

Towards a more scenario- and problem-based engineering curriculum – or *How to change the world* by educating students differently

by Eva Sorensen, Deputy Head (Education), UCL

It's great to be an engineer, to be revered as a person who can design, build, operate and control things, who is competent by virtue of your fundamental education and training by applying scientific methods and outlook to the analysis and solution of engineering problems. But how do we ensure that this fundamental education adequately prepares a young person for a career as an engineer? UCL Engineering, whose motto is *Change the World*, believe they have the answer – To change the world, students need to be taught differently.

Traditional engineering education, in larger departments at least, is often based around lectures delivered to entire cohorts in lecture theatres by single lecturers, interspersed by a handful or so laboratory sessions and some design work in smaller groups. The lectures are often long, typically 1-2 hours, during which the lecturer talks and the students listen. During the course of a term, coursework problems may be given to the students at regular intervals, for them to complete individually in their own time in order to assess their progress. The problems are often of a rather closed nature to make them fit into a standard coursework assessment scheme applied to the entire cohort. A professional institution, such as the IChemE, will on the other hand, define their desired learning outcomes at a higher level, and a typical outcome statement might be for a student to be "*able to solve open-ended chemical engineering problems, often on the basis of limited and possibly contradictory information*". How do we reconcile the requirements of our profession to educate graduates who have these skills with the constraints of a university setting with ever increasing student numbers?

UCL Engineering's Integrated Engineering Programme (IEP), introduced in 2014/15, is a teaching framework that allows both specialist and interdisciplinary engineering education to be delivered intelligently across different engineering disciplines, and in programmes that teach fundamental technical knowledge in tandem with interdisciplinary, research-based projects and professional skills. Students still register for a core discipline, but alongside their studies in this discipline they also take part in activities that span across departments. The IEP aims to produce engineers who understand the context of their work, are independent and self-directed, and have an impact in their field. Transferable professional skills, such as communication and ethics, are taught using real world examples tailored to each subject. This approach to learning will produce well-rounded graduates with a strong grasp of the fundamentals of their discipline and with a broad understanding of the complexity and context of engineering problems.

The IEP programme is based on a number of innovative methods of teaching which encourage personal and professional development as part of the degree process. Throughout the programme there is a strong emphasis on design activities, and in developing the skills needed to design innovative solutions and technologies in a 21st century industrial setting. The IEP is based on a scenario- and problem-based learning approach, both cross-disciplinary and within disciplines. In particular, all first and second year engineering students take part in projects either intensively over a week within the discipline, or over several weeks across several departments or the whole Faculty.

Engineering Challenges

Our students are introduced to their discipline and to engineering through real world challenges in their very first term via two major five-week design challenges, intrinsically linked to authentic global challenges, rich in social awareness and ethical context. Smaller design workshops replace large lectures, allowing all students to actively participate in modelling, testing and making prototypes of their engineering solutions. All students take part in design reviews, meetings, presentations, portfolio management and technical writing, giving the students insight into regular practices found in industry.

In 2015/16, the two challenges were:

1. **Sustainable Planet:** "Define 'sustainable energy' appropriate to your assigned country. Design a suitable 21st century Sustainable Energy Solution for the benefit of those who live in that country."
2. **Global health:** "In a multi-disciplinary team, come together to design technical aspects for a new vaccine production facility in a remote part of Sub Saharan Africa."

Students worked together in teams of 6-8 students from across the Faculty on the first Challenge, and in similar team sizes within a subset of departments for the second Challenge. For chemical engineering students, this meant working closely with biochemical engineering and biomedical engineering students in designing a reactor for the production of the vaccine, whilst the mechanical and civil engineering students considered design for the production of power to the plant as well as for ultra clean water for the production facility, and finally, the electrical engineering and computer science students designed the control system for the reactor based on the requirements set out by the chemical engineers. The different disciplinary teams came together at regular intervals to share their work and their requirements for the work conducted by the other disciplinary teams.

In both Challenges, the work is conducted predominantly in teams and the students are assessed based on both individual work (30%) and team work (70%), thus students are learning to focus on the development of their team working skills from the very start of their degrees. In our pre-IEP programmes, the first time students experienced real team-working was not until their capstone design project in the third year – when it often came as a nasty shock to some of the students that they were not in complete control of their work, but had to contend with lazy, or overly demanding, peers.

Alongside the Engineering Challenges module, all Faculty students also take four additional modules within the IEP over the first and second year: two modules on Design & Professional Skills and two modules on Mathematical Modelling and Analysis. Both sets of modules have core material focussed on general engineering skills, with additional disciplinary aspects. The former set introduces students to basic elements of the design cycle and to ethics, sustainability, team-working, communication and professional conduct, and is intended to support the Challenges in Year 1 and to build on these skills in Year 2 in preparation for the capstone design project and future careers.

Scenarios

Each department delivers six week-long projects, called Scenarios, across the first and second year; for the Department of Chemical Engineering involving up to 160 students split into 22-27 teams of 5-7 students in each. The Scenarios are focussed around real-world problems facing the specific discipline, and the topic for each Scenario is chosen to reflect the material taught in the regular modules running that term, thus supporting the students' learning and providing an opportunity for them to test out their new knowledge. Within the Department of Chemical Engineering, the problems are also chosen to reflect different aspects of the chemical industries, for instance oil & gas transportation, air separation, separation of biofuels, production of pharmaceutical tablets and design & operation of valves, pumps & compressors, to give the students an awareness of the types of problems they may encounter as practicing engineers.

Students undertake two Scenarios in the second term of Year 1, and two Scenarios per term in Year 2. This has meant reducing the number of traditional teaching weeks from 10 weeks down to 8 weeks, which initially was a great concern amongst colleagues across all departments. However, seeing what the students are able to cover in just five days, whilst inspired by an actually real-world problem, has more than made up for the four lectures lost per module in those two weeks. As an example, I teach Separation Processes involving distillation and absorption, and will, as all my colleagues in other departments teaching the same topic, introduce my students to the concept of column internals and to the pros and cons of random versus structured packing; a subject which generally fails to enthuse my students as much as it does me. However, following a week-long scenario on the design of an air separation unit for the production of nitrogen for a food packaging company, my students were not only concerned about random versus tray packing, but also whether Mellapak 250.X would perhaps be better than Mellapak 250.Y!

The assessment of each scenario varies depending on the problem statement, and involves oral presentations, poster sessions, or videos, as well as written reports of different formats, e.g. newsletters, technical bids etc. The aim is to reflect the aspects of technical presentation and writing the students may encounter later in professional life, and to make them used to considering the audience for their work, be it the Provost of UCL or 17 year old A-level students.

How to Change the World

The final key aspect of the IEP is "*How to Change the World*"; a two-week programme that brings all engineering students together from the various disciplines to address some of the toughest of global problems. It is a specialist element of UCL's Global Citizenship Programme designed to engage our students with global challenges. It is distinctive to UCL and is part of our drive to develop an 'education for

global citizenship' that prepares our students to demonstrate leadership with an awareness of social, ethical and political responsibility; to work with others to change the world for the better; to solve problems through innovative and entrepreneurial thinking, and to prosper in the global employment market.

Each inter-disciplinary team of 5-6 students will work through a structured design process to answer a global challenge sponsored by organisations from third, public and private sectors, such as The UK Department of Energy and Climate Change, Practical Action, The UK Department for Transport, Buffalo Grid, Pump Aid, The Overseas Development Institute among others. The teams have the opportunity to meet members of these organisations and other experts who give them feedback on their ideas and explain to the students how the companies themselves are working towards solutions for such complex challenges. With their help, students find ways to combine their different disciplinary knowledge and skills to produce design concepts that will help to improve the situation with which they have been challenged.

Team working

No engineer would argue the importance of good team working skills – and no academic would argue that it is very difficult indeed to put together good teams of students which allow them all to further develop their team-working and leadership skills, and them all to learn from the technical and computational aspects of the technical problem in question. At UCL, we have yet to find one allocation method which ticks all the desired boxes, and have resolved to allocating groups differently for each Challenge or Scenario. So far, we have allocated according to ability (best six, then the next six etc), by mixed ability based on accumulated academic average, by mixed ability based on previous scenario/challenge performance, randomly and by student choice. Each method has its own benefits and drawbacks, and much work within higher education is devoted to this topic. Interestingly, one of our students made the following comment on allocation by student choice: *"Picking own teams really shouldn't be repeated. Scenarios are one of the few times we get to meet new people on the course which is really enjoyable."*

In our capstone design project in Year 3, we currently allocated by academic ability and find this to be fair, ensuring that no student is disproportionately advantaged or disadvantaged in terms of academic ability. Our only cross-allocation rule is "no gender alone", i.e. all groups either have at least two members of one gender, or only one gender, this in line with our Athena Swan ethos. Where possible, we also try to mix Home students and Overseas students, and students from different ethnical backgrounds.

Team-working generally faces the challenge of uneven work load distribution; either because some team members are lazier than others, or because some find it hard to agree to an even work allocation as they do not feel that the work of their peers is of sufficient quality. We therefore give our students the opportunity to assess the contribution of their peers, and in the Scenarios, 20% of the mark is adjusted based on this peer assessment. Teaching staff do, however, reserve the right to ignore peer marks if these are found to be based on issues other than constructive feedback.

Student Feedback

So what do the customers say? So far we only have feedback from students, as the first full IEP cohorts will not graduate until June'17 (BEng) or June'18 (MEng) so it is too early to say whether we are indeed producing the graduates that industry wants, although industrial partners have been involved since the conception of the IEP and in the development of all its modules. The first batch of IEP students are about to enter their third year of studies, and with that, we will see the real test of the early focus on team-working and communication in terms of how these students will approach and tackle their capstone projects. Some promising feedback from their earlier years:

"I really love [the IEP] as it exposes us to real-life situations."

"I enjoy [the IEP] as it gives you a chance to interact with people across the different engineering disciplines."

(2205 words)