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A CDIO APPROACH TO THE FINAL YEAR CAPSTONE PROJECT

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ABSTRACT

The principles and standards of CDIO are being implemented in the MEng programme in Mechanical and Manufacturing Engineering at Queen's University Belfast. As part of the implementation plan the final year of the programme has been modified in order to provide an integrated learning experience centred on a new team-based project. The changes to the programme are described and examples are presented to illustrate the type of project carried out by the student teams. Finally the new project's role in helping to meet the CDIO Standards is discussed, conclusions are drawn and future work is outlined.

INTRODUCTION

The School of Mechanical and Manufacturing Engineering at Queen's University Belfast has a number of established engineering programmes, to which it has recently added a new programme in Product Design and Development. As a participant in the CDIO Initiative the School aims to adopt CDIO in all of its programmes. In the case of the new programme the opportunity has been taken to implement CDIO in a comprehensive manner in the first year, and this will be repeated in subsequent years as the first cohort of students progresses through the programme. In the case of the established programmes the adoption of CDIO has inevitably posed additional difficulties, but an implementation plan is being followed that will introduce the necessary changes over the next few years.

The reference point for the CDIO implementation plan is the twelve CDIO Standards. In terms of planning the curriculum the Standards require an introductory course that incorporates design-build experiences, followed by at least one further design-build exercise of a more advanced and demanding nature. The Standards also stipulate that the curriculum should address the CDIO Syllabus which covers a wide range of personal, interpersonal and product and system building skills. Furthermore the development of these skills should be integrated with the acquisition of disciplinary knowledge and, where appropriate, disciplinary subjects should be linked together in a meaningful way. Within individual courses the Standards require an emphasis on active and experiential learning, and that every opportunity should be sought to develop students' skills simultaneously with the teaching of disciplinary topics.

The School's implementation plan for its established programmes covers all of the above requirements, and progress is being made with all aspects of the plan. However the initial focus of the plan was the project undertaken in the final year of the School's MEng programme in Mechanical and Manufacturing Engineering. As discussed in the remainder of the paper, this project was felt to have the greatest potential for addressing a significant number of the CDIO Standards in a single initiative.

MEng PROGRAMME IN MECHANICAL & MANUFACTURING ENGINEERING

The MEng programme consists of four years of study and entry is restricted to applicants with superior academic qualifications. Students must maintain high standards to remain on the programme, and many of those who graduate with MEng degrees progress to positions of responsibility. Until recently the structure of the programme was as outlined in Figure 1.

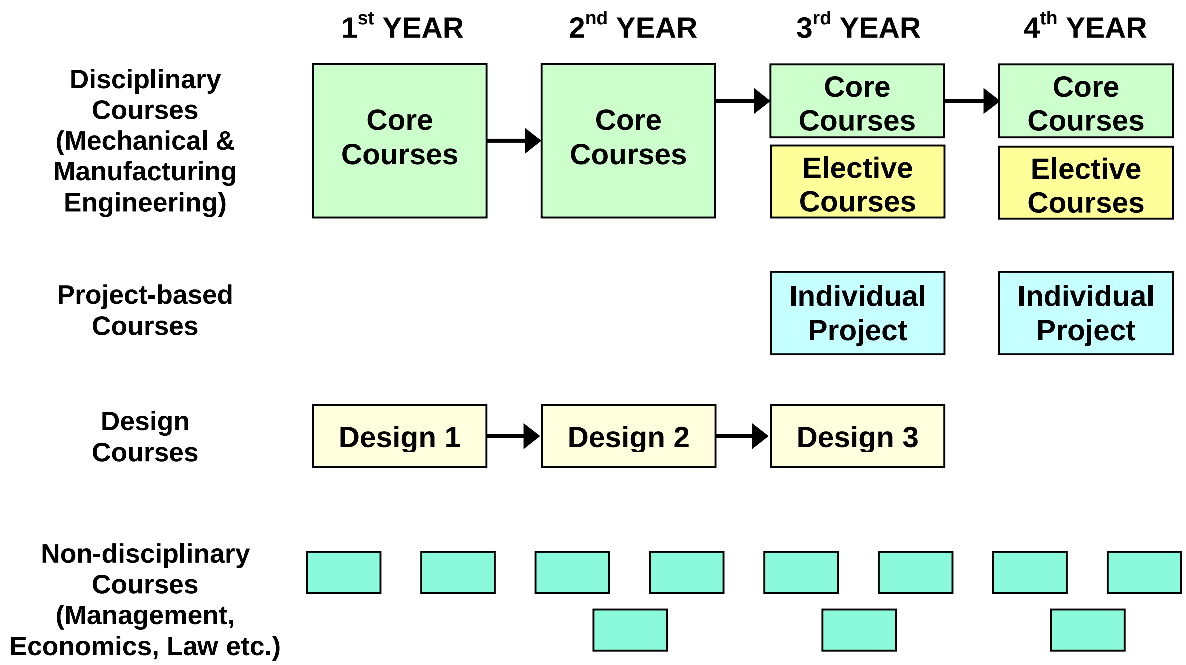

Figure 1: Previous Structure of the MEng Programme

As shown in the figure, core mechanical and manufacturing courses extended over all four years, with electives provided in both the third and fourth years. The elective courses were shared with other programmes. In the case of the third and fourth year individual projects, students chose a year-long project from a list containing both research-based and design oriented options. The non-disciplinary courses covered mainly "professional" topics such as management, economics, accounting, health and safety and employment law.

RE-STRUCTURING THE MEng PROGRAMME

The School decided to re-structure the MEng programme for a number of reasons. A team-based project rather than an individual project was to be included in the final year. A unique set of elective courses of an advanced nature was felt to be more appropriate for MEng students in their final year than shared electives with students on other programmes. Finally there was a need to integrate the non-disciplinary courses more fully with the remainder of the curriculum. The revised structure of the MEng programme is outlined in Figure 2.

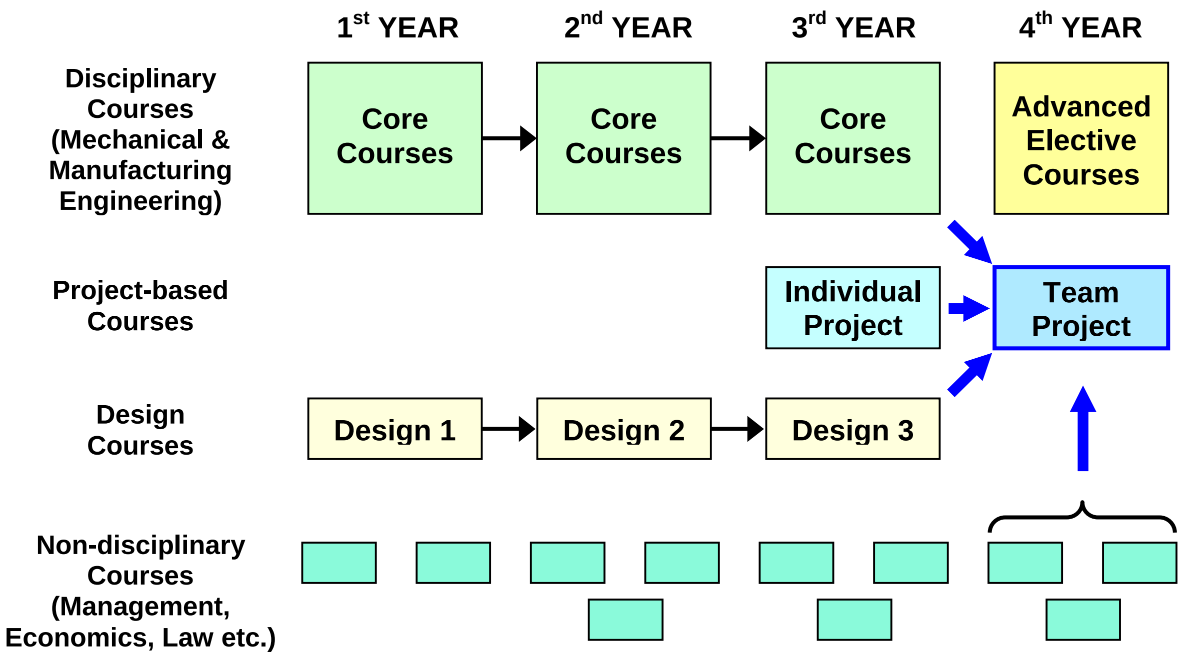

Figure 2: Revised Structure of the MEng Programme

As Figure 2 indicates the core disciplinary courses are now covered by the end of the third year. This allows students to study advanced electives in the final year. In addition the final year team project can now be legitimately regarded as a "capstone" project, since students have completed all core courses before it commences, as well as all of their courses in design. Furthermore, having gained the experience of carrying out an individual project in the third year, it is logical that students should extend their project skills by participating in a team-based project in their final year.

THE FINAL YEAR TEAM-BASED PROJECT

The new final year project was introduced in part to provide the advanced design-build exercise called for in the CDIO Standards. It was also to be a vehicle for developing as many skills as possible from those listed in the CDIO Syllabus. With this in mind a wide-ranging project was envisaged where students working in teams of five or six would:

a) Generate an idea for an innovative product

b) Form a hypothetical company to design, develop and market the product, with designated roles and titles for each team member.

c) Conduct a detailed market analysis including the identification and assessment of competing products.

d) Create a product design specification for the product.

e) Select a design concept for the product, after assessing a range of concepts.

f) 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.

g) Build and test a prototype, and develop the product until it meets its design specification.

h) Prepare and present a detailed business plan (ostensibly for potential investors) covering the financial, business, technical, manufacturing and personnel issues involved in setting up a company to market the product.

In essence the project simulates the process that a start-up company would go through to launch a new product, in as complete a manner as possible. In so doing it brings together the technical, business and marketing issues that professional engineers must contend with in the real world. (Our experience has been that it also re-creates the tensions, time pressures and interpersonal problems that graduates have to learn to cope with in their working lives.)

As already noted, the project provides final year students with the opportunity to apply design and project skills as well as the disciplinary knowledge they have acquired in the previous years. However additional knowledge and skills are inevitably needed to meet the demands of the project. This need is met in a number of ways. Students acquire relevant expertise by independent learning through the university libraries and the Internet. They are also provided with vouchers that enable them to "buy" consultations with appropriate experts in the university. In addition, courses and seminars are provided on subjects of general relevance to the students' project work. Providing such courses and seminars was possible because of the flexibility that exists with the non-disciplinary courses shown in Figure 2. Unlike the disciplinary courses, the non-disciplinary courses do not follow a logical progression, but tend to be independent from each other and unconnected with the remainder of the curriculum. This means that they can be modified and re-arranged without repercussions, and if required new courses can be introduced to produce a more integrated curriculum. To date the focus has been on the non-disciplinary courses in final year and the need to integrate them more fully with the final year project. This has led to the arrangement shown in Figure 3 where support has been provided for the project through three non-disciplinary courses and a programme of seminars.

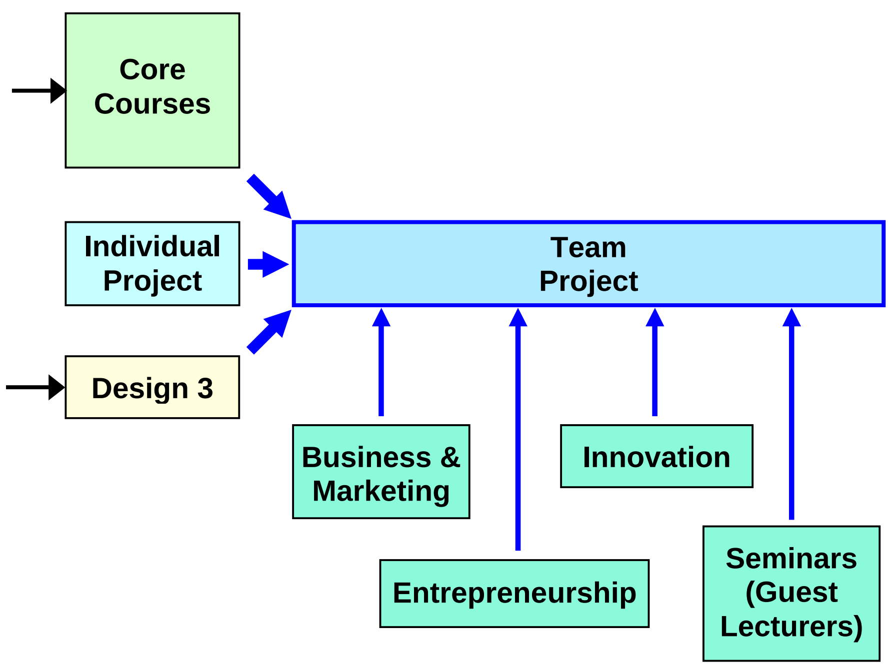

Figure 3: Final Year Project with Supporting Courses

As Figure 3 shows, prior learning that contributes to the final year project is supplemented by a course 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 “Entrepreneurship” which deals with the formation of start-up companies, alternative business models, sources of finance and advice, management topics and legal issues. There is also a course on “Innovation”, which has the aim of placing the final year 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 new product introduction. The intention is that students will make connections between their experiences in the project and the topics covered in the course.

The seminars shown in Figure 3 are designed to provide background on more specialized topics. Subjects addressed have included patenting, IPR, project management, risk assessment, team building, quality auditing, human resources and rapid prototyping. Case presented by design practitioners have also been included in the seminar programme.

EXAMPLES OF PROJECTS

The most difficult part of the project for many student teams is generating the initial idea for an innovative product. Ideally the product idea should come from the students, since the team will then have “ownership” of the concept and, in our experience, will tend to promote and defend their idea more vigorously. In some cases individual students propose innovative products that have been suggested to them by family members or friends. Providing the student can convince the other team members of the merits of proposal, this is acceptable. From time to time product ideas are submitted to staff in the School by companies or external organisations. Having given the teams a period of time to come up with their own ideas, these are brought to the attention of the students. In the final resort, the staff responsible for co-ordinating the projects will suggest product ideas to any team that has failed to produce one of its own, but this has rarely been required.

By way of illustration, one of last year’s teams felt that it would be worthwhile to develop a gearbox for a wheelchair, in order to facilitate hill climbing. As with all student teams, they were encouraged to seek out groups and individuals in the local community when undertaking their market research. In this case they consulted wheelchair users, staff at an orthopaedic hospital and a local wheelchair manufacturer. They discovered that a more pressing and fundamental problem was stopping a wheelchair from rolling backwards. As a result they changed the project to one involving the design, development and marketing of an anti-roll back system for wheelchairs. Figure 4 shows CAD models the team produced to explore different design concepts.

Another of last years’ teams became aware of a problem in nasal surgery through a relative. Consultants in this area have a requirement for flexible forceps to enable them to reach into a patient’s nasal passages. The team set about satisfying this requirement, having refined the design specification through interviews with surgeons, and other relevant medical staff. The device developed by the team is shown in Figure 5.

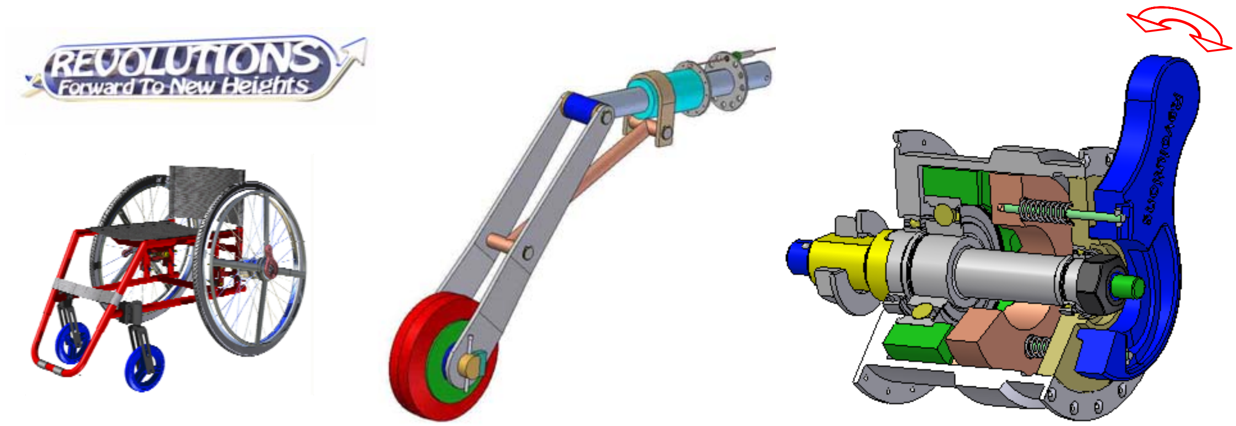

Figure 4: Wheelchair Anti-Roll Back System

Figure 5: Nasal Forceps

A further project from last year arose from a problem raised by the Northern Ireland Ambulance Service. When critically ill patients are transferred on stretchers by ambulance they are normally accompanied by various items of monitoring and life sustaining equipment. These tend to be heavy and unsecured, which poses difficulties when the stretcher is moved, and the inertia of the equipment creates obvious dangers 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 easily, but securely, be attached to a stretcher and quickly removed when required. A CAD model and a photograph of the prototype carrier developed by the team are shown in Figure 6.

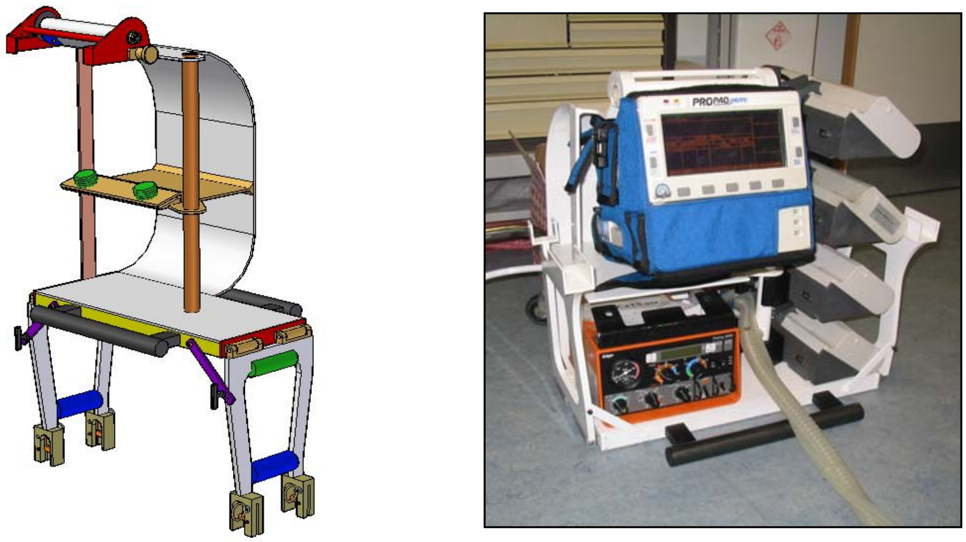

Figure 6: Equipment Carrier for Stretcher

CONTRIBUTION TO CDIO STANDARDS

The new final year project addresses a significant number of the CDIO Standards. Clearly it represents an advanced design-build exercise and while it qualifies as a capstone project, students continue to learn actively and experientially and acquire further knowledge and skills as the project proceeds. As indicated, other courses are integrated with the project in order to provide support and add meaning to the topics covered. The result is a coherent integrated learning experience that constitutes around half of the final year curriculum.

A major contribution of the final year project and its support courses is the extent to which it covers the CDIO syllabus. The syllabus contains sections on the technical knowledge of the discipline, personal and professional skills, interpersonal skills (including teamwork and communication) and the knowledge and skills involved in conceiving, designing, implementing and operating products and systems. A wide variety of personal and professional skills are developed in the project. Students for example have to exercise engineering reasoning to solve problems that are open-ended and ill-defined. They must learn to make decisions on the basis of estimation rather than precise quantitative data, and take cost, uncertainty and risk factors into account. The project will inevitably involve time spent on experimentation and knowledge discovery, as teams explore and evaluate concepts and principles that may be incorporated in the design of the product. A holistic systems approach is also essential, so that design decision making encompasses relevant marketing, business, manufacturing and societal factors, and not just the immediate technical aspects of designing a product. In addition personal attributes are developed through the need for creative and critical thinking, initiative, perseverance and successful time and resource management. It has in fact been observed that students mature and become more confident during the project, in part through the realization that they can conceive and create a product and at the same time plan in some detail how a company could be formed to manufacture and market the product.

The project clearly makes a major contribution to the development of interpersonal skills. The role playing element in the project simulates the situation found in professional practice, where each team member has a designated area of responsibility which must be respected, but also has a responsibility to accept collective decisions made by the team. Communication skills are developed within the teams and also by requiring the teams to make a series of presentations during the year, produce team reports and write individual dissertations. In addition teams are encouraged to involve the local community in their projects by surveying potential customers and consulting users, companies and appropriate government agencies. Describing their project to non-engineers and eliciting information from these groups provides further practice in communication skills.

The final year project directly addresses the section of the CDIO Syllabus on conceiving, designing, implementing and operating products and systems. CDIO requires that these activities are set in their enterprise and societal contexts. Since the project involves the detailed planning of a start-up company to market the product, the enterprise context is automatically addressed. Students are also encouraged to take the societal context into account, and as it happens a high proportion of the products proposed by the teams are intended to fill a social need, with many choosing to develop medical devices or disability aids.

CONCLUSIONS AND FUTURE PLANS

As part of its CDIO implementation plan the School has introduced a new final year project that contributes to a significant number of CDIO Standards and addresses all sections of the CDIO Syllabus. As part of the initiative the curriculum has been altered so that students complete all core disciplinary courses before undertaking the project. In addition the final year non-disciplinary courses have been revised and re-aligned in order to support the needs of the project. The result is a final year curriculum that combines a choice of advanced elective courses with an integrated project-based learning exercise. The latter focuses on the central theme of CDIO that the conception, design, implementation and operation of products and systems should be the primary concern of engineering education, with due regard paid to the enterprise and societal environment. A strong emphasis on this theme in the final year would seem appropriate, on the basis that students are effectively rehearsing the role they are likely to assume when they become professional engineers.

Current work on the School's implementation plan is directed towards the earlier years of the School's established programmes. It is planned that additional project work will be introduced, and the opportunity will be taken to further integrate the curriculum. Again the flexibility that exists within the non-disciplinary course provision may be exploited, and courses relocated or modified in order to facilitate integration. During the time frame of the implementation plan, the School's new degree programme in Product Design and Development will have progressed to its later years. The results of adopting CDIO within this programme will therefore be available to inform the redesign of the School's established programmes so that they fully comply with the principles and standards of CDIO.