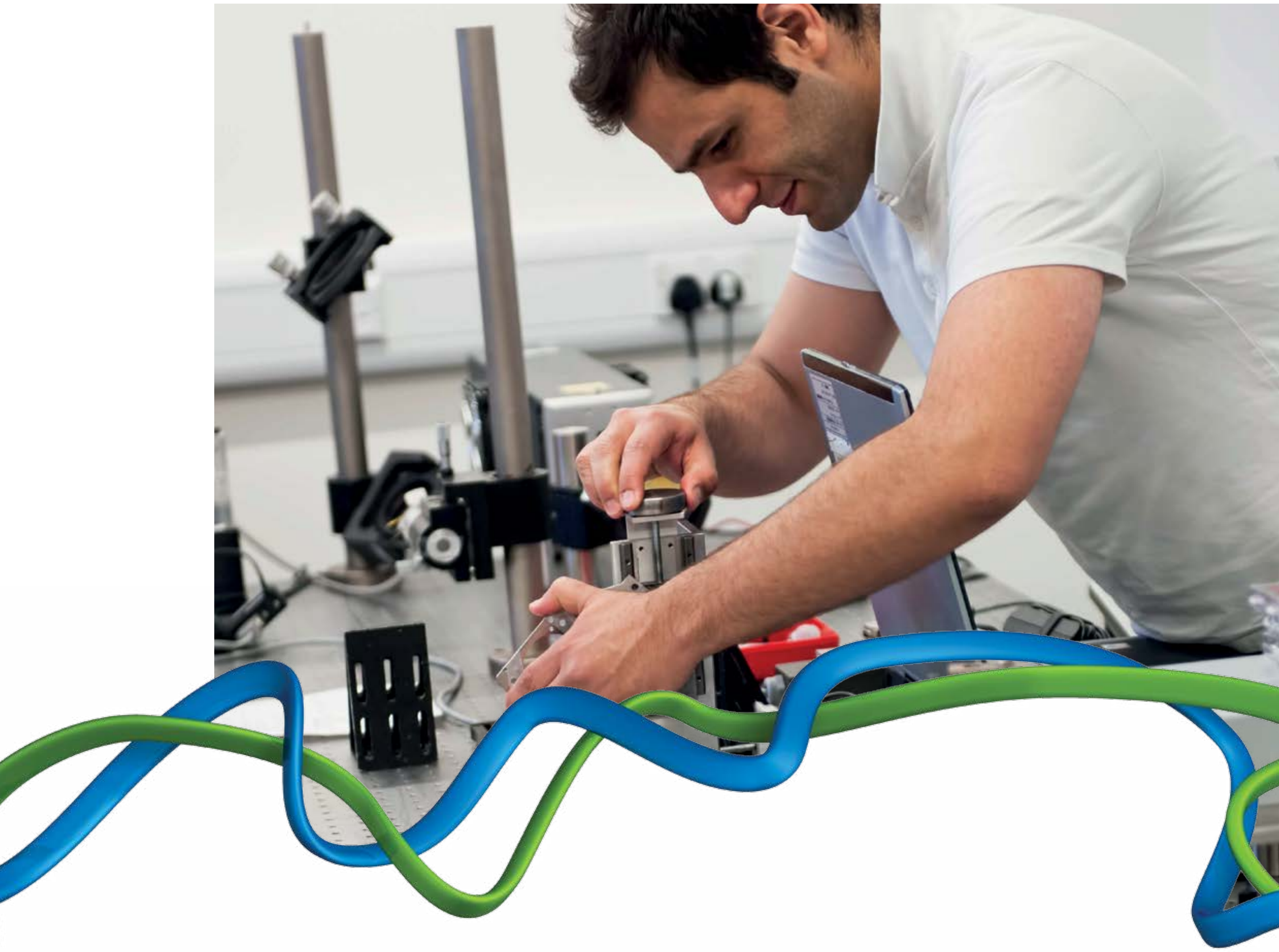

Experience-led learning for engineers

– A good practice guide

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Cover image courtesy of IfM Cambridge

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Contents

Executive summary

The ability to apply theoretical knowledge to real industrial problems is regarded by industry as the single most desirable attribute in new recruits, according to research previously published by the Royal Academy of Engineering.

For some time now, universities have been encouraged to help their students develop the skills and aptitudes that underpin the ability to apply theoretical knowledge in practice. This technique is known as 'experience-led learning', and while the components of experience-led learning are well established, significant challenges remain in implementing experience-led learning in undergraduate courses.

This report focuses on three challenges that teaching staff face in delivering experience-led learning: the tacit nature of many industry-related skills; the social nature of many industry-related skills; and the use of judgement.

Ten principles to implementing experience-led learning in undergraduate curriculums, demonstrate how to overcome these challenges, and suggestions are provided to implement these in the classroom.

The ability to apply theoretical knowledge to real industrial problems is regarded as the single most desirable attribute in new recruits [2].

Image of courtesy of Think Up

Introduction

Four recent reports published by the Royal Academy of Engineering highlight the need to improve the quality and scope of engineering education if we are to meet the demands of students and employers for industry-relevant skills[1-4]. The Academy has consulted widely in industry and academia and has reported the results: the ability to apply theoretical knowledge to real industrial problems is regarded as the single most desirable attribute in new recruits[2].

In practice, getting students to apply theoretical knowledge to real industrial problems requires them to develop the range of industry-related skills listed in **Box 1**. These skills are what the Academy has in recent reports defined as the components of '*Experience-led education*[2]'.

The Academy report *Achieving Excellence in Engineering Education: The ingredients of successful change* acknowledges that the case for engineering education to be experience-led has been made in previous Academy reports and explores how successful and sustainable change has actually been achieved in universities around the world[3]. It concludes that there are significant challenges in achieving sustainable change in engineering education and that the majority of change initiatives revert to the status quo in the years following implementation. In the cases where change initiatives have been sustainably implemented, it is usually because those changes have been widespread, radical and have extended beyond the level of an individual course.

The purpose of this guide is to provide an additional resource for those attempting to implement changes in the engineering curriculum. It outlines some practical, workable suggestions for frontline educators to help them deliver industry-related skills through experience-led education. The first part provides a brief overview of the current state of experience-led education in UK higher education institutions and identifies the key challenges in the development of industry-related skills. The second part sets out ten principles that should be adopted in experience-led teaching and offers practical ideas for doing so. The third part summarises examples of best practice in experience-led education provided by recent Academy reports.

This guide provides many references to online materials. If reading this document on a screen, please follow the hyperlinks in the text, otherwise please find the web references in the table of resources. If you are reading a printed version of this document then you can find the web addresses in the table of resources.

Box 1 – Industry-related skills

Getting students to apply theoretical knowledge to real industrial problems requires them to develop a range of industry-related skills, such as the ability to:

- Think critically
- Work across cultures and contexts
- Be creative
- Innovate
- Solve problems
- Use information technology to interrelate and communicate
- Self-manage
- Work in teams
- Understand business and customer needs

"

Experience-led education[2]

The term 'experience-led' is used to describe components of an engineering degree that develop industry-related skills".

Current practice in experience-led learning

Accredited undergraduate engineering programmes are required under the Engineering Council's UK Standard for Professional Education Competence (UK SPEC) to ensure that graduates have industry-related skills[5]. While the UK SPEC is focused on learning outcomes, nothing significant is said about how particular outcomes should or could be achieved or demonstrated.

Professional engineering institutions are responsible for the accreditation of programmes on behalf of the Engineering Council and provide further guidance to higher education institutions with more detail to cover the engineering field for which they are responsible. Here again, professional institutions focus primarily on specifying outcomes, although in some cases guidance is given about how the outcomes might be achieved. On the whole, it is left to the universities to decide on curricula and educational techniques to achieve the required learning outcomes.

From a number of case study universities, the repot *Engineering Graduates for Industry* [2] identified the activities listed in **Table 1** as effective in developing industry-relevant skills.

Industrial placement year (sandwich courses)	Direct student experience
Other industrial work opportunities	
Relevant employment for part-time students	
Relevant student-led activity	
Industrial simulation (such as Constructionarium and process demonstration rigs)	Indirect student experience
Project-based learning and other forms of active learning	
Industrial group projects, design projects, multidisciplinary projects	
Case studies from industry	
Influence of part-time and mature students on full-time students	
Site visits and field trips	
Entry to national and international competitions	
Student involvement with professional institutions	

Table 1
Activities that have been identified as being effective in developing industry-related skills, listed from most effective to least effective.

While a number of examples of good practice have previously been reported by the Academy, the amount, quality and effectiveness of these sorts of activities are variable across programmes and institutions.

Having observed the execution of these sorts of activities in a great number of contexts, it is the authors' view that this variability in quality and effectiveness is a result of three challenges faced by teaching staff.

Mike Lehmann/Wikimedia Commons

The Millau Viaduct

Designed by Lord Norman Foster and Michel Virlogeux FREng, it is the highest bridge in the world at 343 meters, creating a direct route between Paris and the Mediterranean coast.

Challenge 1 – The tacit nature of many industry-related skills

Much of an engineer's education is focused on developing explicit skills and knowledge. In contrast, many industry-related skills are tacit. This distinction is important because the ways that tacit knowledge and skills are developed are quite different to the ways that explicit knowledge and skills are developed.

Even when the educators demonstrate tacit skills themselves (for example the skill of having an idea) they struggle to explain what they are doing in a way that helps the students. The first challenge, therefore, is to enable lecturers to help their students develop these tacit skills.

Challenge 2 – The social nature of many industry-related skills

Many industry-related skills are social in character, depending on the interaction between people. The development of management skills requires someone to manage and someone to be managed; developing presentation skills requires a range of appropriate audiences.

Not surprisingly, self-awareness, self-control, empathy, cultural sensitivity, an understanding of human psychology and the ability to adapt behaviour are all important in developing those industry-related skills with a social dimension. Although there are some notable exceptions, it is probably fair to say that the typical engineering academic does not feel very qualified or comfortable dealing with this sort of material in their teaching.

The second challenge then is to help student engineers to develop the social skills necessary to meet the challenges of life in practice.

Challenge 3 – Developing judgement based on broad, partial and subjective evidence

Judgement is the evaluation of evidence to make a decision, and plays a critical part in the key industry-related skills of design and problem-solving.

Engineering education is generally focused on helping students to develop the skills associated with asking and answering apparently objective questions based on narrow, complete and unambiguous criteria. For example, "What is the maximum bending moment in the simply supported beam under a uniformly distributed load?"

In industry (and in life), the ability to make judgements based on broad, partial and often subjective evidence is critical. On the whole, when industry talks about the importance of judgement, this is the sort of judgement to which it refers.

The third challenge then is to help student engineers to develop judgement skills.

Definition

Tacit knowledge: knowledge that we have but may not be able to describe in any detail. For example, how to ride a bike.

Explicit knowledge: knowledge that can be easily articulated, codified and stored as information. For example, how to recognise and solve a quadratic equation.

An objective question: a question where competent, well intentioned individuals acting diligently will get the same answer.

A subjective question: a question where competent, well-intentioned individuals acting diligently may get different answers.

Ten principles for delivering experience-led learning in the classroom

This section provides ten principles that help teaching staff overcome the three previously described challenges they face in consistently delivering effective experience-led learning.

1. Use an appropriate learning model
2. Find out what motivates the student and use it
3. Explain why it matters
4. Make the tacit explicit
5. Find out what they already know and build on it
6. Use role-play
7. Use project-based learning
8. Help students develop well-organised bodies of knowledge
9. Use formative assessment
10. Create classroom values that resemble workplace values

Principle one

Use an appropriate learning model

It is important to understand and use an appropriate pedagogical framework for teaching. Doing so helps define a set of consistent and appropriate suggestions for teaching, and enables teaching staff to build on these suggestions themselves. Research shows that for teaching to lead to effective learning, the learning model chosen should: draw out and work with existing understanding; teach for depth of understanding; and teach meta-cognitive skills – the ability to understand, control and manipulate thinking processes.

Drawing on the authors' experience and the work of others [6,7], it could be suggested that the most appropriate learning model for delivering experience-led learning consistent with these three requirements is that developed by engineers at Vanderbilt, Northwestern, Texas and Harvard Universities (including Manchester Institute of Technology). Known as the VaNTH approach, it draws on the book *'How People Learn: Brain, Mind, Experience and School*[8]'. A useful summary of the VaNTH approach is provided by Professor Peter Goodhew FREng in his book *Teaching Engineering*[9].

A key set of ideas in the VaNTH approach is that instruction (or learning) has to be:

› knowledge centred (some facts are needed)
› student centred (it has to start from where the students are)
› assessment centred (everyone needs feedback on how they are progressing)
› community centred (learners need to feel that they are entering a community of practitioners – for example the nuclear decommissioning industry).

In practice

› Using this guide – This guide is intended to suggest practical ways to apply the pedagogical model outlined above. However, while the VaNTH approach has been used as the basis for these recommendations, many of the suggestions will be appropriate to support other models of learning. The key is to be clear about the requirements of the approach and to check that the teaching techniques being used meet those requirements.
› Know where you sit – A good starting point for thinking about how different learning models work is Richard Felder's paper *Engineering education: A tale of two paradigms*[10]. He starts by describing two paradigms in engineering teaching: the more traditional approach based on a positivist understanding of knowledge and an emerging approach based on a constructivist understanding of knowledge. He then contrasts the position of these conflicting paradigms on the issues of how to structure a curriculum, how to assess student work, who should teach, and how staff should be prepared for teaching.

Principle two

Find out what motivates the student and use it

Classroom activities should be designed with student motivation in mind. Motivation affects the amount of time we are prepared to spend on a task. Human beings are motivated to solve problems and develop competence. We are motivated by challenges, but the challenge must not be too easy or it becomes boring and demotivating. Nor should the challenge be too difficult or it becomes frustrating and we give up. As **Box 2** illustrates, students are motivated by a wide range of factors, all of which can inform the design of engaging learning activities.

Considering student motivation obviously has clear benefits for developing any classroom intervention. However, explicitly talking about motivation may also help students to develop the social skills needed for effective professional practice. Developing the right motivational conditions is important for establishing a learner-centred environment, focusing on where the student is starting from. It also helps in the creation of an assessment-centred learning environment where many students get distracted by grades and don't see the benefit of critical feedback.

In practice

In his book, *Drive – the surprising truth about what motivates us*, Daniel Pink describes the limits to traditional carrot-and-stick methods of motivating individuals to action, and points instead to evidence that suggests the power of intrinsic motivation [11]. Intrinsically motivated learners – students who are self-directed, who are committed to self improvement, and to working towards something that matters – are arguably more likely to demonstrate more of the qualities that industry seeks in its graduate employees. The following in-practice suggestions build on Pink's three 'nutrients' ifor developing intrinsic motivation: purpose, mastery and autonomy.

- What's the point? – One of the key drivers for intrinsic motivation is purpose. In all that we are trying to achieve in experience-led learning, we should be clear about the purpose. Here are some additional suggestions for classroom implementation:
    - Why do I need industry-related skills? – use case studies, for example from the lunar landings, or from the design and production or famous nuclear accidents, to show the greater importance of industry-related skills.
    - See for yourself – where possible, send students to observe engineers at work, and get them to identify the skills that are needed for effective practice. Workplace contexts could include a design office, a production line, a client meeting, consumer testing or a research lab, as appropriate.
    - What drives others – encourage students to find out what has driven other successful engineers. The video archive at Raeng.tv is a good starting point for a search.
    - Mock interview – ask an employer to give students a mock interview in which the importance of industry-related skills is emphasised (see suggestions for how to do this under Principle three).

Image courtesy of IfM Cambridge

- Getting better – many people are motivated by getting better and better at a particular skill. Rather than teaching industry-related skills as a one-off module, these skills should be embedded throughout the course. Ways to do this include:
  - Run an annual peer-to-peer review – ask students to buddy up and review each other's development against a matrix of competencies.
  - Encourage students to enter skills competitions – in skill mastery, failure is as important as success. Regular competitions can help individuals develop their skills and get regular feedback. For more information on competitions, see Principle six.
  - Demonstrate progress – it's easy to forget where you come from. For example, an unconfident presenter may not think they are making any progress, but if they are shown at the end of a course a video that they made of themselves presenting at the start, they may well be surprised and motivated by the progress that they have made.
- Go it alone – giving people the chance to be the masters of their own destiny can significantly help to motivate them. Many of the ideas in this report enable student-led learning. Here is a summary of some of the key techniques that could help motivate students by giving them autonomy.
  - What do I learn? – industry doesn't want walking encyclopaedias; it wants people who can apply technical knowledge in practical scenarios[1]. What students learn is therefore much less important than their ability to find out the relevant information, and their ability to develop appropriate skills. Letting students have a greater say over what they learn for example, by asking them to identify what an engineer ought to know about corrosion is an easy way to give them autonomy, and therefore to help them keep motivated.
  - How do I learn? – students should be given the chance to try out a range of learning styles so that they can quickly identify how best they learn and then use that approach. Proponents of a more student-led learning model suggest that as long as students have the opportunity to spend some time learning in a style that suits them, they will develop the confidence that they need to work when the style does not necessarily suit them [10].
  - When do I learn? – with a student-led approach, students can have much more autonomy over when they learn as much of the information they need is available online. While contact time with teaching staff is more limited, universities are making increasing use of virtual learning environments to make access to teachers more flexible.

Box 2 - What motivates students?
According to informal polling of first year engineering undergraduate students by the authors, students are motivated to learn by a number and a blend of factors including:
- The enjoyment of being able to solve tough (usually closed) technical problems.
- The desire to be able to make impressive things (buildings, space rockets, fast cars and so on).
- The desire to make a positive difference to the world by, for example, coming up with a cost-effective renewable energy system or designing water recycling systems.
- The desire to become a professional with status and financial security.
- The desire to outperform other students or in team working other teams of students.

Principle three

Explain why it matters

People learn better when they understand the importance of what they are learning. Many students may doubt or be unaware of the importance of developing industry-related skills. School experience of science and maths, which is usually focused on the solution of closed problems or development of theories, does not shed much light on the work of the engineer in practice, which is focused far more on design, manufacture and operation.

Understanding the importance of industry-related skills is therefore an important precursor to dealing with the three challenges that experience-led learning presents. It is consistent with a student-centred learning environment – starting with the student's beliefs about what is important. It is also consistent with a community-centred learning environment, helping them to understand the community of professional practice that they are entering and its needs.

In practice

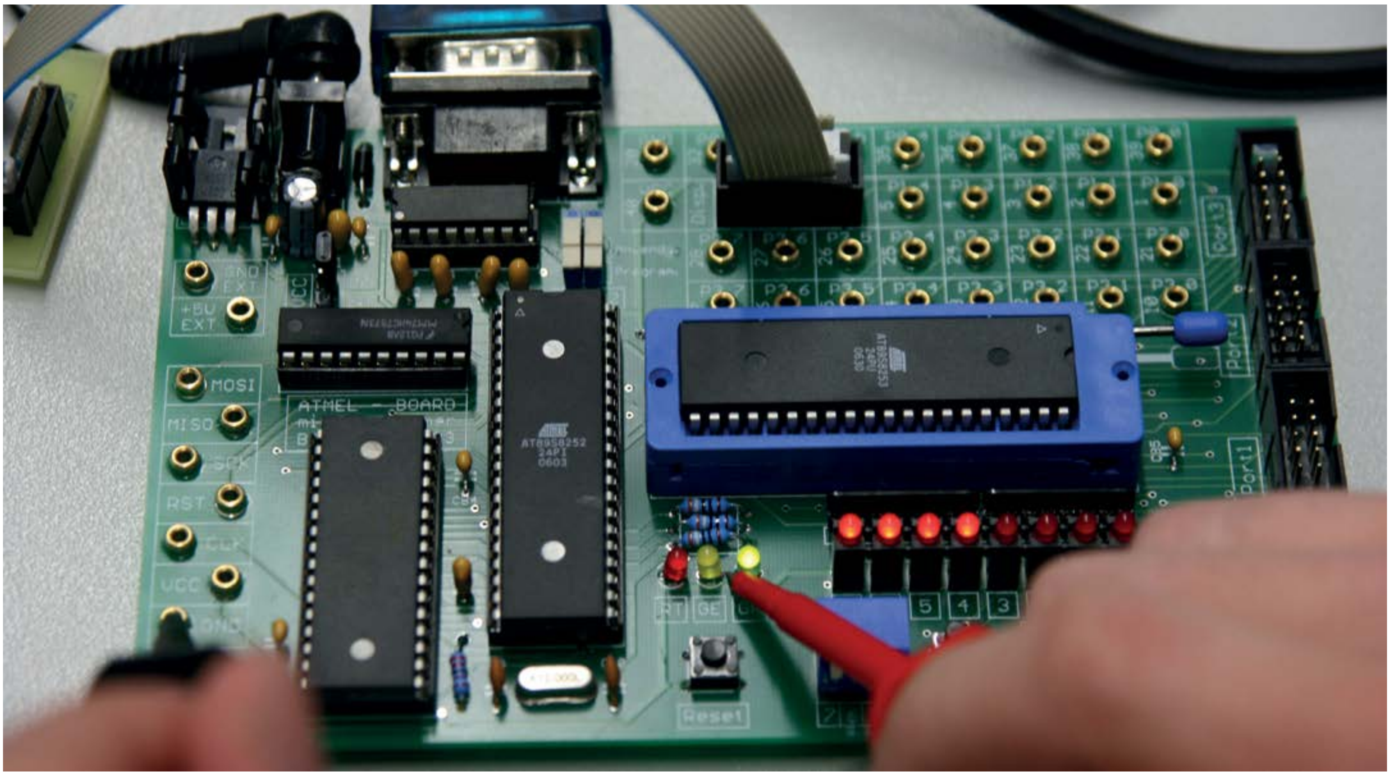
› What do your students think is important – simply asking your class of students what skills they think employers want in engineering graduates is a good way to identify for themselves the importance of industry-related skills.

› Use professional competencies – the list of professional competencies for chartership provides a useful set of skills that engineers need to adopt, as well as a description of what level people at the start of their careers (in other words students) should demonstrate. Use the Engineering Council's UK-SPEC for reference.

› Relate skills to project processes – talk students through the stages of an engineering project, from start to finish, and highlight the industry-related skills as well as the technical skills that are needed at every stage. The exercise should illustrate that the former can be as important as the latter.

› Tell the story of real projects – use examples of real projects to illustrate how industry-related skills have been critical to the success of an engineering project. Invite senior engineers from the project to tell the story from their perspective in order to increase the impact on students. For example, the critical factor for the jury in the design competition for the London 2012 Olympic Velodrome was not the technical expertise of the design team, which in these circumstances is taken as a given. The critical factor was the design team's ability to understand the needs of the user and to develop a powerful vision for the project, both of which require the ability to think critically, to work across cultures and contexts, to be creative, to innovate, to solve problems, to work in teams and to understand business and customer needs.

› Watch more TV – reality TV programmes are a great way to help students identify and understand the value of soft skills and emotional intelligence. Talking about film characters and action heroes could be a fun way to think about personality traits and behaviours: why, using the Myers-Briggs Type Indicator, is James Bond ESTP (Extraverted Sensing Thinking Perceiving) and Jason Bourne INTP (introversion, intuition, thinking, perceiving)?



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- Job interview – get students thinking about what they are going to learn at university by jumping forwards a few years to a graduate job interview and asking them the question 'what did you learn on your degree that is going to make you a valuable part of our business?'. The implication of this sort of question is that one day students will have to account for themselves and what they can offer, and so they should think about what skills it would be useful for them to develop. The impact of asking this question can be increased if it is asked by a representative from industry who comes into the classroom.

Principle four

Make the tacit explicit

As we have already identified at the beginning of this report, many industry-related skills are tacit. According to Edward de Bono[14], important tacit skills, such as how to have an idea, can be developed by making the 'tacit explicit', in other words by seeking to break the process down into its basic steps. The principle goes that as students become familiar with these steps, they will no longer have to think about them explicitly, and so the skills gradually become more tacit.

Of course there are other ways of developing tacit skills, but arguably this approach lends itself well to structured learning. There is great deal of online material that can be used to help students explicitly break down industry-related skills into their component parts – some good starting points are listed below. As this process of making the tacit explicit takes time, it should be implemented early on in the curriculum.

In practice

- Use online resources – there is a wealth of online material available to help students understand the basic concepts behind a range of industry-related skills. Here are a few suggested starting points:
  - Thinking skills – for an in-depth introduction to thinking skills, see the free resources and suggested activities provided by the Open University in its unit *Extending your Thinking Skills.*
  - Interpersonal skills – SkillsYouNeed is an online service providing a range of useful resources to help people develop professional skills, including verbal and non-verbal communication, listening, negotiation, problem-solving, decision-making, assertiveness, and team – and group-working.

    Further in-depth resources on interpersonal skills are also available from the Open University in its unit *The Importance of Interpersonal Skills* and similarly from Microsoft.
  - Learning Skills – the *Learning How To Learn* unit from the Open University, free through its OpenLearn portal, could form the basis of a student-led exploration of individual learning styles. And for the lecturer, MIT's Teaching and Learning Laboratory has produced a free-to-access refresher for teachers on techniques for learning. It is called Guidelines for Teaching @MIT and Beyond.
- Create a starter pack – ask students to work in groups to collate the best introductory resources they can find online and compile them in a shared folder. This can form a resource that future classes can build on, and which can be updated as new material becomes more appealing to the learners – reinforcing a learner-centred and community-centred environment. Students may also be able to add resources that they already use, supporting the principle of building on what they already know – we look at this next, in Principle five.

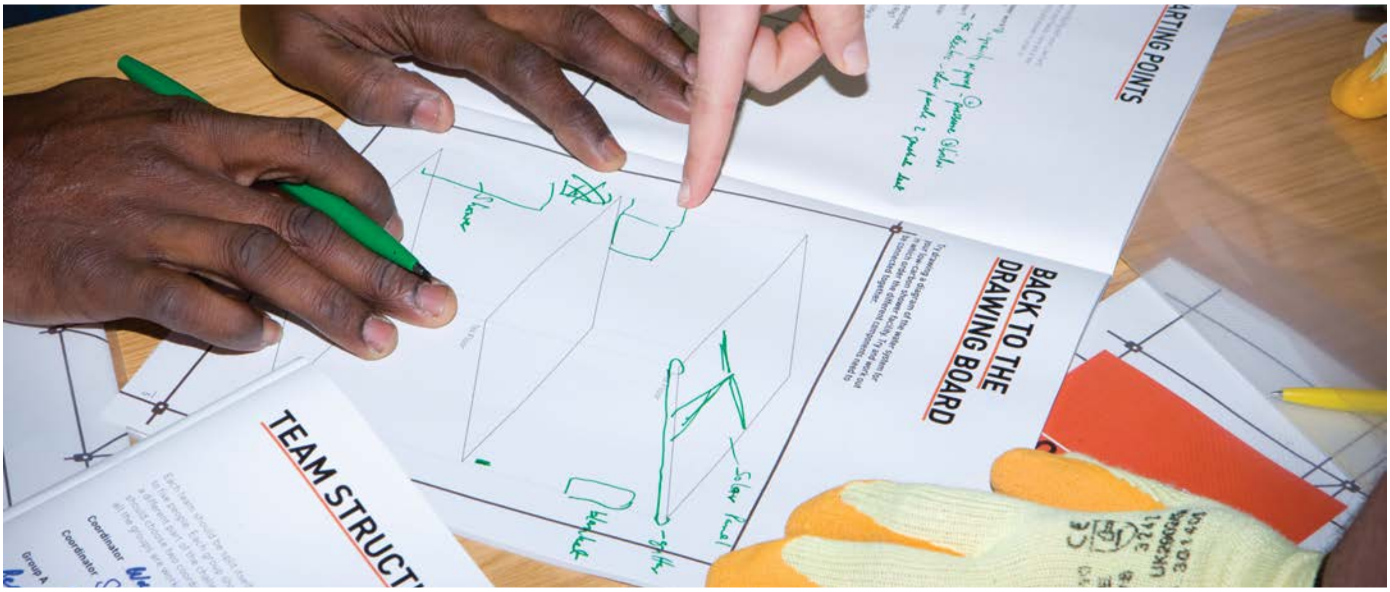


Image courtesy of Think Up

- Talk about communication – Here is an illustration of running a collaborative classroom exercise that makes the tacit process of good communication explicit. Find video clips that show two people negotiating, for example from a reality TV show. Then ask the class to break down the process into its constituent parts – how was body language used, what tone was used, what sort of vocabulary? Students can use their own understanding of communication skills to suggest improvements to the way the parties in the negotiation could have behaved. Having made the tacit explicit in this way, students can then re-enact the scene but using their newfound understanding to cause a different outcome.
- Learn the lingo – the domain of industry-related skills is rich with jargon. Help students quickly assimilate the vocabulary by asking them to observe each other working in groups to solve a practical problem. Before the activity starts, students should assemble a glossary of terms that they have come across during their introductory studies of interpersonal skills. The task of the observers is then to note down when a particular word from the glossary is useful to describe the activity that they have observed.
- Read Carnegie and Pink – the self-help aisles at bookshops are a rich source of easy-to-access introductory material on industry-related skills. The selection can be overwhelming, but two standout as good introductions:
  - *How to Win Friends and Influence People* – Dale Carnegie's text on human relationships in the workplace has remained popular ever since it was published in 1936. Its bitesized chunks lend themselves well to quick reference and revision.
  - *To Sell is Human – the surprising truth about moving others* – A good read for lecturers and students, Daniel H. Pink picks up the baton from Carnegie and updates the vision of how to influence people for the 21st-century knowledge worker – the engineers of the future.

Principle five

Find out what they already know and build on it

Successful engineers combine project experience and life experience to inform their practice and develop their professional skills. This approach is well suited to the classroom because research shows that it is easier to assimilate and remember information if it can be related to something we already know [15]. Educators should find ways at the start of teaching a new topic to discover what students think about that topic and to give them the opportunity to discuss misconceptions.

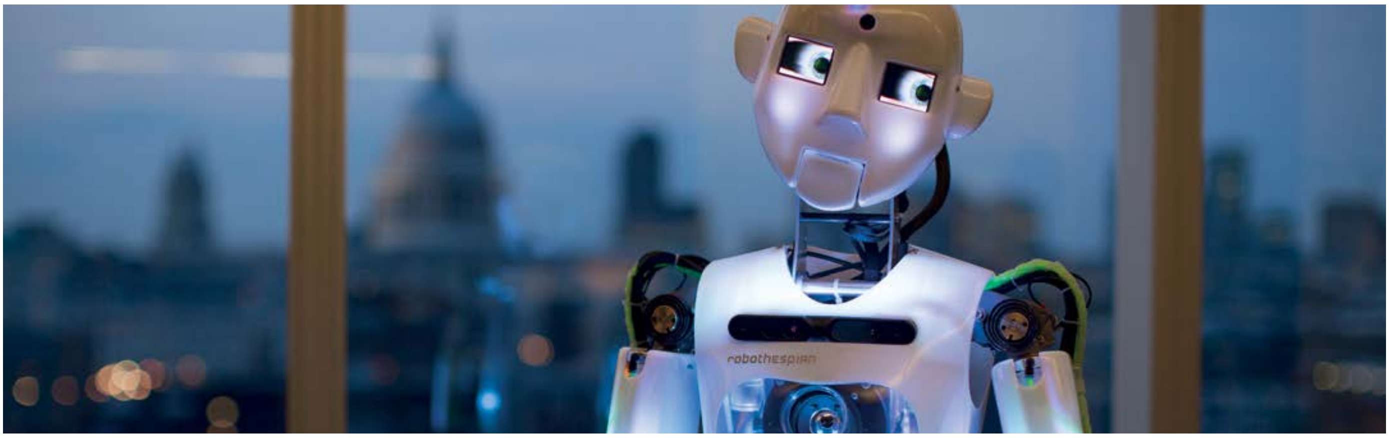
Building on what students already know helps to address the challenge of developing tacit and social skills by looking for and validating examples of where students already demonstrate these skills in other contexts. This principle is also an essential part of creating a learner-centred teaching environment, taking into account what students already know, as well as creating a community-centred teaching environment in which the validation of existing knowledge is considered the norm.

In practice

- Use of interactive classroom technology – one of the challenges that teaching staff face is finding out what students already know when class sizes can number over a hundred. Fortunately there are some computer tools to help.
  - Clickers – this is a classroom technology that allows teaching staff to manage an interactive classroom discussion involving every student. There are a range of clicker technologies on the market. At their most simple, each student uses a handheld device to answer multiple-choice questions posed by the teacher. Individual answers are transmitted by radio to the front of the class and the answers can be displayed using a data projector.

    Dr Stella Pytharouli uses clickers in the engineering department at the University of Strathclyde. In one exercise, the class is told that they will be asked a series of multiple-choice questions relating to teaching matter that they must all agree on. If they are unanimous – and correct – then the class wins a prize. The class gets three chances to answer each question using their clickers. Each time, the results are projected at the front of the class. Whenever the class doesn't agree on an answer, which is almost always, she starts a debate on the topic without revealing the right answer. According to Dr. Pytharouli, the whole group discussion would be to unwieldy to manage without clickers.
  - Textwall – is a web page that learners can send text messages to. The message can then be shown on a projector or an interactive white board for the audience to see. The messages can appear in real time, and can be screened for inappropriate language or blacklisted phone numbers. The messages can be used to create typographic displays (such as a 'wordle'). Students can be notified by RSS feed of updates to the text wall once they have left the classroom. The textwall can be archived for later reference.
  - Google Docs – this collection of online tools from Google provides endless possibilities for student collaboration. Google Forms can be used to create online quizzes, the results of which can be collated in a Google Spreadsheet and displayed on an interactive board. For more suggestions see *'21 Interesting Ways to use Google Docs in the Classroom'*.

- Validate student knowledge from day one – students arrive at university with a wealth of knowledge based on their experience of growing up and what they have learned at school. Run a half-day freshers' week exercise in which students



Robothespian, a life-sized, talking robot.
Image courtesy QEPrize/Jason Alden

work in groups to write down what they know already about engineering disciplines and processes. Ask students to then think about what they don't know, and what it would be useful to learn in their degree. Break the session up into sections related to engineering themes, and ask representatives from each group to present their findings to everyone else.

› Begin each new module by asking what students already know – in a variation of the freshers' week exercise above, begin each new module by asking students what they know about the topic area, and to identify what they need to find out. Two ways to collate and record this information are suggested below:

  » Blog about what you know – students could be asked at the start of each module to write an entry on a class blog or personal blog about what they know about a new topic, and what they would like to find out. During the module, they can be asked to look back at this post and see if they are indeed learning what they wanted to. Educators can read the blog posts of their students and modify course content accordingly. For more guidance on using blogging in education, refer to the Royal Academy of Engineering's report, *The development of e-learning resources – a best practice guide*.

  » Create a class wiki for each new teaching module – a wiki is highly flexible way for groups of people to organise information online. Wikipedia is the most famous example. At the start of a new teaching module, challenge the class to write down what they already know about the topic in a dedicated wiki. In practice, the class would need to agree broad headings for the pages of the wiki, and then in a first round of activity, groups would need to start working on filling in the pages on individual headings. In a second round of activity, students could then go round and see if there are any gaps in the other pages that they can fill in themselves. The educator can monitor activity on the wiki, and use information clashes to prompt discussion. As the course progresses, students can add additional information to any of the pages as they come across it during their studies. As well as helping to establish existing knowledge, this process helps to support community-centred learning and creates a learning resource that they can refer back to later in their studies. For more guidance on using wikis in education, refer to the Royal Academy of Engineering's report, *The development of e-learning resources – a best practice guide*.

› Careful use of questioning – finding out what a class already knows about a topic can be achieved using a carefully constructed question-and-answer session with the whole student group. In his paper, *'Using Questions to Enhance Student Engagement'*, Stephen J. Ressler sets out a series of rules for effective use of questioning in the classroom. "Questions aimed at the lowest three levels of Bloom's Taxonomy can be highly effective for fostering student engagement, reinforcing basic-level concepts and maintaining a dynamic, active classroom environment." [16]

  Taking this advice, teachers can structure a series of simple questions to draw out existing knowledge in an inclusive, confidence-building environment. Ressler also notes three prerequisites for effective use of this technique: knowing students' names, knowing something of their personality, and being prepared to take a risk.

Box 3 - Introducing a new module
To establish what his students at University College London already know about structural engineering, Professor Chris Wise challenges them to find a way to suspend an art gallery ten metres over the ground on the side of a hill, modelling their structure using length of drainage pipe and gaffer tape. The exercise is a fun and informative introduction to the module.

Principle six

Use role-play

Role-play allows students to assume real-world roles and to interact with other students taking on roles in a particular scenario. Assuming a role in a scenario provides an opportunity for testing and rehearsing the kinds of behaviours expected in a particular role in industry. Indeed, industrial simulation role-play has already been identified in the introduction to this report as one of the most effective ways of helping students develop industry-related skills.

Of course, role-play is not new in engineering education. The week-long design exercises that are commonplace in undergraduate courses are forms of role-play, even if they are not considered as such by teaching staff. Arguably, the delivery of experience-led education can be enhanced by more extensive use of role-play in areas where it is not currently being deployed, and more effective use of role-play where it is.

Use of role-play supports the development of tacit skills as it encourages students to think explicitly about how to adopt particular behaviours. Being inherently social in character, role-play helps students develop self-awareness, empathy, cultural sensitivity, and the ability to adopt appropriate behaviour. Role-play also provides contexts within which students can use judgement.

For an excellent and concise review of the principles of good role-play facilitation in the classroom, see *Learning by Doing*[17] , a guide to teaching and learning methods, available online, and the guidance from the 'businessballs' website.

In practice

› Get the basics right – here are some rules:
  1. Be clear about the objectives for the role-play – what do you want to help them learn. Discuss the objectives, expectations and responsibilities beforehand with the students.
  2. Choose the location carefully – running a role-play in a tiered lecture theatre is difficult as the role-players can feel under pressure to perform as if they were on a stage. As far as possible, create an environment that mirrors the real-life setting for your scenario.
  3. Choose or write a role-play.
  4. Run the role-play (preferably having first checked it through with a colleague) and be clear about when it will end and how you will control the ending.
  5. Debrief the role-play – this means holding a session that is sufficiently structured to allow the students to reflect on what they have learned and draw out any new perceptions, knowledge or understanding.
  6. Role-play the entire design and client team – it is common for engineering students to be asked to play the role of the professional engineer. To help students understand the range of interactions they will have to deal with more fully, extend role-play to incorporate roles on the wider design team and client team. This will help students learn about the perspectives of these other stakeholders.

› Role-play with students from other disciplines – building on the previous suggestion, undertaking interdisciplinary role-play, for example between civil engineers and mechanical engineers, will further enhance understanding of other people's perspectives.

Images courtesy of Cogent

- The break-out role-play – in this variation on a traditional role play, a facilitator stops the action at regular intervals to review what people are saying and to ask how the dialogue could have gone differently. It adds a meta-cognitive angle to role-play, and allows an audience to be actively involved.
- Making role-play more real – role-play is common in some teaching scenarios; however, making the role-play more intense could help sharpen many of those skills that industry desires. Here are some suggestions for how to do so:
  - Method acting – ask a student to take on a role for more than just a class. Ask the student to imagine he or she is walking in the shoes of their role for a week. As well as being fun, this exercise emphasises the differences of perspective that students will have to deal with. For ten years, this deep-immersion approach has underpinned the Constructionarium, the week-long learning scenario in which undergraduate civil engineers use real construction materials and methods to build scale models of real engineering projects. More recently this same approach was deployed to create the Nuclear Island Big Rig (see **Box 4**).
  - Using local projects – students are stakeholders in many projects, be it with respect to a medical trial, a new phone technology, or a traffic realignment. By setting role-play activities in the context of projects in which students have a stake, the learners can draw upon real feelings rather than having to make them up, increasing the reality of the situation.
  - Real stakeholders – invite members of the public to take part in role-play in relation to a local project. Dealing with a real person adds an additional unknown for the student, and helps them prepare for dealing with members of the public in their workplace.
- Introduce competition – some of the most highly regarded and high-impact role-play scenarios in engineering education involve competition between teams of students. Competitions such as Formula Student, in which international teams of students design, build and race single-seat racing cars, create a high-octane learning and working environment for practising industry-related skills in a highly realistic context. For a list of other competitions for engineering students, refer to the resources section at the back of this report.

  There are a number of keys to the success of an event such as this. The first key is maintaining the right level of pressure: students are given tight deadlines, and yet they are being asked to make decisions. If they make the wrong call, this may mean they can't complete the project. The second key is reality: using real tools and processes and being presented with real problems helps students become better prepared to applying theory in practice.

Box 4 - Nuclear Island Big Rig
Deep immersion role-play for mechanical, electrical and chemical engineers

At the Nuclear Island Big Rig, undergraduate engineers spend five days taking on the role of contractors responsible for installing a nuclear reactor. The event is designed to simulate working under nuclear conditions at a nuclear new-build site. Students work on a scaled-down mock-up of the primary cooling circuit of a pressurised water reactor, mounted within a two-storey steel structure. Given a set of system diagrams, students must design an installation programme, assemble the reactor components, and then commission the completed system.

Principle seven

Use project-based learning

Before engineers can apply theoretical knowledge in practice, they must first be able to understand the context and correctly frame the problem. Problem-based learning (PBL) is commonplace in undergraduate teaching. Using PBL, lecturers pose a question, provide supporting resources and facilitate the problem-solving process. The trouble with PBL is that it misses out the critical step of training students to define the problem in the first place.

Project-based learning (PjBL), described in detail below, goes one step further than PBL by including problem definition. PjBL is student-led, and requires students to develop skills such as team working, critical thinking, listening to others and presenting ideas clearly. While these industry-related skills are brought to the fore, students will still need to understand the technicalities of the subject matter in order to be able to develop effective solutions to the problems that they have defined for themselves.

PjBL is far less common than PBL, possibly because the educator has less control over the learning outcomes of the activity. Nevertheless, the authors believe that PjBL aligns so closely with how engineers work in practice that they strongly recommend its use to support the development of industry-related skills.

In practice

Here, the example of an undergraduate investigation into the origins of structural failure in bridges is used to illustrate in practice John Larmer and John Mergendoller's Gold *Standard PBL: Essential Project Design Elements*[18]

1. Challenging problem or question – the project should be anchored around an important challenge or question defined by the educator. It is within this broader challenge that students set their own question (see 'student voice and choice' below). The solution to the problem should require substantial thought and be anchored around the key topics that the educator wishes to cover. Carrying out the work in a challenging context can be a good motivator for students as long as the problem isn't too difficult. It also brings meaning to the learning: they are learning for a reason.

   In the above example to motivate learning around the topic of structural design of bridges, the challenge question could be "how can we reduce structural failure in bridges?"

2. Sustained inquiry – the project should provoke sustained questioning and investigation rather than arrival at a quick answer. Questions lead to answers that lead to more questions. At the early stages in the project, the student doesn't know what specific question they are going to focus on; this is the time for exploring the possible solution space.

   In the example, students could begin their search by asking questions about the different bridge typologies, how they transfer load, their construction methods and their materials. As they work through the project they will keep asking questions that they can come back to later as possible directions for future investigation.

3. Authenticity – PjBL goes beyond students deciding to learn because the teacher tells them to: the authenticity of the project compels the students to learn because

they see the importance of what they are doing. That feeling of authenticity can be developed by anchoring the project around real processes, and outcomes that have a real impact on people or that have a real impact on the learner.

Authenticity in the structural engineering example could be derived by giving students access to real engineering assessments of bridge collapse, or they could go on an inspection of a real bridge. The impact of structural failure could be reinforced by encouraging students to investigate the impact on communities of bridge failure. To underline personal relevance, students could focus their study on a bridge that they use regularly.

4. Student voice and choice – the more choice the students have in what they are doing, the more they are likely to feel that they are doing the project for their own reasons. During the project, students should define their own question that they will solve as part of the broader challenge for the project. This question should emerge from the on going investigation that they are carrying out around the topic and should allow them to focus their activities. Students should also decide what the outputs will be for their project will be.

   For example, students investigating structural failure in bridges might become interested in retrofitting bridges and so might set themselves the challenge of finding an economically viable way to retrofit reinforced concrete highway bridges to increase their resistance to corrosion from de-icing salts. The outcome could be a technical report, or it could be a mocked-up cross-section of a bridge to demonstrate their approach at a trade show.

5. Reflection – it is critical that students learn from reflecting on their experiences as they work through the project. They should reflect on the knowledge they are developing, the skills they are learning and the direction their project is taking. Reflection can be informal and self-led or more formal and formative at key check points. In the experience of the authors, developing this habit of reflection takes time and regular encouragement.

   In the example, students might be encouraged to keep a learning journal, but also asked to submit more formal reflections after a field trip or following a presentation of outputs to community stakeholders.

6. Critique and revision – one of the aims of PjBL is to achieve high-quality outputs through regular feedback. Educators should provide students with guidance on how to give effective feedback. Feedback from external parties, for example from practising engineers, can increase authenticity, quality of outputs and provide balance.

   In the example, educators could help students set up a client group for their project with, for instance, representatives from the Highways Agency who would be well placed to critically review their proposals for bridge retrofit.

7. Public product – The project should lead to what Larmer and Mergendoller refer to as a ‘public product’, an output that people outside the close community of learners and educators can engage with. As they explain, a public product has three benefits: motivation to raise the quality of outputs; the creation of a focus point for discussion with other learners, helping to build their community of learning; and awareness raising of this teaching approach.

   The public products from the student investigations in this example could include anything from an app-based check list to help asset managers to identify potential failure before they are too late, or a device for listening to bridges to identify the sounds of wear and tear to a physical mock-up of a way to retrofit additional strengthening members to bridges.

For a survey of recent best practice in PjBL see *UK Approaches to Project-Based Learning by Ruth Graham*[12].

Principle eight

Help students develop well-organised bodies of knowledge

High levels of activity and involvement are not guarantees that students are developing transferable understanding. The key to developing this is to create a knowledge-centred learning environment in which students develop well-organised bodies of knowledge, where they understand how different ideas interrelate and the applicability of different concepts.

Helping students organise their knowledge can help overcome the challenge of developing tacit industry-related skills by being explicit about their application. This principle also addresses the challenge of developing judgement as organising knowledge can help students build interconnections between different subject areas and thereby develop stronger arguments to support their case.

In practice

› Identify misconceptions – knowledge-centred environments encourage students to make sense of what is being taught. Identifying what students know about a topic, some of which may be firmly held but inaccurate, enables the student to correct their misconceptions or build on existing knowledge. The process needs to take place in a gradual, but structured manner. The educator needs to be clear what is being taught, why it is being taught and know what competent performance looks like.

  A simple example of this approach in action is Martin Gillie and Tim Stratford's second-year course for civil engineers 'Tools for Engineering Design'. University of Edinburgh students joining the course often already have some knowledge of the tools covered, such as sketching and use of Excel and CAD packages. Therefore, rather than teaching these skills from scratch, students are set a simple task applying each of these skills. What the students produce quickly identifies misconceptions and gaps in their knowledge so that students and the teachers can adjust the subsequent learning as required.

› What engineers need to know – be clear at the start of the course about the different sorts of knowledge that an engineer needs to have in professional practice. In this way, students can be aware of how they are developing this knowledge and these skills during their course. One way to do this is to run a class exercise in which students collaborate with their teacher to create a large wall diagram showing the different bodies of knowledge. This diagram could become a recurring feature of the course, so that students can see how this knowledge is filled in.

› What does each module do – syllabi typically set out what material courses cover, but they do not necessarily help students understand how each course will help them build the knowledge and skills they need to have. Having identified the knowledge and skills they are aiming for, use the wall diagram exercise suggested above to show students how each part of the course supports this process.

› Explain the hierarchy – using Bloom's taxonomy, show what different levels of competency in a specific domain look like, and what the expectations of the student are. To illustrate, take a look at the American Society of Civil Engineers' *Body of Knowledge* document, which maps a civil engineer's skills and knowledge against the hierarchy of Bloom's taxonomy.

Image courtesy of Think Up

- Highlight interlinkages – understanding the relationship between different subject areas is a useful professional skill, as it helps engineers quickly assimilate information. It also allows learning in one subject to be useful in another. Finding these interlinkages can be either a student- or a teacher-led exercise.
- Provide a blank canvas – one way to help students organise their knowledge is to ask them to take a blank exercise book, and to subdivide it into sections that relate to the broad themes of topic area, for example skills for employability. As students learn a new skill, they can jot it down in this book. The aim of the technique is to motivate students to fill in the gaps and to drive their own development.
- The mile-wide inch-deep problem – many curricula fail to support learning with understanding because they present too many disconnected facts in too short a time – the 'mile-wide, inch-deep' problem, as illustrated in **Box 5**. The key to tackling this problem is to design tests to check understanding rather than the ability to memorise.
- Use the news – use examples from the press to illustrate to students how the knowledge that they are developing could be used to help solve engineering problems. Doing so immediately relates studies to real-world application, and may also help students identify gaps in the knowledge and directions for future study.

Box 5 – Learning with understanding
The following example is adapted from an example given in *How People Learn: Brain, Mind, Experience and School* [8]. It illustrates the importance of learning with understanding.

Medical students may be asked to recall the properties of veins and arteries: arteries are thicker and more elastic and carry blood from the heart, but unless this knowledge is 'conditionalised' ie. the student understands when this knowledge might be useful, it remains just that, knowledge. The student needs to understand why veins and arteries have these particular properties. If they understand the relationship between the properties and functions of veins and arteries the student is more likely to be able to problem solve, eg. how to create an artificial artery.

Engineering skills
Ask students to list all their skills and knowledge that they think would be useful for solving an engineering problem presented in the news, and to identify where knowledge from one area of study could help in another. Examples such as these quickly illustrate to students the importance of industry-related skills and their relation to the rest of the knowledge that they have developed.

Principle nine

Use formative assessment

Formative assessment – that is, not-for-credit assessment that helps students understand what they do and don't know – much more closely resembles the way professional engineers interact than end-of-term exams do. Formative assessment is crucial for both educators and learners. The technique helps the educator to understand where students are in their development journey from informal to formal thinking. It also helps to monitor progress by making the learners' thinking visible to both educators and learners. Research shows that use of formative assessment techniques significantly increases retention of learning.

Despite these advantages, engineering degree courses tend to rely on less effective summative assessment techniques. Typically, the main reason is that formative techniques require much more time to deploy than summative techniques.

There are four ways in which formative assessment has a significant role to play in developing industry-related skills. Firstly, formative assessment helps to address the challenge of developing tacit skills by encouraging students to focus on the process of developing these skills. Secondly, where teaching staff feel the challenge of helping students deal with the social character of many industry-related skills, formative assessment can help by allowing them to see more clearly how their students are progressing. Thirdly, formative assessment supports the development of judgement by focusing on the process of developing an argument rather than focusing on the answer. Finally, by increasing retention time for learning, formative assessment will help students remember for long enough the theory that they are supposed to be applying in practice.

Given the obvious advantages of formative assessment, below are some practical suggestions for use in the classroom, many of which deal with the issue of delivery time.

In practice

- Focus on thresholds – 'threshold concepts' are sticking points in understanding that, when grasped, enable students to make further progress[9]. An example in soil mechanics is the concept of effective stress. Once this is understood, many geotechnical phenomena can be explained. If time is limited, use it wisely and focus formative assessment around threshold concepts to achieve greater impact.
- Automate – if teaching time is the limiting factor in using formative assessment then remove the bottleneck by finding ways to automate formative assessment processes. Here are a few examples:
  - Online multiple-choice quizzes are a powerful tool for formative assessment. Quizzes quickly allow students to identify concepts that they don't understand. Careful construction of multiple choice answers can even help students figure out which aspects of a concept they don't understand by giving them feedback based on the wrong answers provided. Creating a good set of questions is time consuming but it should be regarded as an investment as multiple-choice quizzes can be used over and over again.
  - Provide model answers halfway through an assignment so that students can see for themselves what is expected of them and how they are doing.
  - Ask students to fill out an online survey that asks them to judge their own understanding of different topic areas. From the results, teachers can quickly identify which areas the class as a whole perceive to be difficult, and focus their efforts – and their time – on these crucial issues.

Images courtesy of Think Up

- Use peer-to-peer assessment – build in opportunities for students to evaluate each other's work during teaching modules. In this way, individuals receive feedback from others on their work, but are also able to identify for themselves how they need to improve by comparing their work with the work of their peers. In the authors' experience, peer-to-peer learning works well in groups of five to six, where students get the opportunity to review the progress of a small number of their peers.

  Help students develop feedback skills to support peer-to-peer assessment. Learners need feedback that tests understanding about when, where and how to use what they are learning. Opportunities to work collaboratively in groups can increase the quality of feedback, but learners must be trained in how to give feedback. The readthinkwrite website has some useful guidance for doing so.
- Keep a private learning blog - ask students to keep a private reflective blog of their learning. This blog can be for a specific module or it can be for the whole course. At regular intervals, students can be asked to blog their reflections on their progress, their achievements and their anxieties. Educators, having access to the blog, can help guide students on an individual basis, and can use reflective learning as part of the formative assessment process (see more on blogging under Principle five).
- Annual review – use the sorts of competency-based skills matrices that are used in industry to review staff progress to help students organise and track their development. Adopting this strategy at university will help them prepare for their ongoing development in the workplace. A good starting point is to look at the *Competency Framework Assessment* developed by the Institution of Civil Engineers.
- Transparent student feedback – an important part of building trust between students and teachers, and of changing attitudes about the role of the teacher, is to provide more transparency around the feedback that students give their teacher, for example by asking the teacher to share appropriate comments and to respond to them openly.
- Learn a little but learn it well – if, despite using some of the techniques suggested above, time is still a barrier to using formative assessment techniques, the question should be asked: is there too much content in the course? To help answer this question, consider what would stay in the course if the time available were halved. Focus formative assessment around the topics that remain, and either find other ways to deliver the remaining content, or cut it out.

Student learning blogs
They are a powerful tool for dynamic formative assessment. If students are asked to write regularly about what they are learning and the challenges they are facing, teaching staff can track how their class is progressing, and can provide specific guidance to support individuals on the course.

Principle ten

Create classroom values that resemble workplace values

Students will be able to work effectively more quickly in a workplace setting if the teaching environment more closely resembles the workplace environment. Whereas there may be physical barriers to doing so, group values and dynamics are an important environmental factor. Corporate values are a powerful tool for guiding workplace behaviour and decision-making. In the learning setting, 'classroom values' can be similarly powerful.

Belief in the importance of getting the right answer and scoring a high grade are two values that commonly exist in engineering classes. But experience-led learning needs different values: the value of making mistakes and learning from the feedback; valuing the perspectives and prior knowledge of others, as well as their own; professional behaviour; and an active curiosity about application of theory in practice.

Building an appropriate set of classroom values is fundamental to supporting the other nine principles in this report for delivering experience-led learning.

In practice

- Invoke professional values in the classroom – use professional values to provide behavioural norms, for example, of respect, honesty, integrity and a commitment to self-development. It is common to discuss professional behaviour in the context of a class on ethics, but those values should be extended to how students are expected to behave towards themselves, each other and their teachers.
- Run student-guided revision groups – students working together in groups can request additional support that meets the group's needs. This approach helps develop learner autonomy and responsibility for their working, and helps the teacher focus on their efforts on the area of most need.
- Vertical integration – find opportunities for older students to be role models for younger students, for example through inter-year-group design projects. Even if the more senior students have not worked on the same project brief before, they will be able to use the industry-related skills that they have been developing during the course, potentially inspiring the more junior students and giving the more experienced ones the opportunity to demonstrate mastery (Principle two).
- Bring in experts from industry – experts outside of the university can have a positive influence on the community of learning because they help to connect the world of learning with the world of work. Working to prepare for a visit by outsiders can enhance motivation and develop a better sense of what it is to be an engineer. However, for higher impact, visitors from industry should do more than 'show and tell'. Students will understand more about workplace values if representatives from industry are able to set a piece of work, and communicate their expectations about the quality of student work and how the students should go about doing it.
- Build trust to support peer-to-peer learning – where peer-to-peer learning is used, it must be done so in an atmosphere of trust and respect, where the aims of the exercise are made clear. Some students may find this process particularly difficult if they have not experienced this sort of learning before, for example if they have been taught exclusively in traditional learning environments. Poor language ability and cultural differences may also present learners with barriers in this context. Trust-building work lends itself well to start-of-term 'get to know you' activities. They also work well to help develop communication skills. Below are three themes for self- reflection; the outcomes could be in a wide variety of formats including group discussions, presentations, posters, web profiles or video clips.


Image courtesy of Royal Academy of Engineering

- » My environment – ask learners to think about the physical environment in which they grew up, including what their home is like, the local landscape, what they like and dislike about it, and what would improve their home environment.
- » My motivations – ask learners: why they want to be engineers; who they believe have been great engineers; how did they get to where they are now. Reassure students that they will not be criticised if they didn't have their own burning desire to study engineering.
- » My intentions – ask learners: what they want to achieve as professional engineers; what practical changes they could make to the environment around them; what impact they want to have.

› Harness group diversity – student groups are often made up of individuals from many different backgrounds. Run an exercise with students where they try and find out about differences and similarities between themselves and colleagues from a different background. Themes for discussion could involve motivations for being an engineer, the role of an engineer, differences in business etiquette and engineering practice.

› Support student-led projects – from setting up a student society to participating in an international development project, students naturally develop their own norms for learning and working when they initiate their own project, giving themselves plenty of opportunities for developing industry-related skills. There is now lots of help available for teaching staff who want to support student-led projects:

- » Fiona Lamb and Glynis Perkin at the Centre for Engineering and Design Education at the Loughborough University, and Alison Ahearn at the Faculty of Engineering at Imperial College London have developed a checklist that provides an easily accessible overview of areas that need consideration when embarking on such activity. The steps are not compulsory and the order is not prescribed. Institutions should interpret the checklist as best fits their needs.
- » Student Hubs is a national charity that puts officers into university campuses to help coordinate student-led activity. At a national level, Student Hubs runs student conferences on international development, social entrepreneurship, climate change and community volunteering.

Examples of best practice in experience-led education

This section provides a summary of the examples of best practice in experience-led education from recent Royal Academy of Engineering reports.

Coventry University:

- The development of activity-led learning: examples of a learning process that is student led, problem based, and has an employer and profession focus (*Engineering graduates for industry, Royal Academy of Engineering 2010*) www.raeng.org.uk/publications/reports/engineering-graduates-for-industry-report

Imperial College London:

- Simulated industrial experience – Constructionarium (*Engineering graduates for industry, Royal Academy of Engineering 2010*) *www.raeng.org.uk/education/scet/pdf/engineering_graduates_for_industry_report.pdf*
- Showcasing and extending student-led, employer-focused extracurricular activity (*Enhancing Engineering Higher Education – Outputs of the National HE STEM programme, 2012*). Page 85 of Report (89 of pdf) *www.raeng.org.uk/news/publications/list/reports/Enhancing_Engineering_Higher_Education.pdf*
- Nuclear Island -a framework for the additional curricular material, industry behaviours and delivery methods necessary to meet the requirements of industry (*Enhancing Engineering Higher Education – Outputs of the National HE STEM programme, July 2012*). Page 111 of Report (115 of pdf) *www.raeng.org.uk/news/publications/list/reports/Enhancing_Engineering_Higher_Education.pdf*
- A partnership between Imperial College Business School, Imperial College London Engineering Faculty and the Royal College of Art encouraging cross-disciplinary, radical innovation thinking among postgraduate master's students in engineering (*Educating engineers to drive the innovation economy, 2012*) *www.raeng.org.uk/news/publications/list/reports/Innovation_Economy_2012.pdf*

University of Liverpool:

- Implementing CDIO (Conceive, Design Implement, Operate) (*Engineering graduates for industry, 2010*) ***www.raeng.org.uk/publications/reports/engineering-graduates-for-industry-report*** 'an innovative educational framework that highlights the need to develop skills such as teamwork, communication and problem solving in addition to other core engineering skills' www.cdio.org

London South Bank University:

- Understanding stakeholder needs, English language and critical thinking support for students from diverse backgrounds (*Enhancing Engineering Higher Education – Outputs of the National HE STEM programme, 2012*) Page 82 of Report (86 of pdf) *www.raeng.org.uk/news/publications/list/reports/Enhancing_Engineering_Higher_Education.pdf*

University College London:

- Redesign of the first two years of the curriculum and changes to entry requirements in order to move from 'a very old school' educational approach to one that was capable of responding to the challenges of the 21st century (*Achieving excellence in engineering education: the ingredients of successful change, 2012*) *www.raeng.org.uk/news/publications/list/reports/struggling_economy.pdf*

University of Sheffield:
› Development of a small- scale geotechnical centrifuge (*Enhancing Engineering Higher Education – Outputs of the National HE STEM programme, 2012*).
Page 37 of Report (41 of pdf)
www.raeng.org.uk/publications/reports/enhancing-engineering-higher-education

University Centre at Blackburn College:
› Model for engaging women within the Black and Manirity Ethnic (BME) population into Higher Education engineering programmes. The Blackburn College approach to widening participation has developed as part of its historic commitment to providing education and training in the context of the local environment and culture (*Enhancing Engineering Higher Education – Outputs of the National HE STEM programme, 2012*).
Page 47 of Report (51 of pdf)
www.raeng.org.uk/publications/reports/enhancing-engineering-higher-education

University of Wolverhampton:
› Enquiry-based learning, using formative group projects with level 4 students to improve student attendance and promote student cohort cohesion (*Enhancing Engineering Higher Education – Outputs of the National HE STEM programme, 2012*).
Page 54 of Report (58 of pdf)
www.raeng.org.uk/publications/reports/enhancing-engineering-higher-education

University of Oxford:
› Exploring engineering threshold concepts – ideas within disciplines that open up new ways of thinking, implications for setting up learning environments (*Enhancing Engineering Higher Education – Outputs of the National HE STEM programme, July 2012*).
Page 89 of Report (93 of pdf)
http://www.raeng.org.uk/publications/reports/enhancing-engineering-higher-education

University of Birmingham in partnership with the University of Western Australia:
› Uncovering threshold concepts in first-year engineering courses and implications for curriculum design (*Enhancing Engineering Higher Education – Outputs of the National HE STEM programme, 2012*). Page 106 of Report (110 of pdf)
www.raeng.org.uk/publications/reports/enhancing-engineering-higher-education

University of Hertfordshire:
› Enhancing the student learning experience and engagement by re-engineering assessment (*Enhancing Engineering Higher Education – Outputs of the National HE STEM programme, 2012*). Page 129 of Report (133 of pdf)
www.raeng.org.uk/publications/reports/enhancing-engineering-higher-education

University of Cambridge:
› The Judge Business School in Cambridge uses cross-disciplinary master's programmes in conjunction with innovation modules and entrepreneurial boot camps to give postgraduate engineering students a better understanding of how to exploit novel technologies (*Educating engineers to drive the innovation economy, 2012*)
www.raeng.org.uk/news/publications/list/reports/Innovation_Economy_2012.pdf

University of Nottingham Institute for Enterprise and Innovation:
› Enterprise and innovation programme uses large-scale undergraduate modules to embed radical innovation within the engineering curriculum (*Educating engineers to drive the innovation economy, 2012*).
www.raeng.org.uk/news/publications/list/reports/Innovation_Economy_2012.pdf

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At <bie.org/object/document/gold_standard_pbl_essential_project_design_elements>

Table of resources

Expedition Workshed	expeditionworkshed.org/people	The videos hosted in the People section of the Expedition Workshed website give a valuable insight into what has previously motivated successful engineers.
UK Specification for Professional Engineering Competence	www.engc.org.uk/engcdocuments/internet/Website/UK-SPEC%20third%20edition%20(1).pdf	Summarises the competencies that professional engineers need to demonstrate and to what level. A useful document for encouraging students to develop industry-related skills.
Introduction to thinking skills	www.brainboxx.co.uk/a3_aspects/pages/ThinkingNatCurr.htm www.open.edu/openlearn/education/extending-and-developing-your-thinking-skills/content-section-0	The first link is to the Brainboxx website, which gives a useful basic summary of thinking skills, along with some suggestions for follow-up activities. The second link is to free resources provided by the Open University, which provide a more in-depth introduction to thinking skills.
Introduction to inter-personal skills	www.skillsyouneed.com/interpersonal-skills.html www.open.edu/openlearn/money-management/management/leadership-and-management/the-importance-interpersonal-skills/content-section-0 www.microsoft.com/education/en-us/Training/Competencies/Pages/interpersonal_skill.aspx	The first link is to the Skills You Need website, an online service providing a range of useful resources to help people develop professional skills. More in-depth information is available from the Open University and from Microsoft.
Introduction to Learning	www.open.edu/openlearn/education/learning-how-learn/content-section-0 tll.mit.edu/help/guidelines-teaching-mit-and-beyond	*The Learning to Learn* unit from the Open University could form the basis of a student-led exploration of individual learning styles. The MIT Teaching and Learning Laboratory's report *Guidelines for Teaching @MIT and Beyond* provides a free-to-access refresher for teachers on learning styles and how they should influence teaching.
Using blogging and wikis in learning	www.raeng.org.uk/publications/reports/raeng-development-e-learning-resources	*The development of e-learning resources a good practice guide* A report by the Royal Academy of Engineering giving best practice guidance on the use of e-learning resources in engineering education, including an introduction to using blogs and wikis in education.
Introduction to project-based learning	www.youtube.com/watch?v=LMCZvGesRz8	Introduces the principles of project-based-learning as described by John Larmer and John Mergendoller, 2010.
IT resources that support large-group class conversations and collaboration	www.bedu.com/classtalk.html www.textwall.co.uk esu4socialstudiescadre.wikispaces.com/file/view/21_Interesting_Ways_to_use_Google_Docs_in_the_.pdf en.wordpress.com/classrooms	Classtalk - a networked software system that allows teachers to manage an interactive classroom discussion involving every student. A web page that learners can send text messages to. The message can then be shown on a projector or an interactive white board for the audience to see. 21 Interesting ways to use Google Docs in the classroom. Using Wordpress to host reflective blogs and mini-sites for individual modules.
Learning Style Questionnaire	www.clinteach.com.au/assets/LEARNING-STYLES-Kolb-QUESTIONNAIRE.pdf	Use Pater Honey and Alan Mumford's *Learning Style Questionnaire* to help students identify which learning style they prefer.
Guidance on role-playing	gdn.glos.ac.uk/gibbs www.businessballs.com/roleplayinggames.htm	For an excellent and concise review of the principles of good role-play facilitation in the classroom, see *Learning by Doing* by Graham Gibbs as well as the guidance from the businessballs' website.

Examples of student competitions and deep-immersion exercises	www.constructionarium.co.uk	Constructionarium – weeklong event for civil engineers in which students build scale versions of real engineering projects using real materials and methods.
	formulastudent.imeche.org/formula-student	Formula Student is a competition run by the Institution of Mechanical Engineers in which teams of students design, build and race single-seat racing cars.
	www.airbus-fyi.com	Fly Your Idea is a competition run by Airbus in which teams of three to five engineering students compete in response to one of five challenges related to aircraft design.
	www.raeng.org.uk/events/list-of-events/2013/september/the-innovation-hothouse-the-final	Innovation Hothouse is a cross-engineering industry event to showcase the very best final year student design projects and provide an opportunity for those involved to present their work to a panel of business angels who will offer advice and potentially funding to develop the project into a commercially viable product.
	www.bmfa.org/Contests-Events/BMFA-Events/BMFA-Payload-Challenges	The Heavy Lift Challenge requires aeronautical engineering students to design, build and fly load-carrying model aircraft, piloted by radio control. The aim is maximise aircraft payload to empty mass ratio. The challenge is run by the British Model Flying Association, which aims to increase interest in aviation and engineering through education.
	thinkup.org/innovation/the-big-rig	At the Nuclear Island Big Rig, a team of mechanical, electrical and chemical engineers take on the week-long challenge of installing, commissioning, operating and decommissioning a mock-up of a pressurised water reactor.
Body of knowledge	www.asce.org/CE-Body-of-Knowledge	Produced by the American Society of Civil Engineers, this document maps engineering skill, knowledge and competency against the levels of Bloom's taxonomy.
How to give feedback	www.readwritethink.org/professional-development/strategy-guides/peer-review-30145.html	The readthinkwrite website provides suggestions for how to use peer-to-peer evaluation in the classroom.
ICE Competency Framework Assessment	www.gedcouncil.org/sites/default/files/ICE-Competency-Framework.pdf	This framework can be used as the basis for asking students to carry out an annual review to help them assess how they are developing industry-related skills.
Checklist for development and implementation of student-led projects	cede.lboro.ac.uk/sites/all/themes/cedetheme/downloads/student_led/v9_studentled_checklist_web.pdf	This checklist has been developed to support universities that wish to consider stimulating and supporting student-led activity within their own institution. Student-led activity is voluntary extracurricular activity started up and run by a group of students. The aim of this checklist is to provide an easily accessible overview of areas that need consideration when embarking on such activity. The steps are not compulsory and the order is not prescribed. Institutions should interpret the checklist as best fits their needs.
Student Hubs	www.studenthubs.org	Student Hubs is a national charity that puts officers onto university campuses to help coordinate student-led activity. At a national level, Student Hubs runs student conferences on international development, social entrepreneurship, climate change and community volunteering.
UK approaches to project-based learning	www.rhgraham.org/RHG/Recent_publications_files/MIT%20White%20Paper%20-%20UK%20PjBL%20April%202010.pdf	A survey by Ruth Graham about best practice approaches to delivering project-based learning in the UK.

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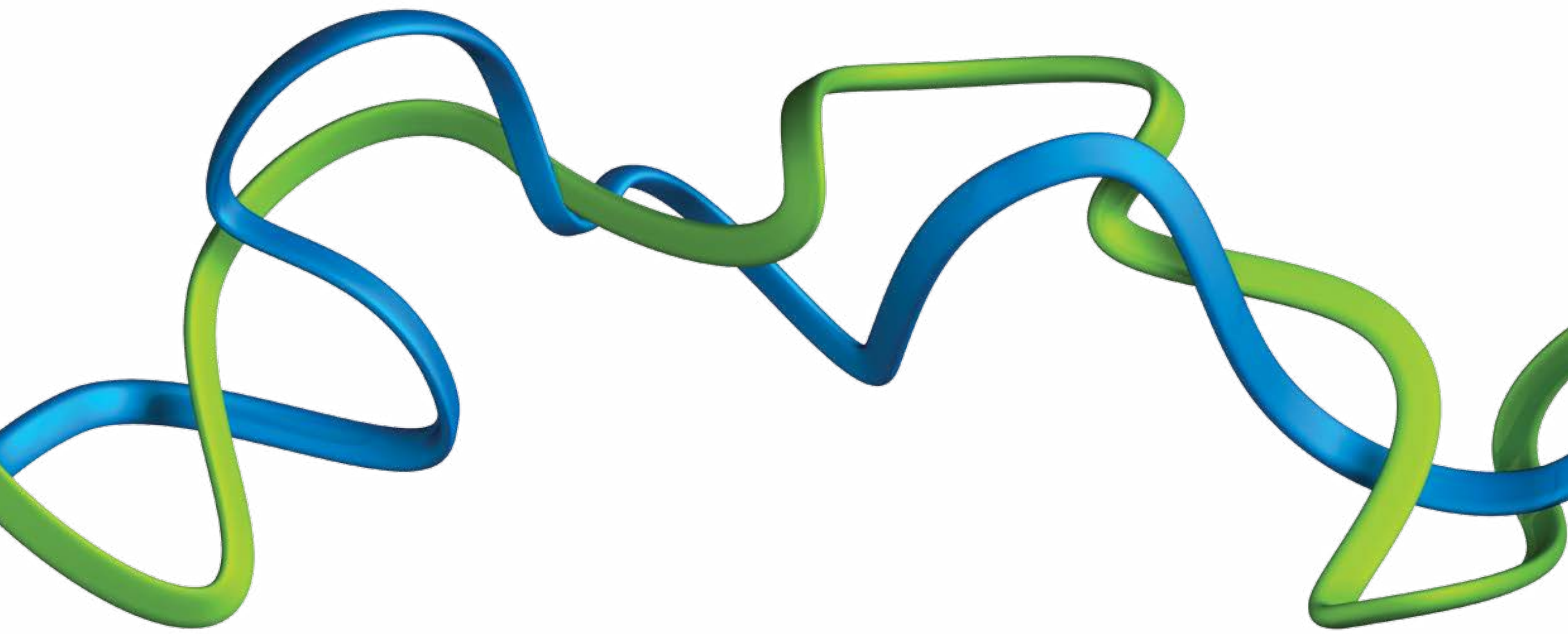

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