AN INNOVATIVE APPROACH TO DEVELOP STUDENTS' INDUSTRIAL PROBLEM SOLVING SKILLS

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ABSTRACT

This paper presents details of the multi-disciplinary capstone course 'Advanced Innovation and New Product Development', which was developed by the INNOVATIONZ research group at the University of Auckland, New Zealand. The course is run in collaboration with the University's Business and Creative Arts faculties, and with a range of industry partners, design consultants and business professionals, and is aimed at providing Engineering students with practice-relevant and multi-disciplinary learning experiences in the areas of product design, new product development and innovation management. The course includes a number of features and approaches which create a rich and integrated learning environment that helps students develop interdisciplinary product development knowledge, practise their teamwork and communication skills, and experience the new product development process through real-life project work.

In the paper we provide an overview of the general concept and structure of our course, including course philosophy, course design and course objectives, which are in line with the needs of industry and with the requirements of the Engineering profession. This is followed by a more detailed discussion of a number of key aspects of our approach, which are particularly relevant to the achievement of our course objectives and outcomes. The main areas we discuss are our project-based learning approach and the associated assessment procedures, which are designed to support those aspects of learning we find particularly relevant for our students. Another important aspect covered in the paper is our approach to fostering the development of multi-disciplinary teamwork skills, which are critical for the successful involvement of professional engineers in the product development process. We conclude the paper with a selection of feedback comments from our students, which illustrate the effectiveness and the educational value of our course.

KEYWORDS

Project-based learning, new product development, multi-disciplinary teamwork, assessment, reflections on learning

INTRODUCTION

To maintain their competitiveness in the globalised economy, manufacturing companies must develop their capability to continually design and produce innovative products that are cost-competitive and exceed or at least meet their customers' expectations. However, the design of new products, and in particular of those which require significant technology or engineering development, is challenging as truly innovative products need to be optimised with respect to a broad range of criteria: Apart from offering intuitive and flawless technical functionality, they need to be aesthetically pleasing, reliable, cost-competitive, and include particular attributes and features that set them apart from their competitors and lead to a superior customer experience.

The design and development of such products requires a New Product Development (NPD) process which includes inputs from a diverse range of perspectives. Successful NPD in the competitive global marketplace depends vitally on synergies between a broad spectrum of disciplines such as engineering design, industrial and graphic design, technology management, business innovation, change management, branding and marketing. Generating and maintaining a creative and synergistic NPD environment and culture is a key challenge for manufacturing organisations; and it is particularly important for them that their design staff have sound professional backgrounds in areas like engineering, manufacturing and design, but also possess multidisciplinary skills and experience, and are capable of playing an integrative role in a creative design-driven business environment.

The NPD process is particularly challenging for Small and Medium Sized Enterprises (SMEs), which often do not have adequate resources and sufficiently competent and experienced staff in this area. This problem has been widely recognised in the last few years, and there have been a range of international programmes and initiatives that are aimed at fostering product innovation in SMEs, for example the European Small Business Portal [1] and the EUREKA Eurostars programme by the European Union [2].

Background of Approach

New Zealand (NZ) is an economy dominated by SMEs which operate in a small domestic market. Many of the country's small manufacturers depend on exports for their survival, and therefore need to be innovative to thrive and compete in global markets. However, it is widely accepted that NZ manufacturing SMEs must improve their NPD capability in order to enhance their ability to compete internationally. Recognizing the importance of these issues, the New Zealand Government commissioned a major study in 2003 into the role of design for the economy [3], which concluded that design was under-used in the vast majority of local SMEs, and that there was a widespread lack of relevant competencies and skills in this area.

The NZ Government funded project 'High Technology Design for Engineering Product Innovation', which evolved into the INNOVATIONZ research group [4] at the Department of Mechanical Engineering at the University of Auckland, was aimed at enhancing tertiary design education in all areas of Engineering, as well as in the Business and the Creative Arts Faculties at the University of Auckland. Its overall goal was to achieve a closer match between human resource requirements in the areas of engineering design, innovation management and new product development of New Zealand's manufacturing SMEs, and the skill profiles of future engineering and other university graduates.

The project's focus was on providing engineering students from the University of Auckland, as well as industry practitioners and students from other faculties, with high-quality, practice-relevant and multi-disciplinary learning experiences in the areas of product design, NPD and innovation management. At the same time a postgraduate programme and a professional development framework for design engineers and other design practitioners from the industry sector were established that cater to their specific training needs, reflect the requirements of professional bodies and industry training organisations, and are closely integrated with the academic curriculum [5].

Emphasis was placed on a holistic and multi-disciplinary approach that integrates academic and educational perspectives with the skill profiles and practical requirements of professional design engineers and other design professionals, as well as with the strategic human capital development objectives of the industry. The implementation of these principles was a significant departure from the traditional, discipline-based teaching system, and required the integration and concurrent consideration of aspects and disciplines from outside the traditional engineering domain, such as industrial design, marketing, branding and innovation management, but also the incorporation of 'soft' topics such as teamwork and cross-disciplinary communication.

A core element of this development is the course ENGGEN 405 'Advanced Innovation and New Product Development', which was established in 2006 in collaboration with the University's Business and Creative Arts faculties, and with a range of industry partners, design consultants and business professionals. The course has been used as the primary tool to develop, test and implement novel learning approaches, which enable students and participating industry partners to develop interdisciplinary product development knowledge, to practise their teamwork and communication skills, and to experience the NPD process through real-life case study work.

In this paper, some of the core aspects and features of the ENGGEN 405 course are discussed in more detail. In order to put this discussion into context, we first explore the role of professional engineers in NPD, and provide a brief overview of other educational programmes which are also aimed at preparing graduates for their roles in multi-disciplinary NPD process environments in industry.

We then introduce the general concept and structure of our course, including course philosophy, course design, course objectives and intended learning outcomes. After that we provide more details on a number of key aspects of our approach, which are particularly relevant to the achievement of these objectives and outcomes, and which are in line with the needs of industry and with the requirements of the Engineering profession. The main areas we discuss are our project-based learning practices and the associated assessment procedures, which are designed to support those aspects of learning we find particularly relevant and beneficial for our students. Another important aspect covered in the paper is our approach to fostering the development of multi-disciplinary teamwork skills, which are critical for the successful involvement of professional engineers in the NPD process. Additional features of our course, in particular the studio sessions and associated workshops, which support and deepen the students' learning experience during their project work, are only briefly mentioned, as their detailed coverage would exceed the scope of this paper.

THE ROLE OF PROFESSIONAL ENGINEERS IN NPD

Professional engineers have always played an important role in NPD by contributing a broad range of traditional engineering skills and knowledge, for example from the areas of material science, mechanics, thermodynamics and manufacturing processes, into the process. In the last few decades, engineers have broadened their involvement in the NPD process with the advent of modern tools and approaches, such as Computer Aided Design (CAD), Finite Element Analysis (FEA), Concurrent Engineering, and other product and process modelling, optimisation and visualisation tools. These technological and organisational developments, together with the increasing competitive pressure discussed above, have fostered significant changes of the traditional tasks and skill requirements of professional engineers in the NPD process.

These developments have also influenced the demands made of engineering graduates by businesses that employ professional engineers, as well as by professional organisations like the Accreditation Board for Engineering and Technology (ABET), the Institution of Engineers, Australia (IEAust) and the Institution of Professional Engineers, New Zealand (IPENZ). Whilst a solid understanding of engineering science principles is still a fundamental expectation of modern graduate engineers, some of the most important requirements now are the ability to communicate effectively, the ability to work independently as well as in a team, and the ability to think both critically and creatively [6]. To achieve this, the ABET Criteria for Accrediting Engineering Programs require that engineering students "must be prepared for engineering practice through a curriculum culminating in a major design experience based on the knowledge and skills acquired in earlier course work and incorporating appropriate engineering standards and multiple realistic constraints" [7], such as manufacturability, sustainability, and environmental, economic, political, social and ethical issues. Expected learning outcomes include the ability to function on multidisciplinary teams, the ability to communicate effectively, and the broad education necessary to understand the impact of engineering solutions in a global, economic, environmental, and societal context [7].

INTERNATIONAL NPD RELATED PROGRAMMES

There are a number of successful educational programmes offered internationally which have evolved as a response to the changed situation in the area of innovative product design and development. UK Universities offer majors at undergraduate and graduate level that combine creative design and engineering. Engineering schools such as The University of Strathclyde, The University of Nottingham, The University of Glasgow and The University of Wales (Swansea), among others, offer BEng or MEng programmes majoring in product design engineering. The Royal College of Arts (RCA) and Imperial University have offered a postgraduate programme in IDE (Industrial Design Engineering) since the 1980s. Cranfield

University and the University of Arts in London offer a Masters degree in Innovation and Creativity in Industry which is aimed at providing graduates with creative, technology and business skills. The UK majors combine innovation and creative thought with a strong background of engineering design and manufacturing. They produce graduates who are equipped for careers in design and manufacturing engineering, or product development. Many of the courses are accredited by professional bodies, such as the IMechE or the IET.

Other international programmes in the area of NPD include the University of Southern Denmark's BSc (Eng) in Product Design and Innovation, the University of Michigan's Integrated Product Development Programme, and Hong Kong Polytechnic University's programmes, which involve close cooperation with a range of academic and business partners. In Australia, the Swinburne Institute of Technology (Melbourne) offers a BE in Product Design Engineering. This is accredited by both Engineers Australia and the Design Institute of Australia. Graduates develop skills relevant to product design, engineering and manufacturing industries in Australia. The course blends the two usually distinct disciplines of industrial design and engineering.

In New Zealand, Massey University offers a full professional degree programme in product development. The Wellington Institute of Technology, Weltec, has launched a Bachelor of Creative Technologies degree. This offers a major in Product Design Engineering alongside majors in interior design, cultural design and visual arts. Otago Polytechnic offers the Bachelor of Design (Product). While this is a Design based major, it claims to offer more skills in engineering design and manufacture than other BDes majors. Otago University offers a major in Design for Technology as part of their BAppSc programme. The major targets aesthetic and technical design. It focuses on design, with elements of mathematics and science available as electives.

Most of these programmes are heavily project-driven, and the students learn through a series of increasingly complex problem-solving projects and supporting teaching. They are aimed at developing skills and experience which cross the traditional boundaries between the engineering, industrial design and business professions, generally in form of an integrated curriculum programme at undergraduate or graduate level.

Our ENGGEN 405 'Advanced Innovation and New Product Development' course has similar aims as these programmes. However, instead of attempting to educate future NPD specialists, our course aims to complement the existing undergraduate Engineering curriculum at the University of Auckland, by providing interested students with a multi-disciplinary capstone experience. Our target is to provide our students with a rich and meaningful, multi-disciplinary project experience which will enable them to accommodate easily and make positive contributions to a dynamic, commercial NPD environment, and which is also applicable in other areas of technology and innovation management in industry.

COURSE DETAILS AND LEARNING OBJECTIVES

As mentioned above, the course ENGGEN 405 'Advanced Innovation and New Product Development' aims to provide professional engineering graduates and senior students of other faculties of the University of Auckland with the knowledge and experience required to successfully apply their professional skills in today's multi-disciplinary NPD environments, which are so necessary for invigorating and maintaining innovation in the manufacturing industry. The course design evolved over a period of several years, and was strongly influenced by the authors' multi-disciplinary academic and professional backgrounds, and by their practical experience with industry based project work and with Project Based Learning (PBL) in undergraduate engineering design, manufacturing systems and technology management courses [8, 9].

The course approach is also based on a number of pedagogical principles which are in line with the educational theories of David Perkins, for example on 'learning for understanding' [10,11], and with the work of Donald Schön and Chris Argyris on learning systems, learning societies and institutions, double-loop and organisational learning [12, 13].

From the start, the course has been based on a multitude of collaborative activities and partnerships across disciplinary, faculty and institutional boundaries. Within the University of Auckland, this boundary-spanning approach involved in particular the close relationships between staff in the Faculty of Engineering, the Business School, NICAI, the University's National Institute of Creative Arts and Industries, and also in a number of instances the Faculties of Education, Arts, and Science, and the Centre for Academic Development. External links were fostered with various professional bodies in engineering, design and business, for example the New Zealand Employers and Manufacturers Association (EMA), the New Zealand Heavy Engineering Research Association (HERA), the Designers Institute of New Zealand (DINZ) and the local branch of the Product Development Management Association (PDMA). Particularly effective has been the direct involvement of six industry partners as host companies for our NPD projects, as well as of professionals from a range of disciplines, such as self-employed design and engineering consultants, business managers from a variety of backgrounds, and design and engineering practitioners from a range of positions and with various levels of professional experience. Links with other educational institutions, which had a positive impact on our educational activities, were fostered with Massey University and some NZ vocational training organisations. Most of these collaborative activities resulted not only in enhanced learning opportunities for the tertiary students involved in our coursework and associated project activities, but also in a two-way knowledge exchange by broadening and deepening the understanding of the participating professionals and managers.

Originally, the course Innovation and New Product Development was hosted by the University's Business School as an approved elective for Engineering students interested in innovation, until a concurrent parallel version was included in the Faculty of Engineering curriculum to account for the requirements of changed regulations of the BE(Hons) degree. At this stage, the course has been run six times with a variety of local manufacturing SMEs as project hosts, with around 200 students from Engineering and five other faculties of the University of Auckland graduating from the course.

In Engineering, ENGGEN 405 is advertised as a course for *"final year Engineering students, which deals with theoretical foundations and practical application of innovation, design processes, new product development and problem-solving within the commercial and cultural context of New Zealand businesses. Students from different backgrounds will be grouped into cross-functional project teams and will work on a real-life industry based project and develop a full product concept for a business client."* [14]

In line with the overall objectives and philosophy of the INNOVATIONZ research group, the course is aimed to introduce students to 'real-world' design problems, and to provide students with a solid understanding and hands-on experience of the New Product

Development (NPD) process by developing a product concept as a team. Engineering students who take the course are provided with opportunities to develop their communication, interpersonal and teamwork skills by working with other senior students from different disciplines and faculties, develop the technical skills and professional techniques that the industry needs, and will be equipped with a better understanding of the 'real world' issues of the industrial and business environment.

Upon completion of the course students are expected to have achieved the following learning objectives and will be able to:

- Present their proposed product concept in a professional fashion to a business client,
- Effectively identify and prioritise key areas for design development to achieve the best commercial outcome,
- Use practical and theoretical methodologies to communicate and evaluate product ideas,
- Apply creative processes and a structured, well-managed team approach for solving a complex product development task,
- Integrate perspectives from art and design, engineering and management,
- Use their practically acquired learning to make academic knowledge more valuable,
- Use new personal skills of teamwork with others from different disciplines,
- Demonstrate experience of working with an industry partner,
- Use effective contemporary professional techniques to ensure value for a real industry derived need.

Due to the multi-disciplinary nature of NPD, a broad range of topics are covered in the course (Figure 1), including:

- Principles and context of New Product Development and innovation,
- The New Product Development process,
- Analysis and communication of a business case for product development,
- Appreciation of business needs and constraints, including cost, manufacturing and other technological and organisational factors, and business strategy,
- Understanding the customer / market for the proposed product,
- Creative methods and professional techniques for NPD ,
- Iterative design cycles that progress the product development effectively,
- Product modelling and presentation using sketching, prototyping, Computer Aided Design (CAD), and visualisation software,
- Client and customer needs assessment and development of a product design specification,
- Creative and systematic development of alternative product concepts,
- Decision making for optimum product concept selection,
- Team based product development and design project management,
- Professional presentation of product proposal.

Figure 1: Course topics and themes listed in the course brochure

Apart from these specific topics, the course includes a number of elements and modules which address the pedagogical considerations mentioned above. Particular emphasis is put on the creation of a learning environment that supports 'learning for understanding' [11]. Therefore, the ENGGEN 405 course contains a range of non-traditional learning activities apart from the usual classroom presentation and discussion elements, such as studio sessions in an art gallery, hands-on workshops on teamwork, learning styles, re-engineering, physical prototyping, and interactions with business managers and site visits. It is based around professional collaboration with a local manufacturing SME as industry partner and client, working on a real-life, commercially relevant product development problem. The project is structured and organised in such a way that it will foster the development and application of creativity, innovation and engineering skills as much as possible. The collaboration with a real-life business provides students with valuable insights, and enables them to acquire a wide set of creative and problem solving skills from this interaction. In particular, it helps students learn to use their knowledge to solve unexpected problems rather than simply recite back facts, and supports learning rich with connection making, i.e. across subject-matter learning, which is necessary for insight and deep thinking [11].

The following sections summarise some of the key course features and aspects which have been designed to achieve these outcomes.

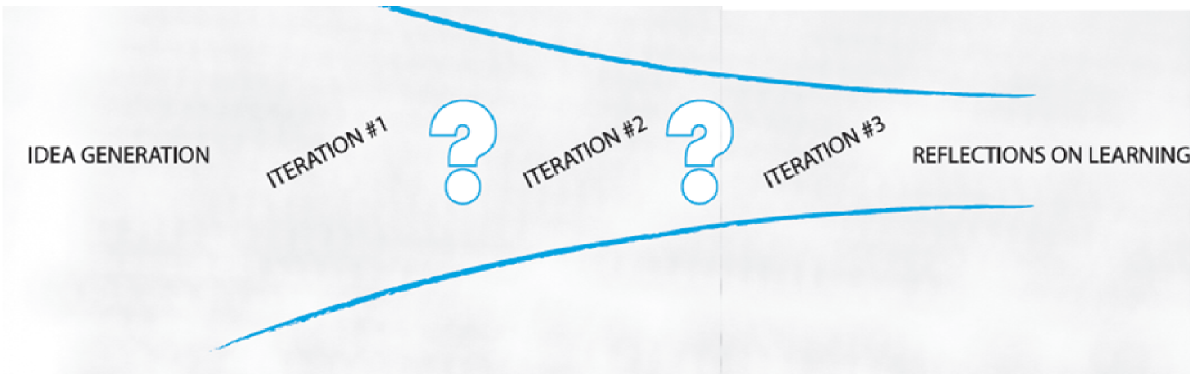
COURSE FEATURES SUPPORTING ‘LEARNING FOR UNDERSTANDING’

Project Based Learning Approach

Project Based Learning (PBL) is the core instructional approach of the ENGGEN 405 course. Our PBL approach has evolved over a period of more than 15 years in a range of design, industrial engineering and engineering management courses (see e.g. [9]), and is in line with Perkins’ learning principles of ‘bridging and hugging’ [15]. Accordingly, teaching staff, mentors and tutors and external collaborators see it as their main role to help our students connect, extend and apply the knowledge and skills they acquired earlier (either in their academic studies within their discipline or in other contexts) to the solution of their project tasks.

The project is designed and presented in ways which encourage the students to generate, or learn, and apply new knowledge in a meaningful, realistic context. This includes the aspect of ‘problem finding’ on top of the traditional Engineering mission of ‘problem solving’. Another important aspect is learning across subject matters and disciplinary boundaries, for example through the requirement of working as a member of a multi-disciplinary team (see below), in order to achieve a holistic project outcome from a broad range of perspectives.

To achieve all this, the project is structured into four stages of three weeks duration each, starting from a deliberately vague task explanation, as it typically occurs in business practice, followed by three design iteration stages. The project concludes with a ‘Reflections on Learning’ submission to encourage deep reflection (Figure 2).



GENERATION	EMERGENCE	CONVERGENCE	PITCH	FEEDBACK
Team building	Models of innovation	Visual communication	Aesthetic culture	Personal views
Creative techniques	Voice of the customer	Business models	Making a profit	REFLECTIONS ON LEARNING
Iteration	Analytical methods	Product economics	Industry speaker	Take outs

Figure 2: Project phases and themes from course brochure

Idea Generation Phase

In the first course session the students are presented with their initial project task “Develop the concept for an innovative new product for your host company”, and are briefly introduced to the current semester’s host organisation. This is followed by a site visit and a presentation of one of the host’s top managers about their business, where information on the company's history, current operations and market position from the business perspective is provided. Students are encouraged to raise questions, and are asked to carry out further research to acquire a solid understanding of the scenario and context of their project. In parallel, a range of other supporting course activities takes place, in particular studio sessions to facilitate the students' team building process, to introduce and practice the principle of multi-disciplinarity, and to illustrate the nature of the product development process using hands-on, practical workshop exercises (see below).

Students are informed that at the end of the first three-week project stage, each project team needs to present a 10-minute 'Idea Generation Presentation' in PowerPoint format to the host company and course team. This requirement motivates students to start their learning journey at, or even before, the 'fuzzy front end' of product innovation, by reflecting on potential product development alternatives on the basis of their current understanding of the host's business environment, resources and capabilities, its market position and potential, and its (assumed) strategic direction. Many Engineering students are very uncomfortable with this vague and fuzzy problem finding task, and consider it a significant challenge, as they are accustomed to working on reasonably clearly defined assignments, engineering design briefs, or exam questions in their other curricular activities.

During this difficult stage student teams are supported and mentored by course staff, e.g. during studio sessions, through communication with course staff and host company via the course website, and in a presentation rehearsal session, to help them develop and present one or several new product ideas that in their view fit the host's situation. Representatives of the host company, generally the owner/manager and/or the head of the design department, attend the presentations and provide their comments and critique ad-hoc during the session. Further comments, constructive criticism and decisions on selection of the most promising projects ideas are provided via the course website to each project team after consultation between course staff and industry partner.

Design Iterations and '4 Cs' Principle

Frequent and timely formative feedback, which is coupled with the assessment structure in the course (see below), is also provided in each of the remaining three stages of the project. These stages are dedicated to three cycles of design concept development, which model the converging nature of NPD processes in practice. Each cycle culminates in the presentation of an iterative refinement of the design task that was assigned to each of the student teams. This concept of cyclic, iterative refinement of a design concept, which is a main characteristic of NPD and many other problem solving activities in business practice, is foreign to most students, who during their studies have become accustomed to the traditional, linear approach to solving a task and to learning practised in academic instruction: namely studying a subject, submitting an assignment or sitting an exam on the topic area, getting it assessed, and moving on to the next subject. Therefore, strong emphasis is placed on helping students adjust to this unfamiliar way of problem solving and learning by providing them with ample opportunities for reflection, abundant practice and meaningful feedback.

The concept of the '4 Cs', a cyclic process of 'Comprehend, Create, Critique, and Communicate' developed in the course has proven to be particularly effective in supporting students to develop a more reflective approach to knowledge acquisition and application, and thus fostering their deep thinking. The nature of the 4 Cs is closely related to the four-step Deming cycle – Plan, Do, Check, Act (PDCA) – of iterative problem-solving commonly used in business process improvement (see e.g. [16]). The 4 Cs are used to structure each of the design iteration cycles, starting from a relatively general and coarse perspective, and zooming in on more specific and detailed design aspects, as students gradually firm up their design solutions.

In the Comprehend phase, students are encouraged to develop and gradually deepen their understanding of the requirements and motivation of their current design step. This covers the acquisition and evaluation of a broad range of issues which have an impact on the design task, e.g. customer (i.e. host company and end user) expectations, technical and organisational requirements and constraints, cost implications, and market conditions.

In the next phase, Create, the students use their understanding to generate solutions to the requirements and issues they encountered in the Comprehend phase. This will generally be in form of conceptual designs and solutions that the team proposes, with increasing levels of depth and detail in subsequent iterative design stages. Students are encouraged to use a variety of approaches to express their ideas, for example written or verbal descriptions, sketches, images, drawings, CAD models, and physical prototypes. A range of workshops in the studio sessions are provided to help them develop their presentation skills, externalise their ideas, and express and communicate their often tacit understanding of the situation.

In the Critique phase students are encouraged to evaluate their proposed concepts, and to identify how these measure up against their stated requirements and constraints. They are also asked to provide a critique of their original understanding, and whether it needs to be modified on the basis of their experience of the concept generation and testing. This is a particularly challenging step for students, who instinctively are rather inclined to defend than criticise their own solutions. However, constructive criticism and open discussion of the merits and demerits of proposed design concepts in a design review meeting is a key factor for successful NPD in business. In the course, we therefore discuss this issue extensively in class, and let the students experience the role of constructive criticism for collaborative development processes through a hands-on ‘micro-NPD’ workshop in one of the first studio sessions.

In the final phase of the 4 Cs cycle, Communicate, students need to submit a clear, short summary of the key elements of the product needing development (or the final product concept in case of the last iteration), and how the preceding Critique phase has shaped this plan of action. The required presentation format has been developed with the input of practising engineering managers and design consultants, and is modelled after a common format used in design reviews in a business environment. The submission is uploaded on the course website and circulated to teaching staff, mentors and design professionals from the host company. They provide their individual feedback and comments on the website and in class sessions within a few days, which are then used by the project teams as inputs into a new cycle of iteration. The final submission after the third iteration includes another formal, oral presentation to all stakeholders involved in the project, including outside professionals and representatives of the host company (usually top management and design staff), as well as interested members of the University community. Each team’s proposal is discussed after their presentation, so students receive concluding feedback on their achievements and on the outcome of their project, including the commercial viability of their concept proposal, from a range of perspectives.

The four-cycle PBL approach summarised above is supported by a range of course activities and features, which help achieve the desired pedagogical aims and course objectives, including deep thinking and reflective learning, the flexible and active use of knowledge, working across disciplinary boundaries, communication skills, and experience with multi-disciplinary teamwork. These features and activities include Studio sessions and a range of hands-on workshops in an art gallery to promote the non-verbal, intangible and kinaesthetic aspects of knowledge in the area of design, engineering and management (Figure 3), an elaborate system to foster and monitor teamwork, and an integrated course assessment programme and communication infrastructure which encourage active learning, and provide meaningful formative feedback in line with our educational targets and practical project aims.

Figure 3: Prototyping workshop

ASSESSMENT STRUCTURE

Meaningful, formative assessment plays a key role in supporting reflective learning and deep thinking [17]. Appropriate assessment is particularly critical in areas such as NPD, where a vast array of information and knowledge from different disciplinary areas needs to be considered, processed and applied. A particular challenge is the assessment of learning which is based on experiential, kinaesthetic, non-verbal and tacit knowledge. Traditional assessment methods are generally based on the examination of factual knowledge and, for example in engineering design, on the evaluation of students' submissions on the basis of a range of tangible, generally predefined, performance criteria.

In our view, a marking scheme based on a set of meaningful, measurable assessment criteria and elements is one of the key tools for motivating students to learn – in particular for those who need strong external drivers such as a course grade to perform to their best ability. However, in our experience this type of assessment, as elaborate as it may be, mainly addresses the tangible and measurable aspects of educational achievement, and therefore needs to be complemented by additional tools, which concentrate on the more elusive aspects of learning. Another important consideration is the encouragement of reflective and close-loop learning, which depends on timely and high-quality formative feedback and constructive criticism. Critical in a team-based project scenario is also to consider and include assessment features and tools which foster and assess team-based achievements, allow the fair distinction between different levels of individual learning and efforts, and prevent 'free-loading' of individual members in their team environment. An important negative aspect of any assessment scheme that is not based on the comparison of the students' outcomes to specific performance criteria is, that it tends to be much more resource-intensive to apply. In particular it requires a significant amount of time and effort to provide students with constructive feedback that helps them progress beyond their current levels of understanding and achievement.

The assessment system in ENGGEN 405 Advanced Innovation and New Product Development has been developed and continually refined on the basis of these considerations. The overall assessment structure, as published in the Course Outline, is shown in Table 1. It should be noted that while the overall number of assessments shown in the table may appear large, most individual submission elements are relatively small, and the associated workload situation for students and assessment requirements have been carefully designed and are closely monitored to avoid any overload situation.

Table 1: Summarised Assessment Schedule of ENGGEN 405

Assessment Type	**Assessment Component**	**Weighting**
Team Assignment	Idea Generation (PowerPoint presentation)	6%
Team Assignment	Concept Development Iteration #1 (PowerPoint presentation)	12%
Team Assignment	Concept Development Iteration #2 (Report)	16%
Team Assignment	Concept Development Iteration #3 (Report and PowerPoint presentation)	22%
Individual Assignments	Weekly Insights from Course Material (Eight one-paragraph blogs)	8%
Individual Assignments	Weekly Workbook (Two short reports in blog format)	8%
Individual Assignments	Studio Work (two short reports in blog format)	6%
Individual Assignment	Reflections on Teamwork (Short report)	6%
Individual Assignments	Reflections on Learning; Professional Involvement and Experience (Two reports)	16%
Total		**100%**

The assessment components in Table 1 can be roughly categorised into three major groups. The first four components cover the assessment of tangible project progress and outcomes by similar means and mechanisms as used for other engineering design projects, namely project report submissions and oral presentations. The second group, Weekly Insights from Course Material, Weekly Workbook, and Studio Work, are informal, blog-like submissions which are aimed at encouraging students to actively engage with the course material and activities, and relate them to their project tasks and to the NPD process in general. They require students to actively participate in class activities, and to reflect and report on 'what's going on in class?' and 'how does this relate to our project work?'. The last group, Reflections on Teamwork, Reflections on Learning, and Professional Involvement and Experience, focuses on fostering deeper reflection on all aspects of the course, close-loop learning and the development of deep insights which may go even beyond the topic areas covered in the project.

Project Assessment Approach

The first four components in Table 1 assess the progress and perceived levels of achievement the different project teams have made in each of the four phases of the project, as demonstrated by their online submissions and oral presentations. These marking components mainly assess tangible project achievements and progress made by each of the teams, although other aspects, such as evidence of the application of the 4 Cs approach, are also taken into consideration. Overall they account for 56% of the final course marks. As there is a significant learning curve involved for the students to adjust to the complex project requirements, the weighting increases gradually from 6 marks for the first presentation to 22 marks for the final submission and oral presentation. In order to foster teamwork and team-based development, marks are generally assigned to the team as a whole, but a number of factors and indicators, such as the outcomes of the confidential peer assessment scheme at the end of the course, and the statements made in the Professional Involvement and Experience reports, can be used to moderate the marks of individual students if deemed necessary.

To help students understand the assessment criteria and focus on the important learning aspects of each of the submissions, specific submission guidelines for each are published on the course website and discussed in class. In order to achieve a basic level of uniformity of the submissions, and in particular to keep the students' workload and the assessment and feedback efforts reasonable and manageable, they include suggestions, specifications and size constraints for format and structure of the submission and/or presentation. As pointed out in the previous section, these specifications are also in line with professional practice of design reviews in the industry, where they have been found to be an effective way of facilitating progress in the commercial NPD process. The use of visual tools for illustrating the proposed solution, such as sketches, diagrams, CAD models or short video clips, is strongly encouraged. It is emphasised that the nature of the submission needs to demonstrate the application of the 4 Cs approach introduced earlier. A rough marking scheme is also published, as for example the following breakdown for the Idea Generation presentation (worth 6 marks):

- Quality of insight into the idea - why does it have merit? 50%
- Clarity of story and validity of reasoning 20%
- Presentation technique 10%
- Confidence in the project team to champion the idea through to a concept 10%
- Techniques and/or perspectives used to generate the idea 10%.

Assessment and provision of feedback for the major submissions is shared amongst course staff, mentors and specialists and managers from the host company. Each member of this assessment group is provided with access to the different team submissions through the course website, and required (course staff) or strongly encouraged (external stakeholders) to add their feedback comments, critique and mark suggestions to the submissions on the website. Feedback comments are immediately accessible to the respective project teams once they are entered into the website, but mark suggestions are only visible to the assessment group. These marking suggestions are discussed and can be commented on, and are used as inputs in the final marking process. The final mark allocation is decided by the course director under consideration of all comments and assessments, and then published to the students.

In this way each student team receives a variety of rich feedback and comments from at least two or three different sources and perspectives, which supports the development of deep insights, and a mark which is based on a moderated process and multiple inputs. Each team can only see their own submission and the relating comments and marks, but there is also a section on the website for more general comments and feedback on all submissions. Students are also encouraged to request further clarifications or discussions on any aspects of the feedback and assessment. This is either handled through a discussion thread on the website, but can also be dealt with in studio sessions or in face to face dialogues with course staff (Figure 4).

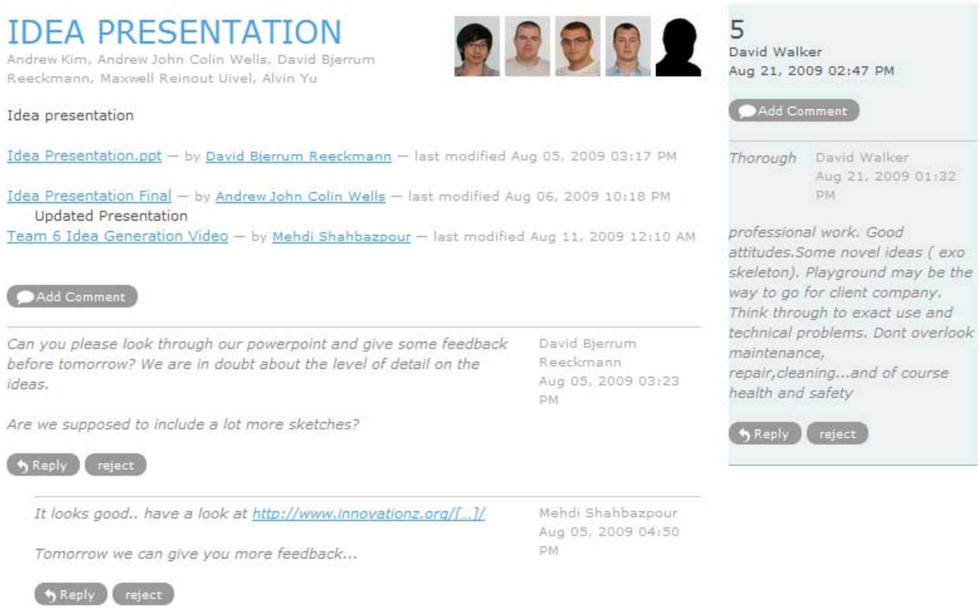


Figure 4: Screenshot of course webpage for Idea Presentation with student submission, presentation video, discussion thread and marking section

Activity Blog Submissions

The assessment approach for project submissions described so far appraises mainly tangible learning outcomes, but combined with the structured project approach, the studio sessions, the real-life scenario and the feedback mechanisms and interactions between students, staff and business partners, already provides good incentives and opportunities for deep learning. However, our observations as well as some student feedback from the first few versions of the course indicated that some of the class activities that we consider especially valuable and important for deep learning, making connections across disciplinary boundaries, and for acquiring tacit, in-tangible and kinaesthetic skills and experience, were not considered as relevant by students as we would have liked. Therefore the ‘blog’ category of assessments was implemented. The blogs are designed to motivate students to actively participate in class activities, and help them process and externalise new knowledge and information as it is generated.

The Weekly Insights from Course Material are brief, one-paragraph blog entries by each student in the website, which have proven to be very effective in motivating students to attend and mentally participate in class (Figure 5). The blog format has been chosen as many of the ‘Web 2.0 generation’ of students are familiar and comfortable with this concept, and as it fits well with the other communication and feedback features of the course website. The requirement is simply to reflect on all the formal class activities during the respective week, and identify their relevance to and their potential impact on the project work of the particular student’s team. Recommended submission format is a bullet point list or a maximum of one or two short paragraphs. Eight of the 12 potential weekly entries count for up to one mark each. The marking process of these submissions is coarse and fast: zero marks are assigned for no submission, ½ mark for just repeating statements from class, and one full mark for a submission that demonstrates sufficient reflection and transformation of the material.

Figure 5: Website screenshot of Weekly Insights

Instead of keeping a formal design workbook for the documentation of their project work, each project team needs to submit a Weekly Workbook, again in the format of an informal blog, to the website each week, alternating between team members. Thus each member needs to submit two workbook blogs at different stages of the project, which count for four marks each. The blogs are expected to summarise the activities of the team in an easily readable and informative manner. Brief explanations of the research, the insights, the team's ideas and plans, and management of the team are required, and links to useful website resources, images and other visual material should be included. To provide an additional feedback mechanism for the students, students can add specific questions to the assessors relating to the content of the blog. The size of the blogs is typically the equivalent of an A4 page, excluding sketches, diagrams, screen prints of relevant websites, etc. (Figure 6).

Studio Work reports have a similar format, but they cover specific studio sessions with workshops that are deemed of particular relevance to the students' project work. All students submit the reports on the same studio sessions, which are assessed according to similar criteria as the other blog submissions, and count for a maximum of four marks each.

Figure 6: Weekly Blog entry on the website

Reflections on Learning

The final group of assessment components in Table 1, Reflections on Teamwork, Reflections on Learning (RoL), and Professional Involvement and Experience, produce particularly beneficial learning outcomes [18]. These components together account for 28% of the course marks, and require students to consider all issues related to their teamwork, learning process and professional roles. The report requirements encourage students to reflect deeply on their activities and roles during their project development, within their team and in other course activities, and ask them to question their existing behavioural patterns, attitudes, and objectives. Our guidelines for the RoL state the principles and objectives of this submission [19]:

"Personal reflection and internal processing constitute an important part of the learning process. If the reflections are recorded (for example in a blog, a diary, an essay, or a report), this generally brings up additional tacit knowledge and helps consolidate understandings developed during the learning process. The Reflections on Learning task is aimed at achieving these outcomes. Think of your experience in this course – the project work, the

people and team issues, the nature of the NPD process, the studio sessions, the discussions and lectures, etc., etc. – to express what happened with you, what you learned, how you felt, how your viewpoints changed, what insights you developed, and what conclusions you have drawn from all this. Use the 'iteration' principle to generate a document that's more than just a historic review or a casual outpour of feelings. Be profound and critical, but be fair and thoughtful."

The submitted reports are generally of a very high standard, and reveal deep insights and a high degree of reflective learning during their composition. Apart from their very beneficial impacts on students' learning, these tools have also provided excellent, in-depth feedback to the course team on all aspects of NPD, learning and organisational issues, which has significantly benefitted the evolution and refinement of our educational approach, and also enhanced the INNOVATIONZ team's understanding of product development in the broad range of industry scenarios offered by our case companies. Below is a typical comment from a student's RoL which demonstrates the value of these tools:

"One final and most important insight I had taken away from this course was the ability and need for the reflection process. Prior to this course, it was not common practice for me to reflect upon completed work, therefore reducing the amount of improvements I can have on the next exercise. However in this course, the constant reflections required for lectures, studio sessions and the presentations had helped in identifying the shortcomings and strong points of the work I have done and the key essence from information I had received. It is from these reflections that real "experience" can be gained effectively for the work done, and maximising the amount of knowledge gained from the process."

TEAMWORK

As mentioned earlier, the ability to function on multi-disciplinary teams has been identified as one of the most important attributes that students are expected to develop during their undergraduate Engineering degree course [7]. Multi-disciplinary teamwork skills are particularly critical in the areas of innovation management and NPD, and therefore have been one of the focal aspects of our course design and activities. In our experience the development of students' teamwork ability is a complex, challenging and sometimes traumatic process and experience for them, and therefore needs to be carefully organised and monitored. Some of the main factors which need to be considered in this context are team composition and team building, roles and responsibilities within the team, fair distribution of teamwork including the prevention of free-loading, and the resolution of conflicts and disagreements. Another issue which is particularly critical in multi-disciplinary teams and/or in projects which involve the crossing of disciplinary boundaries, is the prevention of the segregation of project tasks into specialist topics within the team. This often happens when some students have existing specialist knowledge or skills, have a strong preference for one particular type of work, or want to avoid specific work areas. Some of these aspects are addressed in the specific PBL and assessment approaches outlined above, and a number of additional tools are used in the course to complement these.

When they enter the workforce, young graduates have generally little or no choice of the team environment and the colleagues they will have to work with. Also, during their degree course, students with like interests and levels of achievement tend to group together, creating their own group culture and norms, shared perspectives of their knowledge and of their discipline. Therefore we use a number of factors at the start of the course to form project teams (of between four and six students each, depending on class size), which are as multi-disciplinary and as diverse as possible, in order to provide students with a realistic and rich learning environment. Prime factors for team selection are the students' disciplinary background and practical experience, their academic performance, and also their gender, age and ethnicity. Another factor we deem important is the difference in learning styles [20] of the different team members. In order to generate a good mix of learning styles in each project team, we ask students in one of the first workshops in our studio sessions to participate in a test to identify their own learning style, which we then consider in our team composition.

Once the different project teams are established, we run a workshop 'How to start a project team the right way', based on an approach developed at the University of Linköping in Sweden. The topic is briefly introduced in a PowerPoint presentation, then students are provided with a questionnaire and worksheets that help them agree on some general guidelines for how to work together, and to externalise and share each project member's norms and habits in order to avoid conflicts later on. The workshop concludes with the requirement for each team to develop a their own written team contract on the basis of team contract guidelines provided to the class [21]. Further hands-on workshops in our weekly studios are organised to foster team processes and provide students with insights into their roles and behaviours in their team environment, for example a 'Biopics' workshop to support team building (Figure 7), and a 'Broken Squares' workshop to let students experience aspects of cooperation in team problem solving, and to sensitise them with respect to behaviours contributing towards or obstructing the solution of a team problem.

Figure 7: Biopics workshop using visual 'storylines' to help students get to know each other

Another very effective tool to identify and remedy negative factors and habits which affect teamwork is the Reflections on Teamwork assignment (see above), which needs to be between 600 and 800 words long, and be uploaded to the course website just before the mid-term break. Students are asked to reflect on the experiences they have had with teamwork, on the interactions between individual team members and on team dynamics. They must consider their own perspective and expectations and those of other team members, and describe their opinion on teams at the beginning of the course and at the time of submission. The report is expected to be an open and honest account of each student's thoughts, and should explain the value they have drawn from their experiences involving teamwork which they consider most significant. From our observations and from the feedback in the submitted reports, students find this assignment a very useful way of reminding themselves of sound teamwork habits, and many use their insights to bring their team process back on track. Typical for the insights and conclusions are the following statements from the report of one of the students of our 2010 class:

"... I'm still not fully comfortable about our team's ability in performing at a high level. I feel there is still much more to be done with regards to fully knowing the potential of each member in our team. So far, I have tried to discover the good points in my team to avoid myself feeling discouraged about whether my team is good enough to work together or not. I noticed from my efforts in finding the good points in my team that Kat is good in taking initiative with criticizing (constructively) an idea, and Vikas with initiating team meetings. Sandeep I have noticed is a person who likes to jump into volunteering to finish tasks.

I am hoping that through everyone's efforts in building rapport with each other that there won't be any problems regarding individual preoccupations that might dominate the team's performance. Also, I will continue to look for the good points in each of my team members in this project, and in future projects not just in this course. I know from working previously with other teams that this will help me get through any negative misconceptions that might arise within me when working in a team."

As mentioned above, free-loading has been found to be a major problem in team-based projects, in particular if most team members are interested in achieving an optimum project outcome, and therefore are willing to cover up the poor performance and efforts of a particular team member, rather than 'wasting time' on trying to raise the issue in the team and enforce the rules they imposed on themselves in their team contract. To avoid this problem as much as possible, we use a confidential peer review process, where students must fill in a review form and submit to the website. Students are reminded at the start of the course that this review will be used as an input in moderating the team marks assigned for the major team based assessments.

CONCLUSIONS

The multi-disciplinary nature of the ENGGEN 405 course, and the approach and tools introduced above provide a realistic and very beneficial capstone experience for Engineering students as well as for their peers from other academic disciplines. The emphasis in the course is on the integration of skills in engineering, marketing and design to industrial problem solving, as well as on the development of our students' ability to generate and apply new knowledge in a meaningful, boundary-spanning context.

Feedback from industry partners and students of the programme has been very positive and appreciative of the real-life problem-solving and learning [22]. The value and effectiveness of the approach are best demonstrated through some of the statements of our students in their Reflections on Learning:

"... In conclusion, I am delighted to have completed the course. My initial expectations of the course being different to anything else I had ever done before at university has been surpassed profoundly and as a result I feel it being nothing more than an accomplishment to

be able to say that, yes, I have done it. Yes, it was in some ways the hardest and most difficult paper in terms of its open-endedness I have ever had to do and yes, I have made it to the other side with a new set of skills that some would say are unique for a student to have. The course has strengthened my teamwork skills as well as my project management skills and I would do nothing more than to encourage my peers to do the course."

"... During this course I learned more than just the iteration process for developing new products but also about project management and team dynamics amongst other things. I think the most important thing I have taken away from this course is the real process of iteration. Not just the how-to guide or a list of steps, but actually experiencing it, seeing how different it is from the other side and how much is gained by cycling through it."

"… I've learnt more from the assessments and my team members than I ever could have from reading a textbook on the subject of NPD. I'm glad that I took this course in my last semester at university because it helped me integrate all the skills I've acquired from all my majors in the past 4 years and better prepared me for the working world."

"... I am sure that as I move forward I will be in situations where I step back to think a moment and realise, that the reason I took the certain actions I did was because of the skills learned throughout this semester. For me this is exciting, I am not memorising information for an exam and then forgetting about it once it is over. I have developed skills through practical application that will continue to help me contribute to everything I do."

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