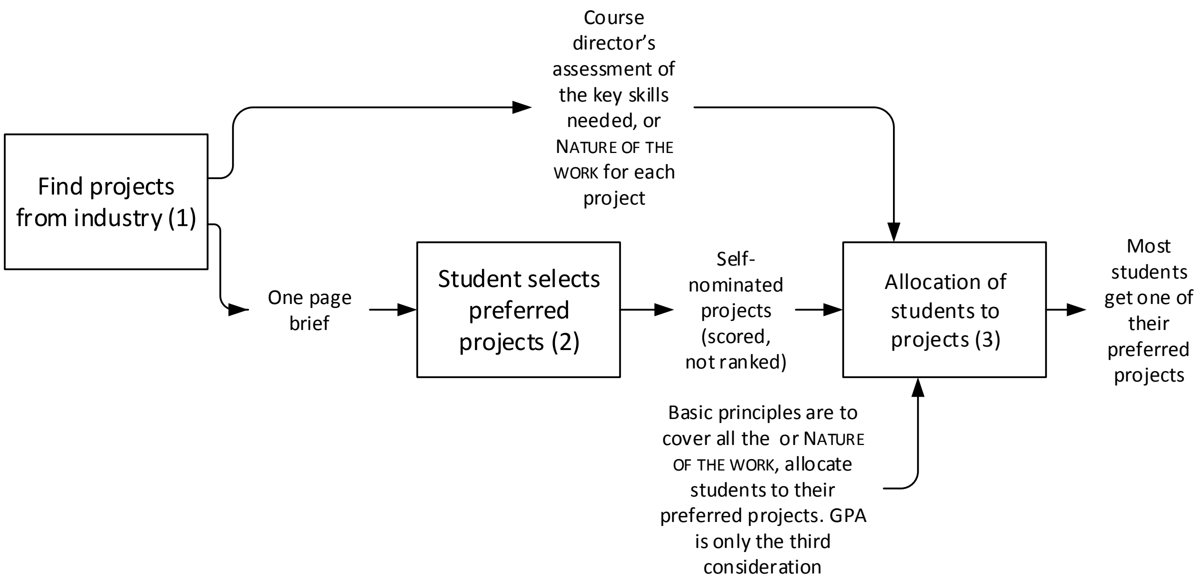


Figure C1: Allocation process

Table C2: Allocation spreadsheet

List of Projects	**Project Title**	**Nature of the work**	**My personal interest in this topic [1..5] where 5 indicates 'very great interest'**	**Area(s) where I offer to contribute to this project**	**Your name in this format: SURNAME, Firstname**	**Your cumulative GPA for your engineering studies**
P01	Snow Probe	Concept design; Mechanical design; Prototyping; Testing; Data acquisition; Other (specify)				
P02	Centre Pivot	CFD; Wind tunnel testing; Aerodynamic analysis; Concept Design; Prototype building; Testing; data acquisition; Industry interaction; Other (specify)				
P03	AIC12 – Glycaemic Control	Physiological modelling; Computational methods; Medical-Device design; Clinical testing; Interface Design; control systems; Other (specify)				
P04	Optimising Ventilator therapy	Biomedical modelling; Computational methods; Medical-Device design; Clinical testing; Interface Design; Control systems; Other (specify)				

Please repeat this information for the projects that interest you. Leave the uninteresting projects blank. Return the whole spreadsheet.

Whereas many other FYP programmes use GPA as a main allocation factor, we have instead used project fit. We try to get as far away from GPA as possible as it gives more trouble than it is worth in terms of making the decision-making contentious for students, causing dysfunctional teams comprising solely GPA addicts, and producing teams with entirely low GPA students. So we get a better mix of GPA across the teams with our method, better match of students to project needs, better student satisfaction, and happier supervisors.

D Appendix: Marking rubrics for assessment

Table D1: Marks scheme for Individual assessment is based on the Washington Accord graduate profile

Mark recommended by Supervisor:	/100			
<35%	35% to 49%	50% to 64%	65% to 79%	>80%
Not much has happened. Need Needs major rework	Needs to tighten focus. There are some contributions, but there are also some gaps. Not quite up to expectations yet.	Good! Progress is sufficient. Contributions are being made in a thoughtful way to most of the criteria. There is a plan and a sincere intent to address any obvious gaps.	Great! The evidence for contribution is specific for most if not all the criteria below. The work has covered all the criteria to at least a moderate level and there are several cases where effort has been applied beyond the nominal.	Wow, that is incredible! There is really good evidence for specific contributions in most if not all the criteria. Those contributions are consistently of high quality and well beyond nominal engagement. The personal progress so far is just so complete in every way.

For use of Project Supervisor and Moderator:

	Not at all	Some extent	Moderate extent	Great extent	Very great extent	Comments, or Summary of the evidence
Mandatory All the following are expected:						
Individual work Function effectively as an individual, risen to the challenges, coped with the ambiguities, and taken identifiable initiative in some area, personal effort.						
Team work Function effectively as a member of the team, contribute to the functioning of the team.						
Communication Communicate effectively, write effective reports, design documentation, give presentations, give and receive clear instructions						
Specific contribution Students are expected to be making a contribution to outcomes in one or more of the						

following ways, but not necessarily all of these:						
Problem analysis Identify problems, research literature, apply first principles of maths, science and engineering knowledge						
Design or development of solutions Design components, systems or processes to meet specified needs						
Investigation Application of engineering research methods, experimentation, analysis of data, synthesis of information						
Use of engineering tools Use and application of relevant engineering tools, including software tools, with an understanding of the limitations						
Project management and finance Manage one's own work, and contribute to the management and organisation of the team						*At a minimum, each student is expected to perform the roles of Chairing a meeting, and taking minutes once a term.*
Professional contribution Apply contextual knowledge to assessing societal, health & safety, legal, cultural, environmental, sustainability, or ethical issues.						
Other contribution Please specify						

Supervisor:	The student's CONTRIBUTION STATEMENT (with any edits as attached) is an accurate description of his/her work Signed Date

Table D2: Team assessment rubric for reports and presentations.

		Not at all	Some extent	Sufficient extent	Great extent	Very great extent	Comments, or Summary of the evidence, or reference to specific work
Mandatory **All the following are expected:**							
Report quality	Clarity of communication, Report Presentation and language and structure, Abstract, Context clear, Approach replicable, Results & interpretation thereof, Clear implications for client						
Complexity of problem addressed	Engineering problems which cannot be resolved without in-depth engineering knowledge. Have some or all of the following characteristics: Involve wide-ranging or conflicting technical, engineering and other issues; Have no obvious solution and require abstract thinking, originality in analysis to formulate suitable models; Requires in-depth knowledge that allows a fundamentals-based first principles analytical approach; Involve infrequently encountered issues; Are outside problems encompassed by standards and codes of practice for professional engineering; Involve diverse groups of stakeholders with widely varying needs; Have significant consequences in a range of contexts; Are high level problems possibly including many component parts or sub-problems						
Contribution statement	Looking for an honest recognition of the contributions of the wider team						
Specific **A contribution in one or more of the following areas is also expected. The more the better.**		Not applicable	Some extent	Sufficient extent	Great extent	Very great extent	Comments, or Summary of the evidence, or reference to specific work
Engineering Knowledge	Apply knowledge (both theoretical and practical) of mathematics, science, engineering fundamentals to the solution of complex engineering problems						
Problem Analysis: Complexity of analysis	Identify, formulate, research literature and analyse complex engineering problems reaching substantiated conclusions using first principles of mathematics, natural sciences and engineering sciences.						
Design/ development of solutions: Breadth and uniqueness of engineering problems i.e. the extent to which problems are original and to which solutions have previously been identified or codified	Design solutions for *complex* engineering problems and *design* systems, components or processes that meet specified needs with appropriate consideration for public health and safety, cultural, societal, and environmental considerations.						

Investigation: Breadth and depth of investigation and experimentation	Conduct investigations of complex problems using research-based knowledge and research methods including experimentation, analysis and interpretation of data, and synthesis of information to provide valid conclusions.						
Modern Tool Usage: Level of understanding of the appropriateness of the tool	Create, select and apply appropriate techniques, resources, and modern engineering and IT tools, including prediction and modelling, to complex engineering activities, with an understanding of the limitations.						
The Engineer and Society: Responsibility and engagement	Apply reasoning informed by contextual knowledge to assess societal, environmental, health & safety, legal and cultural issues and the consequent responsibilities relevant to the ethical practice of professional engineering.						
Project Management and Finance:	Demonstrate knowledge and understanding of engineering and management principles and apply these to manage projects.						

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