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The development of a module to equip students with real-world problem-solving skills

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Abstract

Today's global society generates 'wicked' problems - problems that are messy, intricate, untidy and difficult. Engineers are constantly faced with such problems. A creative approach to problem-identification and problem-solving is required for effective engineering design to tackle these 'wicked' design scenarios.

An innovative active-learning strategy aimed at promoting the evolution of engineering students' design skills was first implemented at The University of Manchester in 2002. The approach was process-oriented rather than task-oriented and was based on seven interactive sessions, each of which dealt with an aspect of the design process. To date students from disciplines including Civil Engineering, Construction Management and Materials Science have successfully undertaken this unit. There has been a positive student response from all groups with students recognising the need for a different approach.

Recognising that engineers work in multidisciplinary environments a second generation of sessions has been developed with the intention of offering a wider range of students' access to this module. The updated module has an improved framework which includes revised coursework and more detailed feedback. This is delivered as a ten credit module entitled "Real-world problem-solving" over a twelve week period which includes both individual and group coursework, a reflective report and oral and poster presentations.

This paper describes the rationale behind the development of the original and revised module. The primary aim of the module is to provide students with the problem-solving skills they will need as future practitioners working in cross-disciplinary teams.

Introduction

Today's complex global society presents us with a whole host of messy problems such as those relating to sustainability and environmental issues. Engineers and others are constantly faced with such 'wicked' problems and there is the expectation that effective engineering design should be able to tackle such issues creatively.

"'Wicked' problems are often those where different groups of key decision makers hold different assumptions, values and beliefs, and where component problems cannot be solved in isolation from one another. Conversely 'tame' problems (Rittel and Weber 1973) have low dynamic and behavioural complexity and can be solved using conventional analytical methods involving data collection and 'static' analysis (ie analysis that does not require dealing with delays, multiple feedback loops, and non-linear relationships.” (Lane and Woodman, 2000)

Such ‘wicked’ problems and complex challenges require engineers to develop a creative approach to problem identification and problem-solving within multi-disciplinary environments. There is no easy answer to such ‘wicked’ problems ‘… trying to solve ‘wicked’ problems using ‘tame’ problem solving techniques will cause the wrong problem to be solved.’ (Lane and Woodman, 2000) Yet answers which provide a satisfactory solution option do have to be found.

The authors’ experiences indicate that there is an expectation from industry that graduates will have already acquired the basic professional skills which underpin the creative problem-solving process. In Higher Education (HE) a similar expectation, that those entering HE have already acquired evidence-based decision-making skills and critical evaluation, is often proved to be unrealistic. The realities of these situations means that industry frequently expresses concern that students are not adequately prepared for the workplace and that they need to develop basic transferable skills before they can practice their profession satisfactorily.

“Furthermore, there are mismatches between the skills of graduates and postgraduates and the skills required by employers (for example, many have difficulty in applying their technical knowledge in a practical environment and are seen to lack strong transferable skills).” (Roberts, 2002)

At this point it may be worthwhile considering what qualities experienced practitioners are considered to require. ‘Most professions have a recognised base of complex, systematic, codified and generalised knowledge that they bring to bear on activities and which also form the basis of training, this is explicit knowledge.’ (Boyd and Pierce, 2001)

Explicit knowledge is dynamic and can be transient so experienced practitioners are not valued for memorising large quantities of data, but for their implicit or tacit knowledge. In other words, their ability to exercise judgement and to assess what knowledge is required in a specific context; where to find it, how to critically evaluate it and how to determine its significance in relation to the problem in hand.

Implicit knowledge although difficult to define is generally considered indeterminate, intuitive, and personal. Some authors and practitioners consider implicit or tacit knowledge to be similar to intuition in that it allows the integration of isolated fragments of data and experiences into a complete picture to provide a holistic perception of reality (Boyd and Pierce, 2001). Judgment grows from and is enhanced by experience and depends in part on an individual’s ability to benefit from prior knowledge and so facilitates the subsequent processing of new information (Norman and Schmidt, 1982). Contextual experience is therefore important as a basis for developing such abilities, however to profit from this, each individual must be self aware and able to reflect on their experiences and feed forward the lessons learned, (Boyd and Pierce, 2001). Within any learning experience activities which reinforce the development of implicit knowledge and develop reflective thinking need to be incorporated.

The authors’ experiences indicate that both graduates and undergraduates are very often uncomfortable and wary of an open-minded approach that is process-oriented rather than solution-oriented and which requires defendable decision-making within a dynamic open-ended scenario. Undergraduates are generally solution-oriented as their prior learning experience has usually focused on the regurgitation of explicit knowledge and has generally been based on the belief that there is always one correct answer to any problem. There is a general consensus that university education should challenge and equip students with divergent and convergent thinking strategies to promote creativity and lateral thinking.

“It is generally accepted that university education should be challenging – encouraging the development of an enquiring mind that does not accept things at face value and the confidence to argue from an alternative viewpoint. ... Nurturing such attributes means respecting the autonomy of the *student* to make decisions, stand by them and to take responsibility for risk taking and its outcomes.” (Hargeaves, 2007)

The terminology that practitioners and educationalists use can also be problematic. For example, ‘design’ is often, mistakenly, perceived by students to be the application of ornamentation and therefore not something that an engineer should be involved with. In addition creativity is often thought to be an innate gift. The authors of this paper consider design to be creative open-ended problem-solving (as discussed below) and to be an activity that everyone does and is involved in on a daily basis.

“…design eludes reduction and remains a surprisingly flexible activity. No single definition of design, or branches of professionalized practice such as industrial or graphic design, adequately covers the diversity of ideas and methods gathered together under the label.” (Buchanan, 1992)

Although there is no single universally accepted definition of design all definitions allude to the same core characteristics which can be summarised as follows:

- a decision-making activity combining imagination, analysis, reasoning and skill;
- a process involving the interpretation of conflicting requirements, views and constraints based on need and problem-identification aimed at achieving a best compromise, following the evaluation of solution options;
- the balancing of project specific risks and rewards;
- a process involving the questioning of assumptions;
- a process based on iteration;
- a process including communication of the solution option to non-practitioners;
- in engineering, more specifically, the process, in its broadest sense involves the translation of a concept into useable form through the appropriate use of materials and ‘structure’.

Smith and Browne (1993) talk about design problems having five elements – ‘goals, constraints, alternatives, representations and solutions’ and that information systems, production systems, business strategies and organisations are designed, as well as products.

From the authors’ experiences of and research into the teaching of the design process, it soon became apparent that design was essentially about enabling an individual to choose an appropriate and defendable solution from a range of options arrived at through a creative problem-definition process in an open-ended context. This definition was considered to equate with the terms ‘design’ or ‘design process’ in engineering and many other disciplines.

Design is therefore considered to be a creative problem-solving process, within which problem-definition and decision-making underpins progress towards an outcome. Each decision made affects future decisions and the potential for solution options.

This being so decisions made during the concept phase have the most significant effect on the outcome, for example in terms of the potential for success. Understanding that the initial stages of the problem-solving process are crucial and set the quality of the outcome is difficult to take on board if a solution-oriented approach has always been used. This is especially true for students, as Harris (1980) comments, 'design is not working out the dimensions of a beam; the significant decision was to have the beam.'

The development of the initial 'design process' module

The authors believe that although there is no substitute for real-life experiences, many of the abilities required by practitioners can be developed and practised effectively in education. In addition those abilities and skills which are specific to the work context can be introduced into the curriculum. Many support this view; Harris (1980) comments that appreciation of problems can be practised, that exercises in conceptual problem-solving (design) are both possible and desirable and that critical evaluation can be developed.

In 2002, a module was developed by one of the authors to teach design skills to civil engineering and construction students at The University of Manchester. This module was introduced as experience had shown that students found the design process very difficult. Their experience of secondary education had instilled an approach which focused on solutions and not processes; individual effort rather than team work. Students also found the notion of there being more than one appropriate solution to any problem an alien concept. The approach used combined interactive presentations with team activities within workshops. The students' response was positive. They welcomed being encouraged to think and being given the opportunity to be creative. However, students initially found it difficult to work on how they would arrive at a solution rather than concentrating solely on a guessed solution.

The module framework was planned so that the whole process was progressively revealed through the exploration of a sequence of concepts. Each workshop focused on a core characteristic of the design process and encompassed a briefing on a relevant issue and a related activity. For each workshop there was an assessed assignment, the feedback for which was provided at the beginning of following session. A crucial part was the provision of prompt feedback to underpin cumulative learning and inform the current activity. 'Quality instruction incorporates … assessment and prompt feedback.' (Chickering and Gamson, 2002) A part of each session was also devoted to facilitated teamwork to enable students to begin to address issues in a collaborative environment, forming a platform for their subsequent individual work.

The assessed coursework associated with each session was a mixture of individual assignments based on an initial team discussion, a reflective report and a team assignment (Figure 1). Team working was considered an important element, not just because of the benefits of group working as a preparation for the workplace, but also as an aid to the problem-solving process itself. 'Creative problem solving … is cooperative in nature and is most productive when done as a team effort' (Lumsdaine and Lumsdaine, 1994). The individual reflective report reinforced learning and was used as a module evaluation tool. The importance of reflective practice has been well documented in Donald Schön's book *The Reflective Practitioner* (1983).

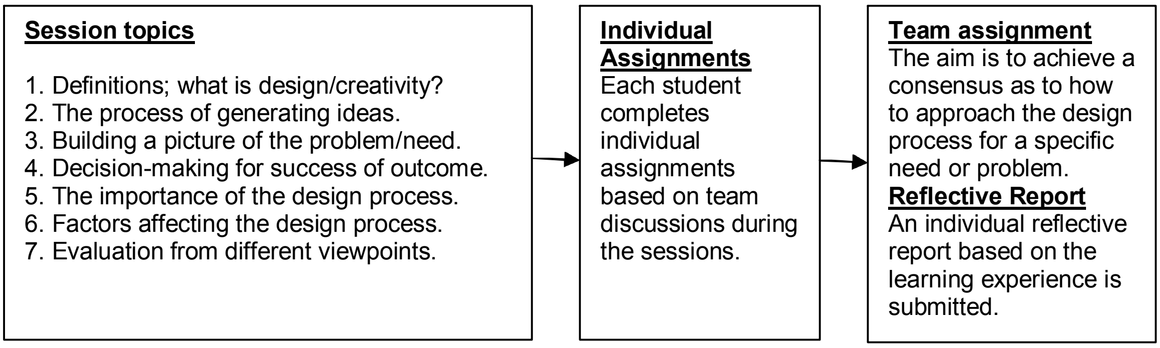

Figure 1: Overall structure of the initial design process module.

The student response to the original design process module

The response of the original student cohorts indicated that transferable design skills can be developed, even within the restrictions of a modular system, and that the learning strategy is generic and therefore applicable across a wide range of disciplines. Through their assessed reflective reports students gave evidence of how these skills could be applied both to other academic modules and non-academic activities.
Our evaluation of the reflective reports found that there was a very positive response to the learning strategy. The students came to recognise that they needed to develop a different approach to design and problem-solving which is process-oriented rather than solution-oriented. It is also evident from the appraisal of their experiences that many found changing their approach initially very challenging and difficult.

“I found the problem solving quite difficult to get my head round at first. I now believe that I look at problems in a different way and am able to think and analyse problems with the use of annotated sketches, which I never would have done without the guidance of this course.” (student quote from reflective report, December 2002)

Students frequently referred to the ability to transfer and apply what they had learned to other modules and activities. Examples given of where they had subsequently applied their skills included planning a five day trek in Hungary, designing a logo for a university sailing team and setting criteria for making applications for summer placements. They also often talked about a new awareness of their abilities and a progressive improvement in their skills. The importance of using a design language was also frequently cited as was the realisation that different designers will come up with different solutions. Students often said they were surprised with what they had learned.

“My first experiences of design gave me a bit of a shock. I (had) envisaged myself working at a drawing board examining intricate details of a design. I had not given a second thought to how one actually got to the stage of initially being able to put this almost complete design down on paper. Never before had I realised the whole range of steps that needed to be undertaken just to write a design brief let alone get a complete design down on paper.” (student quote from reflective report December 2002)

Some further quotations from students follow.

"I felt I was encouraged to find my own method of solving a task and then allowed to practise that method and then refine it to become a more efficient and effective line of action. I describe my development with Design 1 to be holistic rather than specific. These are skills I can apply to any task, problem or crisis." (student quote from reflective report December 2002)

"As a whole after completing this module I have discovered that I had so many abilities that (can) only be seen when explored. I wish that I had discovered these abilities earlier." (student quote from reflective report December 2002)

"Initially I was not very creative. I mostly stayed within the conventional solutions that first came to my mind. This severely restricted the options I considered. When I constructed my criteria, I would already be thinking of what implication it had on my chosen design. This meant that I was risking adding constraints that I unintentionally initially presumed." (student quote from reflective report December 2002)

"During the discussion groups that we undertook in the tutorials I found that two people can interpret the same question in two totally different ways, both come up with a design and neither of them be wrong." (student quote from reflective report December 2002)

"Thinking from concept level was totally new to me, as I am one of these people who used to dive in and start coming up with elaborate ideas to solve the problem, instead of first trying to determine what the task and indeed the problem actually was." (student quote from reflective report December 2002)

To better evaluate their responses a random sample of anonymised sections of student reflective reports were compiled. These were carefully read to find phrases providing evidence of the development of design abilities, of difficulty and of transferring of abilities and so on. From this a series of positive and negative indicators were identified. The frequency with which these phrases occurred was recorded and a picture was built up of the student experience and the extent to which their abilities had been developed. Figure 2 shows the analysis of one student's reflective report.

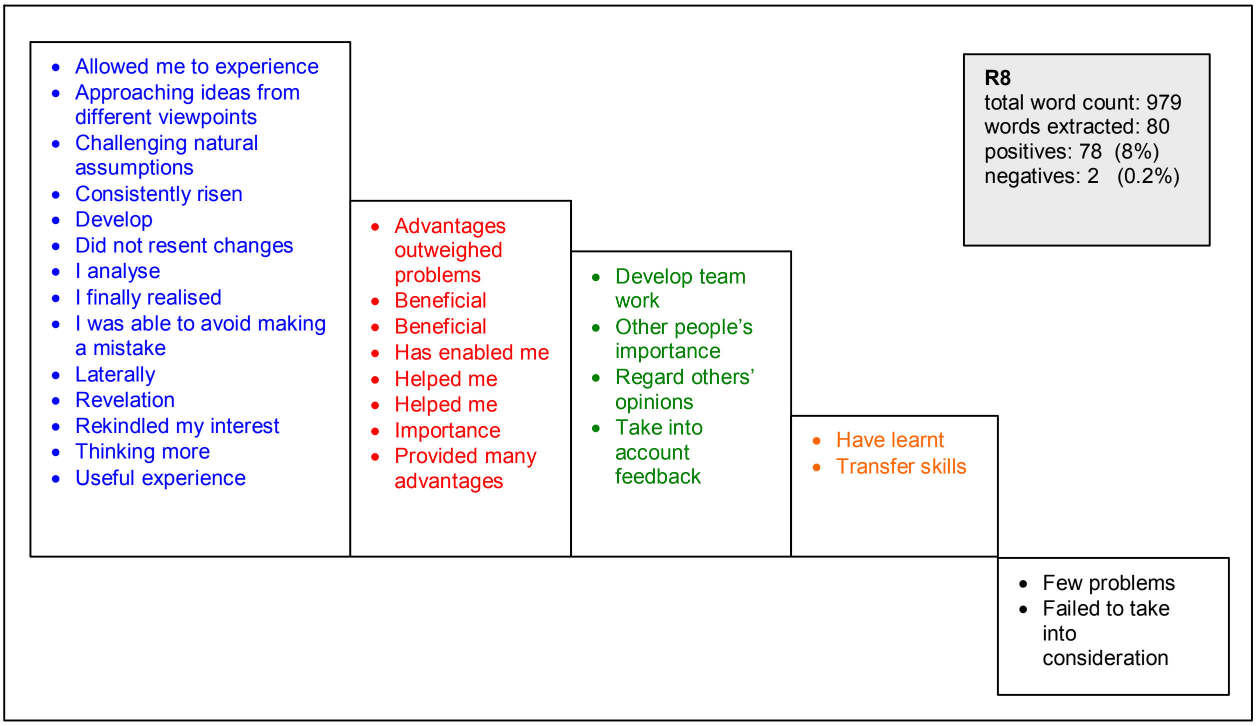

Figure 2: Example of positive and negative indicators extracted from student reflective reports

This evidence from the reflective reports indicated that design can be taught, a concept that is supported by other research, '…..design is not a purely intuitive artistic activity but can be taught…design methodology should integrate knowledge which is being developed, applied and evaluated in order to provide support in designing.' (Achten et al, 2005)

Challenges encountered in delivering the original module

This original module drew upon the experiential, project-based and enquiry-led methods of learning that are characteristic of disciplines such as Architecture and therefore did not fit easily into the culture of more traditional lecture-based engineering programmes. Since there was a weekly sequence of workshops and assessed exercises the workload for students was heavy. For staff there was also a heavy workload as the lecturer was required to mark exercises and provide detailed feedback to a very tight timescale. Prompt feedback was crucial as it encouraged students to build upon their experiences as they worked through the course. Detailed feedback was especially important in the early workshops to promote a deep understanding of the concepts being dealt with and provide a sound platform for the evolution of abilities. Devising the appropriate type of exercise to use was also a challenge. Each task needed to engage the students and promote the required learning experience in a short time frame. Its content had to be such that the level of technical knowledge required did not divert the student from focusing on the process. (Hiley and Johnson, 2003)

For the module to achieve its aim in promoting the evolution of creative design abilities it had to be led by experienced practitioners who have real design experience in industry. Since the focus was on an open-ended process the questions asked by students and therefore the guidance they required was unpredictable; varying according to each student's abilities, attitudes, approach and previous experience. Promoting learning in this context requires a good and practical understanding of the design process.

The development of the current 'real-world problem-solving' (RWPS) module

The evaluation of the original module, described above, was used to revisit its framework and contents, and refine, revise and refresh it. As a result of other research that the authors were involved in (looking at emergent properties in design and the language of design) it became apparent that although design was a generic process practiced by all disciplines, the term 'design' or 'design process' is unhelpful, especially in a multi-disciplinary context. This is because the word 'design' can carry different meanings for different disciplines and even in the same discipline, have different connotations in different contexts. A more appropriate phrase to describe the process is 'creative open-ended problem-solving'.

This led to the original module being further developed so that it would be applicable across a wide range of disciplines and so that it would promote creative open-ended problem-solving skills by encouraging students to become process-oriented rather than solution-oriented. A core aim of the new module is to raise awareness of the interrelationship and interdependency between the quality of the process and the outcome of the process. Students are guided to develop an understanding of the role of the process in predetermining success or failure.

An aim of both the original and current RWPS module is to enhance both self-directed learning and student employability through promoting the development of high level transferable skills. Furthermore developing a generic module enabled the authors to further raise students' awareness of the wide applicability of these abilities. Its generic nature provided an insight into working in a context that was multi-disciplinary or where there were numerous viewpoints that had to be considered. Great importance was attached by the authors to devising exercises which showed the applicability of these creative open-ended problem-solving skills to real-life problems through a range of familiar scenarios. A core characteristic of the module, therefore, is that it aims to promote the evolution of real-world problem-solving abilities; hence its name.

The approach now used continues to be based on guiding students through a series of team and individual activities. Each activity has been devised to raise awareness of particular elements of the creative problem-solving process, while deliberately avoiding discipline-specific technical content. An initial step in the design of the current module therefore was to rethink the discrete elements from the problem-solving process that could be delivered separately, which nevertheless built up a whole framework of steps, activities and best practice which the student could make their own. This practical programme unit aims to equip individuals with the skills necessary for creative open-ended problem-solving through a combination of interactive presentations and activities, group and individual coursework, which includes a poster presentation, and individual analytical and reflective reports.

The sessions and activities are designed to support the following learning outcomes, which are aligned with the core characteristics of the creative problem-solving process. On completion of the module students should be able to:

- define problems, requirements and criteria within a specific context;
- analyse and interpret information; keeping in mind the viewpoints of parties involved or stakeholders affected;
- create, evaluate and assess solution-options;
- exercise original thinking;
- apply non-judgmental critical-evaluation skills;
- arrive at defendable reasoned decisions.
- work independently and be self-reliant;
- work in partnerships with others
- effectively self-manage in terms of time, resources, planning, motivation, initiative and enterprise.

The schedule of sessions and activities

As with the original module the main sessions include an interactive presentation, a related activity through which learning by exploration takes place (not assessed) and, crucially, feedback. The learning is cumulative so that each session builds on and encompasses the content of previous sessions. The core sessions, described and commented on below, are combined with tutorials, a presentation and feedback sessions.

Week 1	**Week 2**	**Week 3**	**Week 4**	**Week 5**	**Week 6**	**Week 7**	**Week 8**	**Week 9**	**Week 10**	**Week 11**	**Week 12**
Session 1 Introduction	**Session 2** Context	**Session 3** Problem Definition	**Session 4** Function & Form	**Session 5** Decision-making & Evaluation	Session 6 CWK tutorial	**Session 7** Reflection & Summary	**Session 8** Posters displayed	Session 9 Academic tutorial	**Session 10** General tutorial		**Session 11** Problem challenge
CWK Issued - Individual reflective log and summary										Individual reflective log and summary submitted	**General feedback – presentation of certificate and prizes**
			CWK Issued - Team project				CWK Team poster feedback given				
							CWK Issued - Individual project set			Individual project submitted	

Figure 3: The module schedule

Introduction: "What do we mean by creative open-ended problem-solving?
This session introduces students to the concepts of 'tame' and 'wicked' problems and the importance of problem-solving. Terms such as 'creative' and 'open-ended' are discussed and defined. A problem that emerges here is the perception that not only is creativity a gift but that the term can only be applied to grand and significant innovations, and not, as is often the case, to small incremental changes. Students also find it difficult to define open-mindedness and to visualise what this means in terms of problem-solving.

Context: "Life on Mars"
This session introduces students to the importance of context, which determines how a problem is going to be solved by setting parameters and limits. Students find it surprising that context includes such a wide range of issues and that this encompasses stepping into another's persona whose world view is probably different to their own.

Problem definition: "How do you solve a problem like Maria?"
Students are introduced to how problems are defined and to the importance of this stage in the process. The main challenge for students here is to avoid fixating on a solution and to focus solely on defining, describing or investigating the problem.

Function and Form: "The Millennium Dome."
Here students are introduced to requirements and constraints and how such criteria affect the problem-solving process. Students find both the definitions of requirements, constraints and criteria and the interrelationships initially confusing as the terms are often used interchangeably with no recognition of the subtle differences. In addition the concept of setting criteria at the problem definition stage is generally new to them.

Decision-making and evaluation: "Eeny, meeny, miney, mo…"
This session introduces students to the factors involved in decision-making and choosing between solution options. Decision-making and evaluation are often perceived as being the end-points of a process. Here awareness is raised that these activities are a continuous thread within the process and the consequences of decisions or results of evaluations should be considered and fed back into the whole.

Reflection: "The benefit of hindsight – if only I'd known…"
This session introduces students to the importance of reflective practice and its role in the creative open-ended problem-solving process. Some engineering students initially find reflective practice challenging as it requires them to clearly communicate their thoughts in writing describing what they have learned and how this might impact on their future.

The assessment process

Assessment has been consolidated into three pieces of assessed coursework. Each piece of coursework has been designed to be marked smartly (effectively with minimum time and effort) to a predetermined set of criteria. The first piece of coursework is an individual reflective log and summary. The process of reflection is an essential part of the development of implicit abilities such as judgement, analysis and critical evaluation. Reflection is therefore an important part of the development of problem-solving abilities.

To help students develop their implicit abilities they are required to keep a reflective log which details how they progress through this module – essentially their thoughts and consequent actions throughout the module. They are given the brief for this in Week 1, with the reflective log being submitted in Week 11. Marking criteria include understanding, frequency and regularity of entries, and consideration of issues.

A reflective summary is also required. This should include, in their own words:

- what they think the module has been about;
- an analysis of how their abilities have developed and what they consider these to be;
- a discussion on how they have or how they could apply the abilities developed to other modules and any other activities;
- references for two relevant academic papers relating to creativity and/or problem solving;
- a brief outline of why they have chosen these papers and what they would highlight as their most salient parts.

In Week 4 students are given a second piece of coursework. This is a group activity to develop students' problem-solving abilities. Students are asked, as part of a team, to show, via appropriate methodology, how they might organise, deliver and evaluate an international academic conference. Ultimately they present their work via an academic poster and a ten-minute oral presentation in Week 8.

The criteria for marking the poster include content, clarity, consideration, layout and attention to detail. The oral presentation is marked for organisation, content and clarity. Students are also asked to award themselves and the others in their group marks for contribution, the ability to work as part of a group and reliability.

The final piece of assessed work reinforces the learning and activities undertaken in the module and develops their writing and referencing skills. Students are asked to write a short academic paper (up to 1,250 words to include a 250 word abstract) entitled *Equipping students with real-world problem-solving skills*. The paper should be underpinned by reference to relevant literature in the field and include reference to similar work being undertaken both nationally and internationally. It should also include some diagrams of the problem-solving process. The abstract is marked for structure and clarity while the main body of the paper is marked for organisation, content and clarity of content and structure. In addition writing is marked for clarity, grammar and spelling, and referencing

Where we are now and the future

This method of teaching has been continually developed since 2002 and the modules delivered to students studying a range of engineering disciplines. The response across the cohorts has been consistent and positive with students generally feeling that they have greatly benefited from the module. However they find it very difficult at the beginning. Experience of delivering the module has shown that students find this process-oriented approach uncomfortable as it requires them to leave their comfort zone and explore unknown territory, and this is supported by research by Norman and Schmidt, (1982). Engineering students, for example, find particular comfort in carrying out calculations without defining the requirements of their design (Chrisp *et al*. 2003).

The main points students make can be summarised as follows.

- As a result of participating in the module they recognise the need to develop a process-oriented approach to creative problem-solving.

- The module is perceived as intriguing, enjoyable, interesting and useful, despite some students finding it very difficult and complex.
- Initially the approach is challenging as it requires them to change their behaviour and go outside of their comfort zone.
- The link between practical and intellectual (thinking skills) work within the module is found to be beneficial.
- The abilities and skills developed can be applied in many other areas of life.

Developing the abilities to be able to cope with and manipulate a process that is complex, multi-layered, multi-faceted and iterative is challenging for students and graduates who are accustomed to defined linear tasks. Experienced practitioners are practised in aligning the process to a specific project and their way of working but often find it difficult to pare down the processes they use and disseminate these to others. This means that in practice new graduates often have to rely on developing their abilities in the work place through observation and trial and error. The authors believe that guiding students to start the process of acquiring professional skills in parallel with cognitive skills underpins current and lifelong learning and facilitates the fulfilment of potential in their future careers.

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