SUPERPROJECTS AND SUPERPOWERS: HOW TEAMS WITHIN TEAMS CAN ENHANCE STUDENTS INTERPERSONAL AND ENGINEERING SKILL DEVELOPMENT

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ABSTRACT
Mechanical Engineering graduates are expected to emerge from their degrees competent in communication, collaboration and other transferrable skills, often learnt through engineering design projects. Authenticity of small-group projects may be limited however, due to reduced complexity of both product and inter-team interaction of educational projects as compared to industry. Four years ago, we restructured a third-year module such that three teams of four students each collaborate in a so-called superproject to deliver a functioning prototype. In the cohort of 180 students, 15 superprojects are defined, each with a different topic. Academics act as the project director for the various superprojects, representing both client and mentor roles. Additional academics are technical advisors and supervisors to respective subassembly teams. Workshop and laboratory technicians provide practical support enabling access to, and design for, advanced manufacture and testing facilities. The module leader and departmental pastoral support team act as the superproject's HR department, providing advice and support for professional skill development and appropriate behaviours. This structure requires strong inter- and intra-team collaboration and communication, and good interpersonal skills for successful integration of subassemblies. Findings after four years of running superprojects include that the nested organisation requires higher staff input than other options but is considered a valuable investment relative to outcomes. The structure allows more complex projects, with variable interfaces and more authentic constraints and working conditions, improving both student experience and employability. Staff development is also facilitated through the hierarchical and collective nature of supervision and assessment on the module.

Keywords: Multi-level teamwork, interdisciplinary engineering, system engineering, educating with authentic constraints.

1 INTRODUCTION
Mechanical Engineering programmes traditionally have a strong focus on underlying scientific fundamentals, with modules such as thermodynamics, fluid mechanics, materials, solid mechanics, dynamics, mechatronics and mathematics. These subjects are often taught using a combination of lectures, tutorials and self-study, and are assessed using a written subject-specific exam. Whilst these subjects are undisputedly an essential part of a student's journey towards being a qualified mechanical engineer. Amongst others, Wolfe [1] and Bravo et al [2] described that it is not this theoretical knowledge that mechanical engineering graduates regularly use in their daily work practice: in addition to communication and teamwork, aspects used most often by mechanical engineering graduates include 'engineering reasoning and problem solving', 'independent thinking', and 'personal and professional skills and attributes'.

In an undergraduate Mechanical Engineering degree programme, these transferrable skills and attributes are often combined under the header of 'Design Projects', where students work in a small team to deliver an engineering solution to an open-ended question, many such projects are described in engineering education literature, two examples are [3] and [4]. In the Mechanical Engineering undergraduate programme at Imperial College London, such engineering design projects are performed in the first, second and third year of the four-year programme, with the third-year module called 'Design, Make,

Test' (DMT). The DMT module is a compulsory module, taken by the entire cohort of approximately 180 students, and has an expected time commitment of 20 ECTS or 500 hours per student. The module essentially serves as the capstone project for Engineering Design-focused learning activities. Each team gets assigned a unique project, ranging from a rocket engine to a setup for the functional testing of sanitary pads and the propulsion system for a robotic turtle.
The formal learning outcomes for the module are to:

- Derive and explore the relationship between customer requirements and engineering attributes
- Design machine systems and select elements to meet specified objectives
- Analyse a given design formally, against specified requirements, and refine it appropriately
- Prepare appropriate Quality, Budget, Health & Safety and Test Plans for a small engineering project
- Realise the manufacture using appropriate engineering drawings and appropriate resources
- Exercise the key skills needed for team working on a realistic Design, Make and Test project
- Record and evaluate progress and decisions in a clear and accurate manner, using a logbook

In short, the module aims to prepare the students for a career in engineering by encapsulating a problem into a realistic project structure, every element of which has an analogue in real world engineering. A limitation of educational engineering design projects is their authenticity [4, 5]. This is due to a variety of factors, such as lack of complexity and time pressures related to the academic calendar. Superprojects were introduced in 2020 following review of the previous delivery of design projects. It was identified that the required quantity of work in most projects was impacting the quality of delivery. The proposed solution was to divide the work required for each project into three so-called subassemblies, allowing each subassembly not only to focus on the quality of their work but also experience collaboration with other subassemblies within the project to achieve a common goal. To successfully complete the module therefore, the students must collaborate within and between groups, building industry relevant teamworking abilities.

2 SUPERPROJECTS

The division of a large, more complex task into three smaller subtasks allows better authenticity, through mimicking an industrial engineering project with complete design freedom and a focus on the delivery of high-quality work whilst introducing the complexity of having to interface and collaborate with additional teams to achieve a common goal.

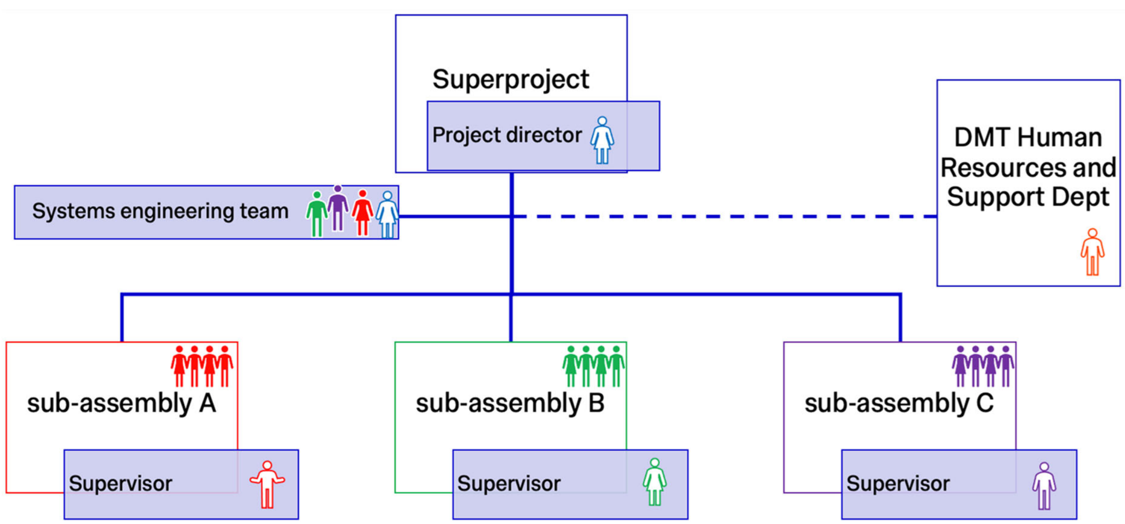

Figure 1. Organogram of a superproject

Figure 1 illustrates the organogram for a typical superproject. The problem owner is the project director, a member of staff who has the role of the client. The superproject comprises three sub-assembly teams of four students, with each subassembly being advised by a supervisor, an additional member of staff in the role of technical specialist. The three supervisors and the project director also have an important informal mentoring role. The DMT Human Resources and Support Department comprises the module leader, student champion, departmental well-being advisor and EDI-coordinator, and provide an additional formal confidential support network for students to provide assistance and advice, in the knowledge that these confidential discussions will not affect any grades. Subassemblies meet their supervisor every week, whilst representatives of each subassembly form a system engineering team that liaises with the project director on a fortnightly basis.

3 PROJECT PLAN AND DELIVERABLES

In our cohort of ca 180 students, 15 different superprojects are defined every year, examples of topics range from upgrades to a formula student vehicle, to a setup for testing of menstrual products and from a rocket engine to a mechanical turtle. All superprojects have a different focus and are being supervised by members of staff with different expertise and capabilities, ranging from theoretical scientists to hands-on engineers, there is no standard format for the completion of the projects. To provide structure, a gated approach is mandated. From a project management point of view the gateways serve as review meetings and mark a go/no-go decision to proceed into the next phase of the project. Didactically, these gateway review meetings serve as formal feedback and assessment moments. The gateways are shown in Figure 2.

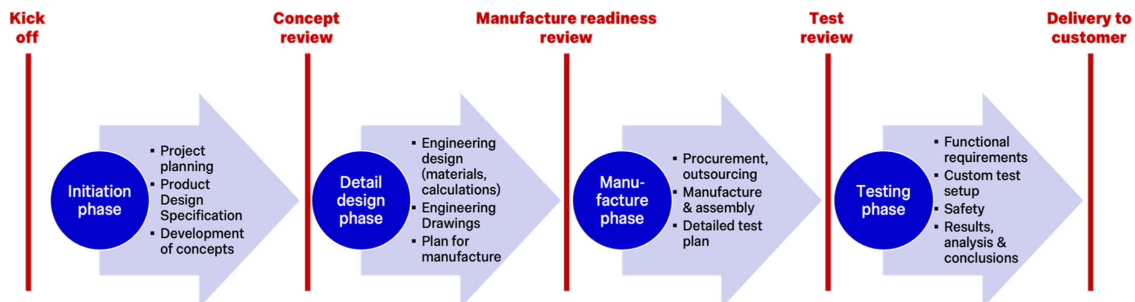

Figure 2. The mandated, gated approach providing structure to the project

Key phases and deliverables during the project are listed in Table 1. All other aspects related to project management, planning and tasks, including definition of objectives, setting of milestones, are determined by the Superproject team in collaboration with the supervisory team.

Table 1. Expected timetable

Task	Time	Notes
Project selection	Week 1	Based on student preference
Project start	Week 2	Formal superproject kick-off with client
Project plan	Week 3	Defining tasks, milestones
Concept review	Week 8	Subassembly
Design & Manufacture readiness review	Week 14	Superproject
Test readiness review & risk assessment	Week 25	Subassembly
Test & Analysis report	Week 25	Superproject
Seminar & Exhibition	Week 26	Client delivery, superproject

Assessment during the first months is mainly on the independent work of the subassembly teams, whilst the second half of the project requires a significant superproject component. Within the subassembly, key deliverables include concept solutions and health and safety documentation before testing, whilst examples of superproject assessment aspects include the final technical seminar to be delivered to the client (represented by the supervisors of all subassemblies in the superproject) and an exhibition, open to all staff and the general public, where the produced prototypes are demonstrated.

4 STAKEHOLDER VIEWS

Since the superproject structure was introduced four years ago, minor adjustments have been implemented based on continuous consultation with all stakeholders. This includes the students, supervisory team, and support structure (laboratory and manufacturing technicians, and the pastoral and administrative teams).

4.1 Students

Student feedback on the introduction of superprojects, through both formal feedback routes as well as informal focus groups, was almost unanimously positive, with recognition that it models industry ways of working, relevant to their future careers. In addition, it was recognised that the superproject structure allows more complex problems to be tackled, which students find enjoyable and rewarding, whilst keeping the workload within the assigned 500 hours per student.

A common issue raised by students was the perception that individuals within their group were not sufficiently contributing to the work and/or not sufficiently engaging with their team. A 360-degree review exercise carried out by the students in each subassembly was perceived unfavourable, with students struggling to balance providing critical and constructive feedback and potentially further deteriorating their working relationships. However, providing and receiving peer feedback is an essential skill for the students' future careers, and therefore both formative and summative peer feedback is continued within the Virtual Learning Environment system. In this system, the supervisory team act as intermediaries with Departmental wellbeing staff available for guidance and advice. In addition, identifying any students who lack engagement and do not appear to contribute is an important role of the supervisory team, particularly the subassembly supervisor, who may decide to call students for one-to-one meetings, or refer a student for a meeting with the DMT Human Resources department.

4.2 Supervisory team

The initial response from academic staff to the introduction of superprojects was mixed; a majority of staff were in favour, acknowledging the limitations of educational engineering projects and the need for students to focus on the delivery of a high-quality engineering product. However, some staff expressed the concern that the reduced number of projects could disenfranchise some colleagues as there would be fewer opportunities for them to participate in a project that is directly linked to their topic of research. To address this risk, additional focus on staff engagement was undertaken by the module leader, including information sessions, fostering broader collaboration in the department.

4.2.1 Project directors

From the perspective of a project director, supergroups are unique; in most academic group projects, the students work towards the same primary goal, thus encouraging cooperation. Hypothetically, all students share the superproject goals, however, in reality most students are, at least initially, primarily focussed on their subassembly. This brings an interesting dynamic to the role of project director, and one which gives an opportunity for academics as well as the students to develop their diplomacy, leadership and teamworking skills. Primarily, the role of the project director is to facilitate collaboration and communication between the subassemblies throughout the project. This takes the form of regular meetings with the systems engineering team.

The project kick-off meeting, with all students and stakeholders physically together in one room, is essential to create a sense of shared understanding, goals and ownership. During this meeting students begin to comprehend the scale and complexity of the project and the management structures surrounding it. The creation and curation of a shared Teams space for documentation and communication is also an important part of a project director's role as communication and information sharing between subassemblies is vital for project success.

In the regular system engineering meetings, students discuss progress and the interfaces between sub-assemblies, collective plans for testing, and clarify any communication needs between groups. The management team meetings are also a place to ensure overall superproject goals remain aligned with the original brief. This is essential as the brief is developed by the director, whereas project supervisors may have been recruited onto the team due to their technical expertise relative to the subassembly's needs, rather than because of their interest in the overarching project aim.

The project director plays a key role in the success of the superproject, setting regular meetings with the groups and/or representatives of the groups. The integration between the subassemblies is enhanced when the project director has a clear vision for the aims and outcomes of the superproject. The project directors – project supervisor relationship also offers an opportunity for mentoring and supporting other academics on the project who may be new to design projects, or the department.

4.2.2 Supervisors

Unlike the project director, who developed the idea for the project, the supervisor does not necessarily have a vested interest in the outcome of the superproject. The supervisors are recruited because of their specialist expertise, to initiate a collaboration with the project director, or they volunteer because they find the project interesting and would like to be involved. At the start of the project, the supervisory team meets enabling the project director to explain the vision and scope of the superproject.

The main roles of the supervisor are as a technical expert and pastoral support. Additionally, the supervisor provides formative and summative assessment at multiple stages throughout the project. The summative assessments are all completed in association with the project director. The supervisor meets the subassembly team weekly, develops a close working relationship with the students in the group and focuses on the progress of the project. The high frequency of these meetings means the supervisor develops a bond with the students and is continuously updated and aware of the project status. The weekly meetings are an opportunity for the group to discuss design choices, receive feedback and advice, and ask questions on aspects that are unclear. The team also discusses perceived issues, including delays or with interaction with the other subassemblies in the superproject.

The role of the supervisor is to guide and advise the team with approaches to overcome obstacles and to potentially step in to discuss these with the other relevant supervisors on behalf of their group. The success of a subassembly is down to the motivation and efforts of the students, but is also reliant on the supervisor to oversee the time management and expectations of the project.

4.3 Technical Support

The students utilise existing Departmental academic support structures, which includes the departmental student teaching workshop for “making” and the academic laboratories for “testing”.

4.3.1 Manufacturing technicians

The departmental student teaching workshop is a hands-on facility where the students can manufacture and assemble their components. Available equipment includes manual lathes, milling machines, pillar drills, and facilities for the fabrication of sheet metal, as well as computer aided manufacturing machining centres and professional additive manufacturing machines. The students received formal training on all equipment in year 1 when they pass a qualifying test, whilst in year 2 they revisit to deepen their understanding of select manufacturing processes. All infrastructure available in the workshop is at the DMT students’ disposal. A team of 7 manufacturing technicians is available to provide the teams with advice on Design for Manufacture, and whether parts can be made in-house, either manually or using CNC processes, or whether it is advised to outsource manufacture.

The introduction of superprojects has reduced the total number of individual parts that require manufacture, whilst the stronger focus on delivering quality has increased demand on detailed design advice. Nett there has been no discernible effect on the required workshop manpower.

4.3.2 Laboratory technicians

Testing is an essential aspect of the DMT module, and the laboratory technicians have an important role in the planning, safety and execution aspects of testing. The superproject teams are tasked to define a total of six meaningful tests on their product (two per subassembly) with the objective of validating their design and manufacture efforts and informing any potential design improvements. Whilst the students have attended laboratory sessions, performed data analysis and written laboratory reports in years 1 and 2, in year 3, the DMT module requires them for the first time to plan and set-up a novel experiment, source equipment and sensors and hypothesise on potential outcomes. The various laboratory technicians provide support for these activities. They have organisational responsibility for dedicated laboratories within the department, and students liaise with the technicians responsible for the infrastructure they need. The technicians also check the risk assessments delivered by the students, which are subsequently approved by the supervisors.

The added complexity of the superprojects has made testing more elaborate, and as a result the students require more detailed advice. However, the reduction of the number of setups to be tested, from 45 individual projects to 15 superprojects, has reduced time that the technicians spend on coordination and setting up experiments. Overall, the introduction of superprojects has had no significant change to required laboratory efforts.

5 KEY TAKEAWAYS & CONCLUSION

Staffing requirements of the superproject structure are high, with 4 supervisors required for every superproject of 12 students. This is an inherent consequence of the introduction of superprojects, and apart from growing the size of subassemblies to a larger number of students, or increasing the number of subassemblies in a superproject, this cannot be improved. A positive aspect is that the management structure allows ample opportunity for unexperienced teaching staff, such as junior academics and senior postdoctoral researchers to be trained in supervision, with the project director taking a mentoring role. Additionally, the role of project director as client does not require strong design engineering skills and is therefore ideally suited to members of staff with a more theoretical or computational focus.

The introduction of the superproject structure means that the students are introduced to a way of working that mimics practices in industrial engineering, thus enhancing authenticity and employability skills. To successfully and efficiently complete their project, the students must understand and define the interfaces between the separate subprojects in a similar manner to how they would in their future careers. By necessity, the students need to communicate and collaborate both within their own subassembly team and between the subassemblies. For example, engineering design often requires a compromise between competing parameters such as weight, performance and cost. The superproject concept means as the design develops and parameters are iterated; the individual sub-projects need to communicate changes and collaborate with each other in order to achieve a successful outcome.

It can be concluded that the introduction of superprojects in the undergraduate programme has improved the quality of the engineering efforts performed by the students, whilst also training them in collaboration and communication skills.

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