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# The development of a capstone project course based on CDIO principles

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ABSTRACT: The principles developed within the *Conceive – Design – Implement – Operate* (CDIO) Initiative are being implemented in the School of Mechanical and Aerospace Engineering at Queen's University Belfast (QUB) in Belfast, Northern Ireland, UK. As part of the School's implementation plan, a new capstone project course was introduced in the fourth year of its MEng programme in mechanical and manufacturing engineering. The main aim was to satisfy a number of the CDIO Standards, including the requirement to address as many topics as possible in the CDIO Syllabus. The development of the project course is described in the article, along with the associated changes in the third and fourth years of the programme. Examples of typical projects are given, and it is argued that the prime objective of introducing the project course has been achieved.

## INTRODUCTION

The School of Mechanical and Aerospace Engineering at Queen's University Belfast (QUB) in Belfast, Northern Ireland, UK, is implementing the principles of *Conceive – Design – Implement – Operate* (CDIO) in its degree programmes. This means that the programmes are being redesigned to meet the CDIO Standards, particularly the following Standards, since they relate directly to the design of the curriculum [1].

Standard 2: CDIO Syllabus Outcomes

Standard 2 requires programme learning outcomes to be adopted that address the topics in the *CDIO Syllabus* that are deemed to be consistent with the programme's goals and have been validated by the programme's stakeholders.

The CDIO Syllabus is an organised list of all the areas of knowledge, skills and attributes that an engineering graduate could reasonably be expected to possess [2]. The main topics in the syllabus, which has additional levels of detail, are listed below:

1 Technical Knowledge

2 Personal and Professional Skills:

2.1 Engineering Reasoning and Problem Solving;
2.2 Experimentation and Knowledge Discovery;
2.3 Systems Thinking;
2.4 Personal Skills and Attributes;
2.5 Professional Skills and Attitudes.

3 Interpersonal Skills:

3.1 Teamwork and Leadership;
3.2 Communication;
3.3 Communication in Foreign Languages.

4 Product and System Building Knowledge and Skills:

4.1 External and Societal Context;
4.2 Enterprise and Business Context;
4.3 Conceiving;
4.4 Designing;
4.5 Implementing;
4.6 Operating.

Standard 3: Integrated Curriculum

Standard 3 requires a curriculum that is designed with mutually supporting disciplinary subjects, with an explicit plan to integrate personal, interpersonal, and product and system building skills.

Standard 4: Introduction to Engineering

Standard 4 requires an introductory course in the first year of the programme that provides the framework for engineering practice in product and system building, and introduces essential personal and interpersonal skills.

Standard 5: Design-Build Experiences

Standard 5 requires a curriculum that includes two or more design-build experiences, including one at a basic level and one at an advanced level.

One of the first tasks undertaken by the School was to develop a new capstone project course for the fourth year of its MEng programme in mechanical and manufacturing engineering. The primary aim was to provide students with an advanced design-build experience, thus contributing to Standard 5. However, it was decided that the capstone course would also make a significant contribution to Standards 2 and 3. In other words, it would address as many topics in the CDIO Syllabus as possible and would be introduced as part of an integrated fourth year curriculum. Some restructuring of the third and fourth years of the programme was necessary and the changes made are explained below. The new capstone course is then described, examples of projects are presented and it is argued that the aims defined above for the new course have been achieved.

## RESTRUCTURING THE PROGRAMME

Previously, the MEng programme featured core (ie compulsory) mechanical and manufacturing courses in all four years, plus optional or elective courses in both the third and fourth years. Students also carried out substantial individual projects in the third and fourth years, selected from a list that included both research-based and design-oriented projects. Restructuring involved moving the fourth year core courses to the third year in place of the third year electives. This would allow a new integrated set of courses to be introduced into the fourth year that would provide support for the proposed capstone project. The latter would also be a *true* capstone project in the sense that students would have acquired all of their core engineering knowledge before starting the project.

## THE NEW CAPSTONE PROJECT COURSE

The new project course was to be team-based, and would, therefore, complement the individual project that students undertake in the third year. To satisfy CDIO Standard 5, it was to include an advanced design-build exercise. A broadly-based project was also called for in order to ensure that as many topics as possible in the CDIO Syllabus would be addressed. After some thought, it was proposed that the project would simulate a real-world situation where a group of people came up with an idea for an innovative new product, formed a company, developed the product, and prepared a business plan to acquire the funding to manufacture and market the product. The instructions given to the teams (of five or six students) when they start the project are as follows:

- Generate an idea for an innovative new product;
- Form a hypothetical start-up company to design, develop and market the product with designated roles and titles for each team member;
- Conduct a detailed market analysis including the identification and assessment of competing products;
- Create a product design specification for the product;
- Select a design concept for the product after assessing a range of concepts;
- Produce a detailed design in the form of CAD models and engineering drawings, supported by analyses based on engineering science and the application of CAE tools;
- Build and test a prototype and develop the product until it meets its design specification;
- Prepare and present a detailed business plan (for potential *investors*) covering the financial, business, technical, manufacturing and personnel issues involved in setting up a company to market the product.

The sequence of tasks involved in completing the project is shown schematically in Figure 1. As the figure indicates, the teams work in parallel on the marketing, business and design aspects of developing their product ideas. This provides important experience of the compromises that must be made in product development and the need for a holistic approach. After presenting their marketing and business plans (to an invited panel of industrialists, bank managers, etc) the teams concentrate on producing and testing a prototype of their product. This is demonstrated at a final presentation, and each team member then submits a technical report.

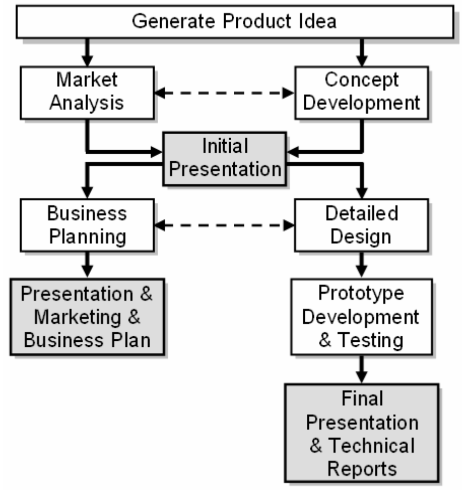


Figure 1: Tasks involved in the capstone project.

As already noted, students have completed all core courses before starting the project. They have also carried an individual project and studied engineering design for three years. Hence, each student brings significant knowledge and a variety of skills to the capstone project and this is shown schematically in Figure 2. However, additional knowledge and skills are needed in order to meet the demands of the project.

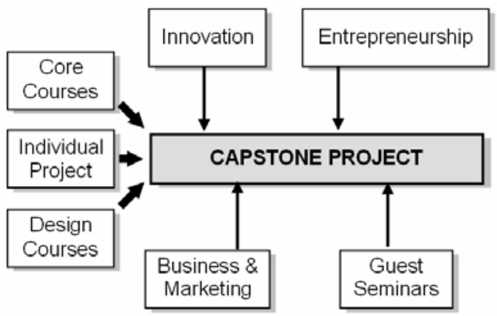


Figure 2: Capstone Project and Supporting Courses.

As shown in Figure 2, supporting courses are provided, including one on *Business and Marketing*. This covers many of the non-engineering aspects of the project, from generating ideas for an original product to drawing up a business plan. Included are lectures on market research, strategic planning, product pricing, consumer behaviour, advertising, business ethics and leadership skills. In addition, a course is provided on *Innovation*, which has the aim of placing the capstone project in a wider context. It deals with the importance of innovation to individual companies and the economy in general. It also examines the characteristics of innovative companies, the role of research and development, the management of innovation and the introduction of new products. The intention is that students will make connections between their experiences in the project and the topics covered in the course. There is also a course on *Entrepreneurship*, which deals with the formation of start-up companies, alternative business models, sources of finance and advice, management topics and legal issues. The course helps team-members to make more informed decisions when they are developing their marketing and business plans.

The *Guest Seminars* shown in Figure 2 are designed to cater for gaps in students' knowledge and provide a background on more specialised topics. Subjects addressed have included patenting, Intellectual Property Rights (IPR), project management, risk assessment, team building, quality auditing, human resources and rapid prototyping. The seminar programme has also featured case studies in product design and development presented by practitioners from local companies and consultancies.

In order to add to the realism of the capstone project, the direct supervision of teams by faculty is relatively limited. However, the teams are provided with a limited number of vouchers to enable them to consult individual *experts* of their choice within the University, thus simulating the fact that companies need to pay for external assistance. Of course, students also develop their own expertise through independent learning in the University's library and by utilising the Internet.

## EXAMPLES OF PROJECTS

The most difficult part of the project for many teams is generating the initial idea for an innovative product. It is important that product ideas come from students, since *ownership* of the product has obvious motivational advantages. Students can also change the product as they explore their initial idea, which would tend not to happen if the product idea were specified in advance by faculty. As an example, one team felt that it would be worthwhile to develop a gearbox for a wheelchair to facilitate hill climbing. As with all teams, they were encouraged to consult interested groups and individuals in the local community when undertaking their market research. In this case, they contacted wheelchair users, staff at an orthopaedic hospital and a local wheelchair manufacturer. They discovered that a more pressing problem was stopping wheelchairs from rolling backwards. As a result, they changed the product to an anti-roll back device for wheelchairs.

Some product ideas originate from students' outside interests or from discussions with friends and relatives. In one case, contact with an employee of the Northern Ireland Ambulance Service raised a problem that the team felt they could solve. When critically ill patients are transferred on stretchers by ambulance, they are normally accompanied by various items of monitoring and life sustaining equipment. These items tend to be heavy and unsecured, which poses difficulties when the stretcher is moved, and when the ambulance is braking or cornering at speed. The challenge faced by the team was to design and develop an equipment carrier for a typical complement of equipment that could be easily and securely attached to a stretcher and removed when required. The prototype carrier developed by the team is shown in Figure 3.

Another team became aware of a problem in nasal surgery through a relative. They were told that consultants in this area have a requirement for flexible forceps to enable them to reach into a patient's nasal passages. The team developed a product design specification through interviews with surgeons and other relevant medical staff. The device produced by the team, which allows the forceps to be manipulated using a trigger, is shown in Figure 4.

The fundamental principle of the CDIO Initiative is that students should acquire the knowledge and skills associated with the conception, design, implementation and operation of products and systems associated with their discipline. In order to satisfy this principle, the project aims to encompass all four lifecycle stages. The *conception* stage receives particular attention because the teams have to generate their own product idea. Having designed the product, they must *implement* the design as a physical prototype. As far as possible, the teams build their own prototypes, but technician assistance is available and the teams use external companies when specialised manufacturing operations are required.


Figure 3: Equipment carrier for an emergency stretcher.

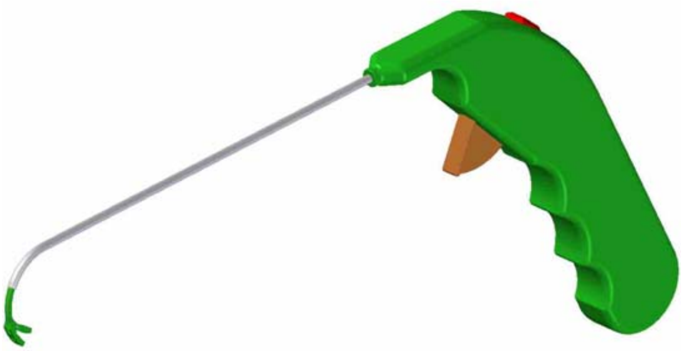

Figure 4: Flexible forceps for nasal surgery.

Figure 5 shows a team building a prototype of a domestic recycling unit, which students designed to compact household waste products. The *operation* stage is limited to the testing of the prototype, but clearly valuable lessons can be learnt if the teams are able to assess whether their design decisions and calculations have resulted in a product that meets its specification.

Figure 6 shows the testing of a remotely controlled *weed harvester* in a large water tank. The student team believed that there would be a market for a machine that cuts weeds in small lakes or large ponds and transports them back to the shore.

## CONTRIBUTION TO THE CDIO STANDARDS

The new capstone project clearly satisfies the need for an advanced design-build exercise (Standard 5). In fact, as discussed above, it could be regarded as an advanced conceive-design-implement-operate exercise. A contribution has also been made to the requirement for an integrated curriculum (Standard 3), since, apart from the elective courses, the fourth year curriculum consists of a number of interconnected courses, as shown in Figure 2.

Figure 5: Assembly of a domestic recycling unit.

Figure 6: Testing of the weed harvester.

Addressing as many topics as possible in the CDIO Syllabus (Standard 2) was a primary objective of the capstone project. Reference to the listing of the main sections of the syllabus presented above indicates that the project addresses topics in virtually every section. This includes *Technical Knowledge* (1), since students invariably need to acquire additional knowledge not covered previously in the curriculum. The project exposes students to *Engineering Reasoning and Problem Solving* (2.1), and the problems involved are often open-ended and ill-defined. They must learn to make decisions on the basis of estimation rather than precise data, and take cost, uncertainty and risk into account. Time needs to spent on *Experimentation and Knowledge Discovery* (2.2), as the teams explore and evaluate alternative concepts and different operating principles. The importance of *Systems Thinking* (2.3) becomes apparent when they realise that design decision making needs to take marketing, business, economic, manufacturing and societal factors into account. A variety of *Personal Skills and Attributes* (2.4) are developed and, as a consequence, it has been noted that students become noticeably more confident and self-assured. Faculty have also observed that the project contributes to the development of *Professional Skills and Attitudes*, primarily as a result of its role-playing element. Students take their roles within their hypothetical start-up companies seriously and conduct their business with a degree of formality. Each team creates a company logo, and they usually produce literature and other items for publicity purposes. Clearly, an important contribution is made to the development of skills relating to *Teamwork and Leadership* (3.1) and also *Communication* (3.2). However, a major outcome is that the teams realise that they have the ability to transform an initial idea into a functioning product, for the most part with limited assistance from faculty. In the process, they acquire experience of *Conceiving* (4.3), *Designing* (4.4), *Implementing* (4.5) and *Operating* (4.6) in an *Enterprise and Business Context* (4.2), and, in many cases, an *External and Societal Context* (4.1). Hence, the capstone project provides a platform for ensuring that students are exposed to the full breadth of the CDIO Syllabus.

## CONCLUSIONS

As one of the first steps in implementing CDIO principles in its degree programmes, the School has developed a new capstone project course for the fourth year of its MEng programme in mechanical and manufacturing engineering. The project was designed to satisfy several CDIO Standards, including maximum coverage of the topics in the CDIO Syllabus. This has been achieved by basing the project on a real-world scenario, where a group of students has an idea for an innovative new product, undertakes market research, sets up a *company*, develops the product and seeks funding from potential *investors*. The third and fourth year curricula were restructured to ensure that students were as fully prepared as possible to undertake the project, and to provide supporting courses and seminars on relevant subjects in parallel with the project.

During the first few weeks of the project, there is undoubtedly a high level of anxiety among students, mainly because they have not previously faced a task that is as open-ended as having to produce an idea for an innovative product. However, significant feedback is obtained at the end of the project through student questionnaires and a face-to-face discussion with faculty. This feedback, along with team presentations and assessed work that students submit, have established that the project provides an excellent learning experience. Students ultimately enjoy the project, become fully engaged in the challenge and believe that they have acquired a variety of important new skills. The School is also satisfied that the new capstone project has achieved its stated aim, namely to meet a number of the CDIO Standards and cover a significant range of topics in the CDIO Syllabus.

## REFERENCES


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