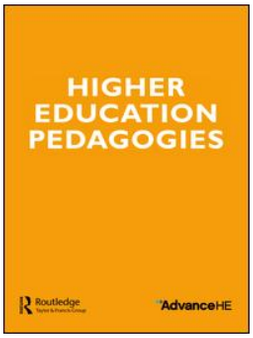

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Philosophies and pedagogies that shape an integrated engineering programme

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ABSTRACT

Accredited engineering degrees call upon students to develop a wide range of knowledge and skills. These range from technical, scientific and mathematical knowledge, through to transferable skills such as communications, teamwork, business acumen and critical analysis. Through a faculty-wide curriculum development programme we have sought to implement cross-department teaching framework whereby a range of pedagogies are employed to deliver against core philosophies for a new way of teaching aimed at developing students' knowledge, skills and attitudes while meeting a diverse range of learning outcomes. We argue that is it vital that learning takes place in the context of authentic engineering problems and processes. In this paper, we look at the philosophies, pedagogies and outcomes of an educational-based project which creates a connected curriculum that joins distinct disciplines at key points during the students' education to provide preparation for, and experience of, professional engineering. It describes the motivation for change and described the implementation and impact of these approaches.

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Teaching philosophies; pedagogy development; curriculum design; problem-based learning; skills-based learning; teamwork and group-based learning

Introduction

Pressure from industry, professional bodies and students have led to calls for a reform of the current curriculum and delivery style of engineering education (see e.g. Rugarcia, Felder, Woods, & Stice, 2000, CBI, 2009; McMasters, 2004; Morgan & Ion, 2014, National Academy of Engineering, 2004; Perkins, 2013; Rauhut, 2007; Spinks, Silburn, & Birchall, 2006). This pressure has been mounting in recent years. Although there have been many excellent individual initiatives, curriculum developments that cut across a whole school or faculty, encompassing a number of disciplines and departments are far rarer. The Integrated Engineering Programme (IEP) at UCL aims to provide a broad engineering experience within the context of a strong, discipline-based technical education. This change has been implemented within a faculty the comprises a wide range of study/research areas, from traditional core engineering disciplines such as Mechanical and Civil Engineering, to newer disciplines such as Biomedical Engineering and Computer Science. The IEP is built on a common curriculum that is shared across disciplines, breaks down barriers and creates space for inter-disciplinary

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learning and team activities. The first intake of approximately 700 students into the three and four year versions of the IEP joined in September 2014, with the first students (those on the BEng/BSc routes) graduating in 2017.

This paper describes the rationale and drive for this faculty-wide curriculum development. It places particular emphasis on the students' experience of teaching and learning in engineering and what they take from it; this was central to all pedagogical considerations and ultimately, the design of the curriculum. We also give an overview of the context in which the developments were made. Following this, our main focus is the key ideologies and philosophies, which have informed the development of the Programme and the pedagogies employed to align with our strategic objectives and vision. We provide a sample of practical examples to show how these pedagogies have been implemented in different parts of the Programme. These are threaded through the paper to give further insight on how we have made use of a variety of approaches in a large-scale interdisciplinary programme. The paper concludes by offering a summary of the Programme practice and observations on its effectiveness.

Rationale and methodology for the development of the programme

In 2012, the then Dean instigated a change programme, and the UCL Engineering Sciences Faculty set out a radical vision for a new interdisciplinary education experience for undergraduate students. Drawing direction from the calls for development in engineering education and enhancement of graduate skills that we refer to above, it aimed to deliver a distinctive educational offering.

A programme of change began by identifying specific areas of educational activity in order to probe best practice, understand the faculty baseline and create a vision of the educational reform that was required. This was a research exercise, which included:

- a review of the engineering education research literature,
- consultation with industry and analysis of industry led reports graduation skills and employability.
- alumni focus group
- an engagement programme with academics across the Faculty, predominantly through a series of workshops and focus groups, some of which focused on single disciplines while others were on cross-cutting topics such as mathematics and transferable skills.
- consultation with senior management and educational leaders.

This process identified a number of core aims and values for the redesign that met the expectations already identified, while addressing core values of the faculty.

Front and centre of the new design was creating an inclusive programme that attracted a diverse cohort of students. Although achieving a better gender balance was a priority, the design process also sought to develop a programme that engaged students from a wider range of background and interests. Since UCL is strongly research-intensive, a curriculum that connected research and teaching was a key strategic objective. In addition, a variety of transferable skills were identified for integration throughout the academic journey of students in order to enhance the employability of our graduates. The programme's goal is to give

undergraduate students, regardless of discipline, an abundance of opportunities to put their core technical knowledge into practice while developing their own transferable skill-sets.

To deliver on these objectives, the revised programme enriches the student experience by embedding authentic and research-based learning practices within a set of (mostly) existing engineering and computer science degree programmes. Departments were requested to undertake a fundamental review of the core curriculum in each discipline. In addition, a series of problem- and project-based learning experiences where interspersed throughout the undergraduate journey, underpinned by additional support material and instruction. Some of these elements cut across disciplines, while others maintained a single discipline focus.

One unanticipated and important realisation thrown up by the curriculum review process was that a typical approach to utilising core science topics as the connecting thread between engineering disciplines would not be appropriate for the desired aims of this programme since individual disciplines had nuanced differences in the way that they call on the basic sciences. Instead, an emphasis was placed on engineering design, problem-solving, application of engineering theoretical knowledge and skills development as key areas where engineers from distinct disciplines could meet more productively and share common ground.

At the culmination of this process, five key philosophies were identified that could guide the delivery of the redeveloped programme and deliver the overarching learning outcomes identified above:

- Interdisciplinarity
- Problem-Based Learning
- Authenticity
- Embedded Skills
- Promotion of Intrinsic Motivation

These are discussed in greater detail later, with examples of how they were realised in the new curriculum.

Programme structure

The curriculum review initiative created a cross-departmental curriculum that is connected in two ways. Firstly, the curriculum has been constructed to connect theory and practice through student-centred activities where students are required to utilise and apply their knowledge and skills within authentic projects. Secondly, students in different departments are connected through shared projects, syllabi and cross disciplinary learning.

The degrees which form the IEP cover a broad range of disciplines; Biomedical Engineering, Biochemical Engineering, Chemical Engineering, Civil Engineering, Electronic and Electrical Engineering, Mechanical Engineering and Computer Science. The reforms maintained direct student entry into each of the disciplines but introduced a common structure that enabled regular cross-cutting activities. The IEP framework took the distinct provision of each department and interweaved cross-cutting activities and syllabus elements across the first three years of both three and four-year degree programmes. Activities took place from the first week of term and repeated at regular intervals throughout each degree programme. Because of the scale of the intake (typically >700 students) almost no teaching took place with the whole cohort as one,

rather, common syllabus or common learning outcomes and methods of delivery were implemented across a number of cohorts simultaneously. However, they all shared a common purpose: providing opportunities for students to develop a broad understanding of engineering problems and disciplines through practical, problem-solving activities. A high-level overview of the structure is shown in Figure 1.

These cross-cutting elements form clear threads that run through the first two years of all degree programmes. These can be seen in Figure 2 which shows the student journey through the Programme. The central thread consists of design projects. These come in three different types:

- Engineering Challenges: Experiential, PBL module consisting of two separate, disciplinary and interdisciplinary problems running over 5 weeks. Student teams design solutions to a real-world problem encompassing all elements of the design cycle.
- Scenarios: Six discipline-based, intensive week-long projects during which students do not attend any other class. These are the key opportunities for students to connect the theory they have been taught and to put into practice elements from the Design and Professional Skills thread. They typically follow a pattern of 4 weeks of 'traditional' teaching followed by each 1-week scenario.
- How to Change the World (HtCtW): 2-week, interdisciplinary team-based socially driven engineering design challenge.

All these modules are forms of problem-based learning (PBL) which lead into the traditional year-three project of the kind that is common in the majority of UK Engineering degree programmes. To underpin and support the skills that students require to maximise learning opportunities throughout the string of design projects, two new modules were created:

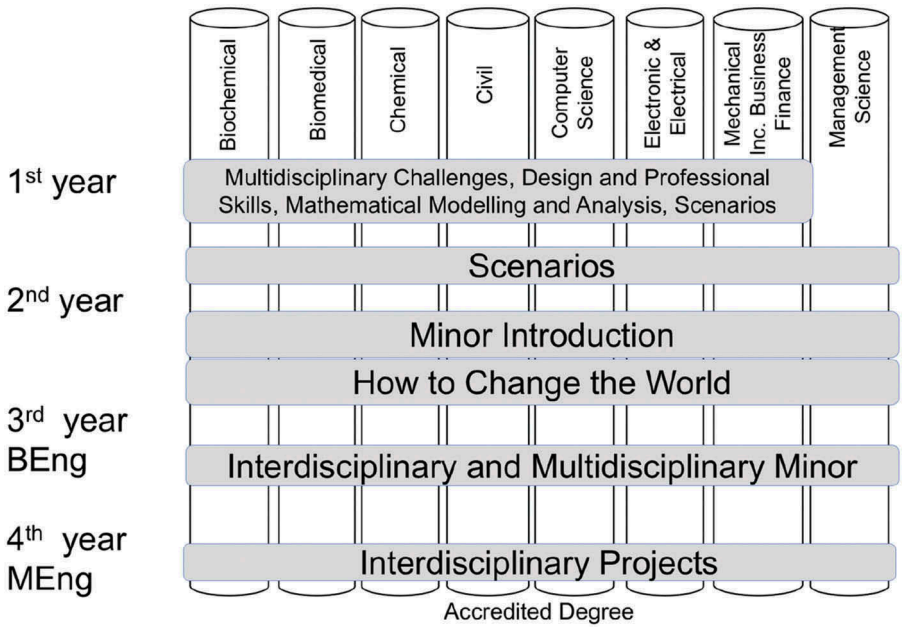

Figure 1. Overall structure of the Integrated Engineering Programme.

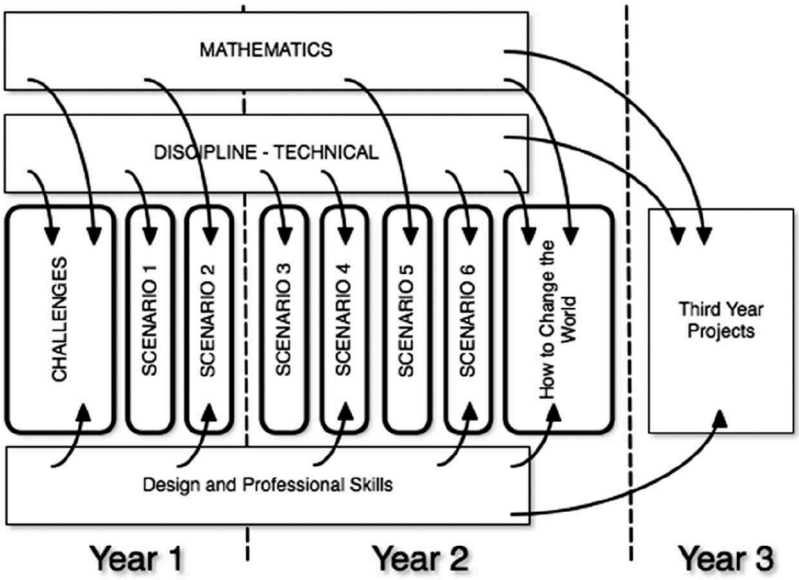

Figure 2. Relationship between the IEP elements.

- *Mathematical Modelling and Analysis*. Applied mathematics module including computer modelling across both years. It is taught using a mixed model of general lecture delivery followed by discipline specific workshops. The aim is teaching fundamental concepts in mathematics coupled with a high degree of engineering application.
- *Design and Professional Skills*. The modules within the first two years aim to develop non-technical skills required by engineers i.e. communications, creativity and ethics.

These new modules run alongside discipline specific technical instruction which encompasses core material delivered by each department, and which still accounts for approximately 80% of the total of the degree. During the development process, departments reviewed and revised their discipline specific curriculum, both to adapt to the new framework but also to align topics with the Scenario schedule.

Programme philosophies and pedagogies

In this section, we aim to articulate how the educational philosophies identified earlier manifest themselves as pedagogies implemented in the curriculum elements of the Programme. For each, we describe the philosophy and demonstrate how this plays out in the learning activities of the IEP.

Interdisciplinarity

Professional engineers do not work within disciplinary silos. It is vital that engineering students experience and appreciate the ways in which different disciplines interact to deliver any modern engineering project. However, the proposal to connect teaching and learning across disciplines is by no means a straightforward task. One obvious route

was to mirror General Engineering programmes, such as those offered in the UK by Oxford and Cambridge and in many parts of Europe, where the first two years of the degree programmes is common across all disciplines with specialisation occurring only in the third and fourth years. The way to achieve this is through joint teaching of subjects such as mathematics, programming, and core science topics such as fluids, thermodynamics etc.

Yet, cross-disciplinary working parties at UCL Engineering opened up the idea that although each discipline had syllabus requirements that looked similar on paper, much of the context and focus differed between disciplines. The only significant common ground to emerge from the traditional subjects was in mathematics. Here, there was potential to add value to the student experience by providing a broader view of mathematics and an understanding that it is a common tool applied outside of their home disciplines. For example, there is value to an electronic engineer in appreciating that the differential equations that underpin circuit theory can equally be applied to the springs and dampers of a car's suspension, or the mixing of fluid flows in a chemical plant. Such learning gives our students a common language and culture, which they understand as underlying engineering as a whole, and facilitates interdisciplinary project work.

Other areas of common ground that had the same potential as mathematics are not technical areas, but topics such as engineering design, problem-solving and transferable or professional skills, such as communication, project management, creative and critical thinking. All of these skills are required in project work and so it made sense to connect the curricula through projects. The real value of interdisciplinary projects comes from bringing individual perspectives and distinct expertise together to collaborate in problem-solving. This marks out a central thread of the IEP.

The pedagogy now in use to deliver interdisciplinary experiences is PBL. Two examples of this philosophy are the 'Challenges' and 'How to Change the World' (HtCtW). Both are interdisciplinary PBL projects that sit in the first term of the first year and the final term of the second year, respectively. There is a pedagogical progression between these two projects. In the Challenges, teams consisting of two or three disciplines each are set the challenge of designing elements of a production plant. This project's solution focused and student learning is directed to the 'specify', 'test/model' and 'build' phases of the design cycle (see Figure 3). HtCtW, on the other hand, challenges students with a social problem, many of them derived from the UN Sustainable Development Goals (United Nations, 2015). In these challenges, students work in mixed discipline teams, which include six engineering disciplines along with management science and computer science students. On this challenge, students have to think through the whole of the design cycle from brief, conception, through to use and impact of their solution.

There is a jump between these two projects in the level of sophistication and skill required to complete them. HtCtW, challenges students with a social problem of a much broader scope requiring them to first define the problem area they wish to address within the wider problem space before working to produce a solution against their own brief. If the Challenges are the introduction to the UCL Engineering style of interdisciplinary learning, then HtCtW is the advanced course. Between these two elements are periodic, discipline-based projects, called Scenarios. These projects share many learning outcomes

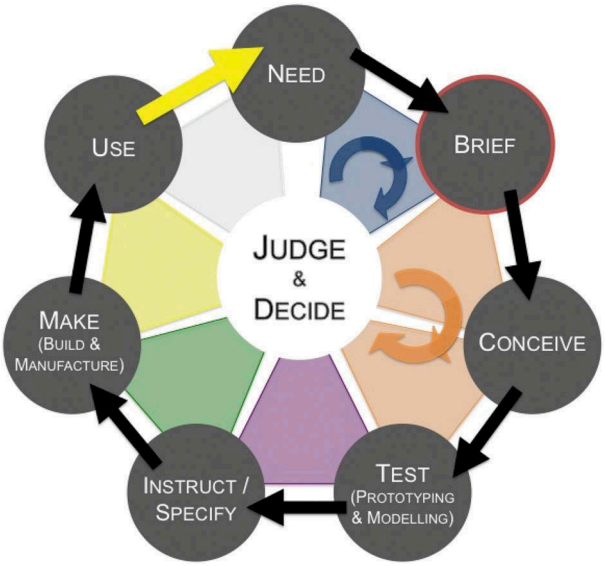

Figure 3. Design cycle.

based on the development of skills and abilities, which surround their technical learning. They also develop the students as the practical disciplinary experts who will be part of future interdisciplinary teams. We believe that the learning and development which occurs between the Challenges and HtCtW is significant in helping the students to become comfortable with the socially driven context of HtCtW and to work well within the interdisciplinary teams in industry. A case study of the Programme is given below.

Problem based learning

A number of initiatives have arisen which redefine the curriculum and introduce active learning techniques. As an example, PBL, which was pioneered in medicine (Barrows, 1992), has credible learning benefits such as enhanced problem-solving skills, creativity and criticality, which are all aligned with vocational/professional demands (de Graff & Kolmos, 2003). Understandably, given the demands described above, such approaches have also been attractive in Engineering.

Today, worldwide, a number of examples of such shifts in the curriculum exist, most notably the CDIO (Conceiving – Designing – Implementing – Operating) programme (Crawley, Malmqvist, Ostlund, & Brodeur, 2007), the Aalborg model of PBL (Kolmos, 2002), Design-Based Learning (DBL) pioneered in Eindhoven (Gómez Puente, Van Eijck, & Jochems, 2011) and a number of developments in Australia e.g. Mills and Treagust (2003). Some of these, for example, Aalborg, are very clearly PBL based while others include a wider range of active learning styles. Despite such high-profile developments as these, there is still concern that 'these changes…have not resulted in major systemic change within engineering education' (National Science Foundation, 2008).

PBL is generally characterised as an active learning technique that is built on the use of ill-structured problems (Barrows, 1992). These problems form the core stimulus for the learning

process which is typically undertaken within groups or teams (Savin-Baden & Major, 2004). The core benefits often subscribed to PBL include the development of critical thinking and analysis skills, team and communications skills and independent learning (Kolmos, 2002).

We define PBL in the IEP as a broad category of activities that encapsulate 'a time-bounded activity which is directed by the project participants or team, who determine the course of the project and the final output in response to a brief of some description.' (Hanney & Savin-Baden, 2013, p. 8). This highlights some key elements of our philosophy. For many practitioner-researchers in engineering education, the activities must be project based and authentic (Savery & Duffy, 1995). We also acknowledge that there are several forms of PBL; for example, enquiry-based learning (Kahn & O'Rourke, 2004), design-based learning (Doppelt, 2009) and scenario-based learning (Thomsen et al., 2010), and project-based learning (Hanney & Savin-Baden, 2013). In engineering, it is only natural that an authentic problem is a project as most of our PBL activities are. However, we also encompass design-, enquiry- and scenario-based learning across the IEP. We acknowledge that this covers a spectrum of activities from problem-based to project-based activities, and so we refer to all the learning experiences within the context of this study as PBL at a general level.

However, there are two elements of PBL that we regard as essential to all of our interspersed projects and these are that activities must be team based, and that they must encourage a level of learner autonomy.

We have found that although the pedagogy of PBL brings many essential features to the curriculum, in and of itself, it is not enough. It is important that there is a supporting curriculum which instructs and bolsters development of the skills required by the PBL activities. This has to be carefully structured since PBL elements themselves may vary greatly in what they demand of the students depending on the learning objectives of a particular element.

The impact of these types of activity is two-fold. They aim to strengthen exactly those skills that are emphasised by industry as being key to graduate employability but also aim to demonstrate engineering as a creative, interdisciplinary and inclusive activity that brings together people with different expertise and capabilities to create innovative solutions to societal problems. The impact of these activities on student engagement and self-efficacy are an important factor it considering how they are designed and where they are placed in the curriculum.

As we have indicated, a variety of PBL activities are threaded throughout all of the undergraduate degrees. Yet the majority of the PBL activities implemented within the IEP very explicitly focus on engineering design with an emphasis on progressing students through various stages of the design cycle (see Figure 3). We constructed a two-level approach to the journey that students take through this central strand of the Programme (as shown in Figure 2). The first level connects other students' technical learning to the project activities providing a context for the theoretical and skills based learning that takes place in other parts of the course. At the second level the projects are connected to one another to provide a hierarchical structure of development for core skills such as project management, communications, collaboration and problem-solving.

The first experience that the students meet is the IEP Challenges. These were specifically structured as two, 5-week projects to provide enough time for students to engage in the supporting skills based and theoretical activities alongside one another.

	Challenge 1	Challenge 2	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Scenario 6	HtCtW
Need		Given		Given	Given	Given	Given	Given	
Brief		Given		Given	Given	Given			
Conceive				Given	Given	Given			
Test					Given				
Instruct / Specify									
Make									
Use									

Figure 4. An example of mapping the problem-based learning activities to the design cycle across the first two years of the programme.

This is the longest of the PBL activities and was designed as such to provide an introduction, or an induction, to the style of work and learning that is required in PBL and to provide scaffolding and support students in making a successful transition from much more prescribed learning in school. These two projects also introduce the students to a broad range of aspects within the design cycle as a prelude to more focused activities that follow.

Subsequently, students engage in tightly focused 1-week activities, called Scenarios, within their departments which connect discipline-specific theoretical learning with real projects in a demanding and concentrated burst. Again, there is an emphasis on elements of the design cycle and on the production of authentic artefacts by way of realistic means of assessment. The students are provided with increasingly less structure and scaffolding and increasingly broader and more open-ended problems. In the final activity, at the end of the second year, a project called How to Change the World, expands the scope to an intense 2-week project, where the students are presented with 'wicked' problems (Buchanan, 1992), which cover potentially the full design cycle, require a wider range of skills and ask the interdisciplinary teams to first identify the problem within the scope of a much boarder challenge space. Figure 4 demonstrates an example of how these activities can be mapped on to the design cycle, emphasising the expectation that although each element may cover very different content (in terms of technical and transferable skills), there is a progression in terms of exposure ever more complex problem-solving and design activities.

Authenticity

A touchstone philosophy of the IEP has been the provision of authentic learning experiences within, and across, engineering disciplines. We hold the view that the

undergraduate engineering education curriculum should be the foundation upon which students can begin to build and develop their expertise in engineering practice. For this to happen, the curriculum should provide multiple authentic tasks that require the integrated application of various knowledge and skills (Litzinger, Lattuca, Hadgraft, & Newstetter, 2011).

In our view, authentic learning is neither a learning theory nor a specific pedagogy (Herrington, 2015), rather it is a general model or pedagogical approach. We use the term in a general sense to refer to constructivist pedagogies in which learning objectives align with real-world tasks, content and context. Our aim has been that students create their own understandings and skills by integrating their previous experience, their own research within learning environments and opportunities that we invite them to take part in.

With this in mind, the context and content of the problems given to students is of paramount importance. Authentic activities give the students the opportunity to put into practice their technical and theoretical knowledge while at the same time enhancing a wide range of transferable professional skills and also broadening their understanding of the societal context in which their solutions can operate.

Authentic environments are, of course, in part created by the students themselves since it is their own learning processes that come to mirror the kinds of learning processes that working engineers go through on a day-to-day basis. Authenticity means that the technical knowledge which students learn is not abstracted from the way it is eventually being used. Instead, our students have to ask themselves, 'How can I apply this technique?' or 'Which technique is applicable to this particular situation, within this team, within this context, for these users and at this time?'. As pointed out by Ambrose, Lovett, Bridges, DiPietro, and Norman (2010, pp. 107–112) this type of application is vital for students to develop mastery and to enable 'far transfer' of the knowledge, i.e. transfer from classroom learning to practical problems outside the classroom.

The problems explored within our use of PBL include the concepts relevant to the subject domains and the problems are as *real* as they can be. Some have stipulated that PBL must be *real* as these problems are more multifaceted than is possible to fictionalise, and that real problems are more engaging perhaps because students may be more familiar with real contexts (Savery & Duffy, 1995). Barab and Duffy (2000) consider PBL as a special case of authentic learning, and support this argument for real problems by taking forward the notion of real life richness. For other reasons, authenticity may be difficult to pre-plan, or pre-authenticate because students must find their own authentic learning answers, in other words there *should* be many variations of right answer (Barab & Duffy, 2000).

By definition, design-oriented projects of the kind we thread through the IEP have a variety of 'right' answers. What we aim to achieve by presenting design problems to students, is an opportunity for them to develop their knowledge, skills and understanding through *situated cognition*. This term was first employed by Brown, Collins and Duguid (1989) who took their prompt from exploring learning in the workplace and argued convincingly that knowledge is always shaped by the context of its use. Their call for changes in education to situate learning in authentic tasks seems particularly applicable to such STEM topics as medicine and engineering which are strongly applied and are as much as making and doing as they are about discovering (Mitcham,

1994). Authenticity pervades in the range of topics, learning tools, activities and assessments within the curriculum.

In the IEP, repeated authentic learning experiences have been introduced into an undergraduate engineering curriculum that is already time-constrained, and this has implications on the balance between curriculum depth and breadth. Authenticity, and all it brings with it, is consistent with the recent direction of travel of accreditation such as ABET and UK-SPEC toward increased emphasis on industry-relevant breadth with an expectation of socio-economic and business-related learning outcomes being specified. Whilst in many ways this is not incompatible with the view of a scholarly university 'education', there are perceptions in some quarters that this runs counter to aspirations that seek to provide students with deep scientific knowledge, as promoted by many engineering degree programmes. In most cases, this attitude manifests itself not from any ideological objection to breadth, but from a resistance to losing any of the disciplinary elements, particularly in underlying science, that students aspiring to graduate as engineers should have passed through.

The pace of development of new technologies and techniques that require attention has led to over filled syllabi, as engineering departments seek to maintain full coverage of an ever-expanding discipline. It is quite telling that although faculty members involved in the curriculum development workshops could reel off topics that had been added to their syllabi in recent years, few, if any, could remember any syllabus item(s) being dropped from the curriculum. This suggests that whilst faculty members were quite adept at keeping up-to-date with emerging trends within their disciplines, they often did not consider cutting out any syllabus elements that could be in danger of becoming obsolete.

The development of the IEP explicitly asked faculty members to review the essential components constituting the core of their disciplines, in order to focus on fundamentals that would enable life-long learning. This required an acceptance that full coverage of a discipline was impossible within the time constraints of a single degree programme. By accepting a pared-down disciplinary curriculum, we were able to create space to enable students to explore a wider breadth of topics, for example, through the introduction of a 'Minor' area of study in the curriculum. Additionally, the contextual elements of engineering, recently specified by the accrediting bodies were embedded within the core teaching, most often within the project-based elements. Typically, these sociocultural and management topics had been covered in separate standalone modules, which were far too often given little attention by both staff and students. Embedding such topics is not only more efficient but it has a critical role in promoting student understanding of the relevance of their broader studies to their future in the engineering profession.

Embedded skills

As is apparent above, professional bodies representing engineers across a variety of disciplines have added transferrable and management skills to their accreditation criteria alongside technical skills (e.g. IET, IMechE, REFS). Industrial and professional policy organisations alike have highlighted a suite of competences that come under the banner of 'employability' and include such attributes and abilities as communication, leadership, teamwork, resilience alongside a greater insistence on sustainable and

ethical engineering practice (McMasters, 2004; Woods, Felder, Rugarcia, & Stice, 2000). The Royal Academy of Engineering (Rauhut, 2007, p. 14) summed this up as 'University engineering courses must provide students with the range of knowledge and innovative problem-solving skills to work effectively in industry as well as motivating students to become engineers on graduation'.

The challenge for the IEP has been to ensure that these skill sets are put into practice during PBL activities and further developed through reflection and instruction in workshops that are congruous in timing and content with the skills in practice. For example, students begin working in teams from the first day of their undergraduate studies. There is a lot that can be gained from team-based projects, which can promote learning through collaboration between students who have different perspectives and understandings and promote a deeper engagement with materials and stimulate peer to peer learning (Finelli, Bergom, & Mesa, 2011; Oakley, Relder, Brent, & Elhajj, 2004). Team projects are also ideal environments in which to practice communication skills, develop valuable interpersonal skills, resilience and collaborative practice. However, we have also had to recognise that team projects can provide opportunities for freeloading, in that students can potentially avoid doing their share of the project, or more commonly they can avoid practicing the skills that they feel less confidant in and avoid learning in those areas. In order to promote collaborative learning and minimise freeloading, we developed a suite of grouped and individual activities that support and encourage good teamwork.

In all, the undergraduates on the IEP undertake nine team projects in the first two years of their degree. They range in length from half a term, to 1 or 2 weeks, while some are interdisciplinary others are single discipline projects. A range of support mechanisms have been put in place to support students in their development of team-based skills across the first PBL experiences:

- In the first week of the first year of study all groups undertake teambuilding activities followed by reflection on the interactions they are encountering in their teams.
- Teamwork workshops give students an evidence based framework which they can use to reflect on and improve their team practice (Finelli et al., 2011; Hayes, 2002; Katzenbach & Smith, 1993; Levi, 2014).
- A series of team coaching sessions based on the Gallup Strengths Finder psychometric testing (Rath, 2007), which all undergraduates complete during their first term. We use this tool as a mechanism for students to self-identify their strengths as a basis for facilitated conversations within their teams as to how members might function (Tilley, Peters, & Mitchell, 2014)
- A peer assessment exercise based on rubrics, which are generated by the teams themselves, so that the generation of the rubric in itself is a teambuilding exercise (Roach, Smith, Tilley, Marie & Mitchell, 2017).
- One-to-one support and mediation for teams that get into difficulties

The above experiences and opportunities form a strand of activity that runs alongside the project itself so that students have direct and relevant experiences from the project work into which they can apply the outcomes of the support sessions and which they can use as the basis for reflection. The whole approach to teamwork is designed to

encourage the independent development of teamwork processes by providing students with a set of tasks, which if accomplished support the functioning of effective teams. In many ways, our team framework is a set of advisory and support measures that our students will have the opportunity to practice at several points throughout their degree programme. In a recent survey of our first year at the end of their first team-based PBL activity, over half of the students said that they had learned the most from the teamwork, and 'the improved ability to work effectively with a team in terms of team-based and task-based roles' was perceived to be the most effective of all the stated learning outcomes.

Promotion of intrinsic motivation and self-efficacy

Perhaps the core philosophy of the IEP is to encourage and stimulate motivated students; students who are motivated in themselves, intrinsically, without the need for a lot of control measures from their tutors. Intrinsic motivation is a gold standard of student engagement. Internally motivated students are more likely to pay attention, enjoy their work and develop attitudes that support their self-efficacy and development. PBL itself is has been observed to produce high levels of student engagement and motivation (De Graff & Kolmos, 2003). We have already discussed the way in which authentic learning experiences, in some sense, demand that the student finds their own journey, define their own learning, and discovers authentic answers (Barab & Duffy, 2000). By its very nature then, authentic environments offer a sense of autonomy of learning.

This sense of autonomy in learning links to some the psychological literature on learning which suggests that learning can be seen as a process through which students internalise, adapt and integrate new knowledge into their own identities and representations of themselves and their world (Deci & Ryan, 2008). Self-determination theory, as presented by Deci and Ryan (2008) nicely describes the learning environment that we provide for our students. They say that self-determination theory 'has proposed that all humans need to feel competent, autonomous, and related to others. Social contexts that facilitate satisfaction of these three basic psychological needs will support people's inherent activity, promote more optimal motivation, and yield the most positive psychological, developmental, and behavioural outcomes…' (Deci & Ryan, 2008, pp. 14–15)

The IEP aims to fulfil all of these conditions by providing social context and collaborative learning opportunities in teams. It proves instruction that underpins specific skills to support the development of competences required for the PBL activities. It replicates the complexity and richness of authentic environments, which gives students the freedom to internalise and align their learning with their own experience and identities. We see this as key to developing self-efficacy in students through confidence in their ability to apply their knowledge and skills in such contexts.

Case studies

In this section we present two case studies of the implementation of two specific parts of the IEP which demonstrate how the five principles above can be integrated into a curriculum.

CASE-STUDY 1 – the engineering challenges

The engineering challenges are the corner stone of the IEP consisting of two 5-week projects, in which groups of students undertake engineering design-based activities throughout the first term of their first year. The first Challenge seeks to introduce students to the research of the discipline-based department they have joined, providing an induction to not just content which forms the basis of their chosen discipline but also the academic research and researchers who are on the cutting edge of innovation within the discipline, thus building a sense of community within their cohort and department. Students are presented with a requirement for a research-led, high-level design which provides an authentic context (Wang, Dyehouse, Weber, & Strobel, 2012) for their problem based activities. Across the 5-weeks, students meet twice each week for 2 hours in staff facilitated sessions, working towards a set of deliverable elements at the end of the project. These elements are specifically designed to give students opportunities to put into practice the skills being developed in the design and professional skills course, embedding them within the learning of the project.

In the second 5 weeks of the first term, students undertake the second Engineering Challenges project which is again structured as two, 2-hour sessions per week. Here, interdisciplinarity is introduced into this PBL structure. To provide authenticity, multidisciplinary groups are structured as if they are consulting engineers. Pairs of disciplines (Electronic Engineers and Computer Scientists; Biochemical Engineers, Chemical Engineers and Biochemical Engineer; or Mechanical Engineers and Civil Engineers) work together, inter-disciplinarily, on specific technical briefs as part of the overall project and are required to meet with their counterparts working on other technical briefs to share progress and exchange information. This task authenticity that the project resembles, that of the real world, provides significant engagement and motivation to the student teams.

CASE-STUDY 2 – How to Change the World (HtCtW)

The How to Change the World project draws students from across the faculty, including traditional engineering disciplines as well as from the School of Management and Computer Science, into interdisciplinary teams. The problems presented to the students are deliberately very board in their nature, requiring expertise from across the disciplines represented. The problems are derived from the UN Sustainable Development Goals (United Nations, 2015) and so by their very nature require students to consider not only the technical aspects of their solutions but also the societal impact and implications. The cohorts are split roughly 50:50 between contextual 'real-world' challenges in the developed and the developing world considering global issues such as transport (e.g. Smart Intercity Transport in England 2018), materials (e.g. Smart use of materials in construction) or water (e.g. reducing pollution, garbage and floods in the khlong (canal) system). There are around 10–12 teams per HtCtW Challenge. As part of the scoping and idea generation process, teams are encouraged to consider how each discipline can contribute to the problem solution. In these challenges, students work in mixed discipline teams of 5 or 6, students, thinking through the whole of the engineering design cycle from needs analysis and problem definition, brief, conception, through to use and impact of their solution. The project takes the students through structured brainstorming and idea generation processes in the first week, with the milestone of presenting a problem statement and design brief to a HtCtW Challenge Partner, usually someone in

the problem space from a government body (e.g. the Department for Transport), or a Charity or Foundation (e.g. Ellen MacArthur Foundation) for feedback. Cohort leads (i.e. academic staff) are available for much of the week, but the majority of the time is spent in facilitated team work sessions. In the second week, the students in their teams refine their technical briefs and aim to develop a concept solution which is pitched in a final showcase on the final days.

Mapping this activity to the five philosophies outlined, unsurprisingly as the capstone project of the first two years, we see that HtCtW neatly encapsulates all the prescribed philosophies outlined above. It draws students from across the engineering disciplines and beyond into interdisciplinary teams and places them in a PBL environment that, by its very nature, requires students to develop and exercise a broad range of skills. The design and delivery of HtCtW, with a focus on current and unsolved societal problem that engineers are grappling with brings both an authenticity, but also fosters an intrinsic motivation in a large number of our students. By this stage of the IEP, our students have had a number of opportunities to practice their transferable skills; however, it is still important that the exercising of these skills is embedded and relevant. Hence, careful thought is given to only including activities that are core to task being addressed so that students do not see these skills as something they are being forced to practice, but instead, something that feels like a natural stepping stone in the journey through the project.

Summary and conclusions

The work describes the process undertaken to review and reconstruct the engineering curriculum in a large, research-intensive university around an emerging, interdisciplinary view of engineering expertise. Emerging from a review of both research and professional literature, a core set of philosophies where expressed that drove the development of a curriculum comprising a set of PBL activities linking technical content and transferable skills. We have described how these activities must be authentic and how students are exposed to interdisciplinary elements at regular points throughout their chosen degree of study. We have provided examples of how this is achieved across the curriculum, emphasising that no single delivery method or style was possible, or desirable. Rather, we developed a flexible approach which pragmatically ensures that philosophies where met but that local interpretation was possible.

The central connected philosophy identified was the promotion of intrinsic motivation within the cohort. This was seen to cut across all other elements, informing the design of core teaching, PBL activities and other facets of the engagement with students.

It acknowledged that such designs are heavily contingent on the context of the institution and the existing structures but that most curricula have the possibility to offer opportunities to engage students in authentic project-based activities. We suggest that such a change in the curriculum radically alters the student experience of engineering and their view of the role of engineers in society.

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