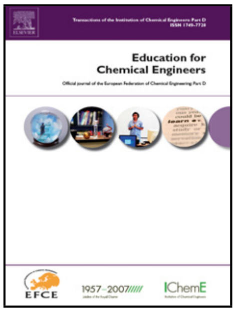
metadata, citation and similar papers at core.ac.uk

Accepted Manuscript



Title: New Chemical Engineering Provision: Quality in Diversity

Authors: David J. Brown, Grant M. Campbell, Daniel J. Belton, Phil Cox, Pablo Garcia Trinanes, Chedly Tizaoui

PII: S1749-7728(17)30111-2
DOI: https://doi.org/10.1016/j.ece.2019.02.002
Reference: ECE 203

To appear in: *Education for Chemical Engineers*

Received date: 6 November 2017
Revised date: 12 February 2019
Accepted date: 28 February 2019

Please cite this article as: Brown DJ, Campbell GM, Belton DJ, Cox P, Trinanes PG, Tizaoui C, New Chemical Engineering Provision: Quality in Diversity, *Education for Chemical Engineers* (2019), https://doi.org/10.1016/j.ece.2019.02.002

This is a PDF file of an unedited manuscript that has been accepted for publication. As a service to our customers we are providing this early version of the manuscript. The manuscript will undergo copyediting, typesetting, and review of the resulting proof before it is published in its final form. Please note that during the production process errors may be discovered which could affect the content, and all legal disclaimers that apply to the journal pertain.

ACCEPTED MANUSCRIPT

New Chemical Engineering Provision: Quality in Diversity

David J. Brown[1], Grant M. Campbell[2], Daniel J Belton[2], Phil Cox[3], Pablo Garcia Trinanes[4], Chedly Tizaoui[5]

[1]School of Engineering & Applied Science, Aston University, Birmingham B4 7ET, UK; corresponding author (davidbrown.solihull@gmail.com)
[2]School of Applied Sciences, University of Huddersfield, Queensgate, Huddersfield HD1 3DH, UK
[3]University of Wolverhampton, Wulfruna Street, Wolverhampton WV1 1LY, UK
[4]University of Greenwich, Central Avenue, Chatham Maritime, Kent ME4 4TB, UK
[5]Swansea University, Bay Campus, Fabian Way, Crymlyn Burrows, Swansea SA1 8EN, UK

Highlights

- Demand has prompted new UK providers of chemical engineering degree programmes
- Issues include course content, infrastructure, industry engagement and accreditation
- The new providers offer an increased diversity of chemical engineering education

Abstract

Recent growth in chemical engineering student numbers has driven an increase in the number of UK universities offering the subject. The implications of this growth are described, along with the different challenges facing new providers in the UK compared with established departments. The approaches taken by the various new entrants are reviewed, with reference to recruitment strategies, infrastructure, the use of external facilities, and the particular flavours of chemical engineering being offered by the new providers. Information about the differentiating features of the large number of chemical engineering degree courses now available is somewhat indistinct: this should be rectified in the interests both of prospective students and of employers. Dilemmas facing new providers include the need to address the fundamentals of the subject as well as moving into more novel research-led areas; enabling students to develop the competencies to sustain them for a whole career as well as meeting immediate employer needs; and providing sufficient industry understanding when academics may lack substantial industrial experience. The central importance of practical provision and of the design project, and the approaches taken by new providers to deliver these components, are reviewed, together with the role of software tools in chemical engineering education, and measures to facilitate industry input into courses. As long as it is not used prescriptively or to inhibit innovation, the accreditation process provides constructive guidance and leverage for universities developing new chemical engineering programmes.

Keywords: Student recruitment; course content; laboratory provision; software tools; design projects; industry engagement; accreditation

ACCEPTED MANUSCRIPT

ACCEPTED MANUSCRIPT

1 Introduction

Chemical engineering is a university subject that has seen considerable increases in undergraduate student numbers since the turn of the millennium. UK applications almost quadrupled between 2001 and 2015, though the most recent data show a fall (see Figure 1) and aggregate intake has grown by almost the same amount. These trends, mirrored to a greater or lesser extent in other parts of the world, have driven growth in established university departments and the introduction of new chemical engineering degree courses in several universities not previously offering the subject.

The subject is a demanding one to teach, with major investments in laboratory and other infrastructure required along with a need to address the breadth of a subject with applications ranging from conventional and novel energy supply and carbon capture to food, water, biomedical devices and ecosystem management, and to do so within cost and infrastructure constraints (Campbell and Belton 2016). Such breadth demands a diversity of expertise among academics, with implications for the staff numbers required to cope with even a modest sized cohort. The staffing challenge is further underlined by the desire that at least some of those involved in teaching should have direct experience of industrial applications, and the accreditation requirement that a significant proportion should be chartered chemical engineers.

The recent experience of several UK universities provides valuable pointers as to how these challenges can be addressed, as well as highlighting some pitfalls to avoid. This paper documents aspects of that experience in the hope that it will be of value to those currently developing new provision and those existing departments keen to maintain their attractiveness to students and value to employers.

Figure 1 here

2 A diversity of provision

At the time of writing, 29 UK departments (two of them within the same institution, University College London) are listed by the relevant professional body, the Institution of Chemical Engineers (IChemE), as having accreditation for the delivery of undergraduate chemical engineering degrees. At least six others are 'in the pipeline' at various stages, from having started courses, having graduated students and now awaiting the outcome of an accreditation assessment, to planning the launch of a course in the near future.

Such growth in university provision, in response to the increase in demand, but now coinciding with a downturn in applicant numbers, creates obvious challenges. However, it also creates opportunity in several ways:

- First, it provides the opportunity for greater diversity in style and content, within the broad scope of what a former IChemE President called 'a boundaryless profession', and subject to the accreditation requirements being satisfied (on which more below). No one degree can address all aspects of the subject comprehensively, so for different places to have different emphases is of benefit to the discipline.
- Second, the growth in provision creates greater choice for prospective students and for the teachers, parents, careers advisors and so forth who advise them, provided that adequate information is available on the particular nature of each course.
- Third, growth enables more students to continue living at their family home while studying at university. While moving away and living to some extent independently is widely recognised as a benefit of the university experience for young people, changes in UK student finance in recent

ACCEPTED MANUSCRIPT

years mean that it is for many becoming a financial impossibility or a prospect that carries the spectre of a debt mountain of >£50,000. The ability to study a subject of one's choice near home has therefore assumed far greater importance than in the past.

- Fourth, growth enables employers to access a wider range of graduates. Employers vary, with some preferring a high level of mathematical and analytical ability while others place emphasis on practical and/or transferable skills, or outstanding depth in a particular aspect of the subject such as process design, control and instrumentation, particle technology, oil and gas, pharmaceuticals or biochemical engineering. Again the usefulness of this wider range of provision depends on useful information about the particular characteristics of each offering being available, and this too is often lacking. The problem is exacerbated by the poor level of understanding of modern university education among many employers, particularly but not exclusively the smaller and medium-sized companies, and the result is that many tend to engage only with a small subset of universities for their chemical engineer recruitment. A more informed 'demand side' would make for improved satisfaction among both employers and recent graduates.

There are both advantages and disadvantages in being a new degree provider as distinct from growing an existing department. In existing large departments (in some cases with intakes of >250), pressure to admit more students is not always matched by university willingness to fund extra staff or build extra laboratories, while it is virtually impossible to expand the number of opportunities for industry engagement to an extent commensurate with student numbers growth, even if the staff time available to develop the necessary contacts is available. Consequently, departments that have grown very significantly can experience lower student satisfaction as the experience becomes more impersonal and personal contact with staff diminishes, resulting in reputational harm and – with the advent of the UK's new Teaching Excellence Framework – potential financial implications. These risks are of concern especially when viewed against the background of steadily deteriorating student perceptions of value for money, as reported by Neves and Hillman (2017). Moreover, staff numbers and low student:staff ratios can be of concern to accreditation panels.

Conversely, new or smaller departments have their own challenges. With a small initial student cohort, it can be hard to justify a sufficient number of staff to cover the breadth of the subject, or to provide the range of practical equipment and facilities to give students exposure to a broad range of unit operations. Meanwhile, the same limited team of staff have to work hard to develop external industry contacts and links in order to secure industrial input into the course and to generate placement and employment openings for students and graduates, all while creating new taught material and compiling accreditation evidence. On the positive side, such a small cohort offers a strong sense of personal contact between students and staff, and a sense of co-creation of a course with the first generations of undergraduates.

Table 1 presents a snapshot of the recent and forthcoming additions to the list of UK universities offering chemical engineering, in chronological order of entry onto the scene. Thus the University of Bradford, having closed its chemical engineering programmes in 2002, reopened them in 2010 and graduated its first cohort in 2012. Hull followed shortly after, with Chester and Huddersfield not far behind and graduating their first BEng students earlier in 2017, and Wolverhampton and Sheffield Hallam due to graduate their first cohorts in 2019. These new providers currently have first year entry numbers mostly in the range 30-100 students. Meanwhile, Greenwich, Queen Mary, Brunel, Canterbury Christ Church and Derby all have started or plan soon to start chemical engineering programmes notwithstanding the dip in applications shown in Figure 1. In all cases, degrees are offered at both Bachelors level (typically three years) and MEng level (the Integrated Masters model, typically four years in duration but widely – though not universally – viewed as corresponding to a

ACCEPTED MANUSCRIPT

combined first cycle + second cycle qualification). Where a year-long industrial placement is included – and employability is much enhanced if it is – it extends the degree duration by a year (this is true at most, though not all, universities, but is currently true for all of the new chemical engineering providers).

Most new providers are in schools or faculties of engineering, with some located in more science-focussed contexts or operating across departments, reflecting the broad base that chemical engineering draws from. Many were initiated to fill a perceived gap in the university's portfolio, in response to the increasing demand for chemical engineering and local industry needs, or serving to integrate existing provision, while others were a natural renewal or outgrowth. In providing the necessary infrastructure, many have accessed facilities external to the university (e.g. through local further education colleges) as well as leverage existing relevant labs, for example, within the university, while drawing on more readily deployed computer-aided learning opportunities through simulation software, for example. Industry input has been engaged in all cases, at varying levels of formality, to design programme content and to support delivery through, for example, site visits, guest lectures and Design Project support.

Table 1 here

3 Student recruitment

The undergraduate recruitment scene in the UK is undergoing change for a number of reasons. Following the tripling of tuition fees in the recent past, the cost incentive to remain at their family home is a factor, pointing to more local and regional as distinct from national recruitment. This factor advantages those universities with strong local/regional missions and connectivity. Neves and Hillman (2017b) report that students who live at the family home tend to learn less, indicating that such universities will need to counter this with increased emphasis on student support – though this reasoning may be contentious to some

A second factor is a trend – welcomed in some respects by good academics – for students to be more demanding: their expectations of value for money, extensive contact with staff and prompt feedback on work, heightened by the knowledge that they are paying in excess of £9000 university fees per annum and suffering exorbitant Government-imposed interest rates on their growing debt until after they graduate!

The wide range of applications of chemical and biochemical engineering, and hence of career opportunities, helps to attract a similarly wide range of applicants. In particular, the proportion of female applicants has been steady at around 26-27% in recent years, roughly twice the average for engineering in general. That said, efforts continue to attract more female students and those from other under-represented categories such as ethnic minorities and students from less advantaged backgrounds. New providers such as Wolverhampton, with a strong commitment to widening access and participation, are well placed to contribute to these endeavours.

The rise in emphasis on apprenticeships, including degree apprenticeships, is a significant feature of the current UK higher education landscape, with students viewing degree apprenticeships as a route to a degree combined with work experience and without the debt implications of a conventional degree. No longer are apprenticeships largely confined to less able students. From an employer perspective too, apprenticeships offer an 'extended interview', allowing employer and individual to

ACCEPTED MANUSCRIPT

ACCEPTED MANUSCRIPT

assess each other and leading to improved graduate retention. While degree apprenticeship provision in chemical engineering has yet to be developed, the model is one for which a number of the new providers are well suited. As apprenticeships have to be led by employers, dialogue with companies is an essential first step.

The possibility of degree apprenticeship offerings is one way of broadening appeal and responding to the downturn in applicant numbers, but is not the only innovation available to new (and existing) providers. There is growing interest in recruiting students other than those from the classic maths / physics / chemistry background typical of engineering undergraduates – for example, individuals with creative and design strengths even though they may bring a weaker grasp of mathematics. Such students may be well suited to 'chemical engineering with x' offerings, where x can for example be chemistry, economics or bioscience. The University of Wolverhampton is one institution pioneering such a model in the UK, while dual degrees combining chemical engineering with a second subject are popular elsewhere in the world, for instance in Australia (e.g. Russell et al (2007). Such degrees can however struggle to achieve accreditation.

As noted above, the diversity of courses available only really adds optimum value if prospective students, the teachers and others who advise them and the employers who hire graduates are provided with useful and timely information about the particular features and differentiating characteristics of each course. A brief review of universities' promotional messages on their websites reveals that few provide a clear differentiation of their chemical engineering offering from those of others, while the highly successful promotional campaign *whynotchemeng*[i] avoids such information, presumably in a desire to maintain impartiality between universities. In the absence of such guidance, the increased number of departments offering the subject is likely to yield simply more confusion among students and risks some becoming disappointed with the subject because they have made an under-informed choice of institution.

Consequently, adequate information must be made readily available on the distinctive emphases and character of each degree programme (in addition to information on the distinctive character of the university itself). While the priority thus far has, understandably, been getting new programmes up and running, more now needs to be done to make such information available by individual universities and perhaps by co-ordinating bodies such as the IChemE. This will be especially important given the increasingly competitive environment faced by universities in attracting chemical engineering students.

4 Course content

Most of the newer degree programmes are located within Engineering schools, with some located in Science schools, giving potentially different emphases for programmes and experiences for students (chemical engineering can look very different if taught predominantly alongside other engineering disciplines compared with taught alongside chemistry or in isolation). The programmes aim, to a greater or lesser degree of overtness, to draw on and promote distinctive strengths in, for example, food, pharmaceutics, biofuels, energy, chemistry, or particle technology. Most new programmes have been initiated to fill a gap in provision in the light of the increased student interest in recent years up to 2016, sometimes drawing on a natural context such as existing relevant teaching and labs, or in the case of Chester, the creation of an entire new Faculty of Science and Engineering at the former Shell site in Thornton. Table 1 also attempts to capture a flavour of how these new providers are dealing with issues of infrastructure, industrial input and the delivery of design project teaching, while Table

ACCEPTED MANUSCRIPT

2 summarises some of the pros and cons of new providers in comparison to established and generally larger providers.

Table 2 here

The use of staff from cognate disciplines and from other parts of the university is commonplace – a chemist colleague teaching thermodynamics for example – with obvious benefits in cost and risk management terms, especially while student numbers remain too low to justify hiring additional specialist staff. That said, two concerns arise. One is specific to the teaching of mathematics, where arguably better results are obtained when it is taught by an engineer rather than calling in a colleague from the mathematics department. (One might infer that students learn more from the engineer for whom maths is a tool and its physical significance essential, than from the mathematician for whom the beauty of the subject is what matters and the physical significance is a distraction).

The second concern is more general and widespread, common to established as well as new courses. It is whether there are sufficient academic staff with backgrounds specifically in chemical engineering, typically with first degrees in the subject, as distinct from those from science backgrounds. The predominance of the latter in some departments is influenced by a number of factors: the competing demand for chemical engineers in industry, with higher salaries on offer than in academia; the pressure to hire staff with strong research backgrounds; and that fact that more highly-cited papers and more prestigious journals are found in the science disciplines.

New degree providers report a number of dilemmas when planning the content and delivery of their degrees. Each requires a balance to be struck in a way that is appropriate to the institution, the likely student intake, and the types of employer of most interest – which means the balance will not and should not be the same across a range of universities.

Dilemma 1 – covering the basics while also addressing the novel areas of the subject

An animated and not always even-tempered debate has been taking place for some time in the discipline about the balance between 'classic' chemical engineering fundamentals – in thermodynamics, heat and mass transfer, basic unit operations and so on – and aspects of the subject which are more novel and viewed by some as peripheral, but which tend to be those most likely to yield highly-cited publications. The former, it is argued, matter most to employers and to those concerned about the coherence and the 'heartland' of the subject, while the latter are more attractive to research-oriented academics and especially those drawn from science backgrounds in chemistry, physics or bioscience rather than from a chemical engineering first degree background, and perhaps viewed as the future direction of the discipline and its employment opportunities.

Dilemma 2 – providing the generic competencies for a 50 year career while also providing for the current needs of employers

There is a fashion in the UK for tertiary education and training to be 'employer-led'. This is all very well, providing the employers recognise that the purpose of education is to equip students for lifelong careers, perhaps taking them into jobs and careers that have yet to be invented. Unfortunately, many employers don't. The solution is for employers and academics to work *together*, just as they do in the accreditation processes of the major professional

ACCEPTED MANUSCRIPT

engineering institutions, to achieve the difficult balance of "skills for today" and "versatile competent graduates for tomorrow and beyond". That means some content, dear to the hearts of some, will have to be left out of any given degree course – but across the range of course providers, the full rich breadth of chemical engineering should be catered for. New providers should consider carefully how they contribute to this mix, complementing rather than duplicating what is available elsewhere, while having the confidence not to aim to cover everything.

Dilemma 3 – ensuring industry experience informs teaching while also satisfying demands for staff to have strong research records

The funding structure for universities in the UK incentivises a focus on research, and the dominant perception among most early-career academics is that research performance, rather than excellence in teaching, is what really drives their career advancement (notwithstanding the protestations of Deans and Vice Chancellors that teaching is rewarded too). These factors can lead to a difficulty in recruiting staff with strong industry experience, save in the unlikely event that they also have an impressive record of published, peer-reviewed research. That said, new providers tend to be universities that are less 'research-led' than some of the established institutions, and frequently have strong industry connections especially on a regional basis. They may therefore be in a position to take advantage of their greater freedom to inject genuine industry experience into their teaching capacity. This may require some creative accommodation. For example, Huddersfield has made a 50% appointment of a staff member who brings substantial industrial experience and has been happy (and able) to create a workable industrial context for his other 50%; this arrangement has brought this valuable industrial experience into the programme, while not contravening the university's policies in relation to its research ambitions. However, it has required the ability and willingness on both sides to construct this arrangement and make it work.

As one would expect, providers often enhance their courses and give them distinctive characters by building on research strengths of the institution. Examples include biofuels at Hull, polymer science and technology at Bradford, particle technology at Greenwich and biomedical materials at Queen Mary University of London. Taking Greenwich as an example, students are introduced to particle technology from the outset of the course and this is followed by case studies incorporating knowledge from research to build students' understanding. Links to chemistry are well used e.g. at Huddersfield, just as at established providers such as Aston.

Overall, the new degree provision is adding useful diversity to higher education in chemical engineering. However, some areas would merit greater attention. Arguably those areas of the subject interfacing with the life sciences, such as industrial biotechnology, bioprocessing and the analysis of biological and biomedical systems in chemical engineering terms, are among examples that might be better served, as argued by Shott et al (2015). Application of chemical engineering principles to materials, or to the design and development of chemical products (e.g. Rodrigues and Cussler 2016) as distinct from chemical processes, may also deserve fuller attention, while process instrumentation, automation and control is an aspect that is still under-served in UK courses. The latter is a topic bridging chemical and electronic/software engineering, which may be one reason why it is less fully addressed than it might be – given the tendency of academic disciplines and accrediting bodies to remain focused on the traditional disciplinary 'silos', i.e. separate branches of engineering. The boundaries between those specialisms should be more fluid, recognising that technology challenges, user needs and indeed careers can embrace several of them.

ACCEPTED MANUSCRIPT

An aspect that appears to be getting increased attention is the importance of underlying chemistry and how this is covered. This is of special importance if graduates are to be able effectively to design new processes as well as operate existing ones, and those providers in which chemical engineering is closely linked to science departments, rather than other engineering disciplines, will have an advantage. Equally of course, they will be able to contribute an understanding of chemical engineering to science students, whose value to employers will be enhanced if they are conversant with concepts such as scale-up, process economics and manufacturability.

This is not to suggest that we should be creating hybrid chemists-chemical engineers (or hybrid biologists-chemical engineers): rather that in a world where individual disciplines seldom work in isolation, engineers should be able to work with chemists and understand their thinking and their language, and vice versa.

From an accreditation perspective, clarity of understanding is required regarding what legitimately falls within the scope of chemical engineering, while maintaining the necessary balance. For example, advanced physical, organic or (to a lesser extent) inorganic chemistry would fit under Core Chemical Engineering within the IChemE accreditation guidance, but an excess of chemistry, while still arguably core chemical engineering, would have to be seen as squeezing out other components to the extent of distorting the balance such that it is no longer distinctively chemical engineering. (Equally, one must be concerned about chemical engineering programmes that contain a bare minimum of chemistry; many employers find their chemical engineering graduates deficient in their understanding of chemistry.) The boundaries between chemical engineering and other disciplines is blurred, but what makes chemical engineering distinctively its own discipline is in part the balance it draws from other disciplines. To give an analogy, flour is undoubtedly a legitimate part of a cake, but an excess of flour destroys the essential cakiness of a cake, while a cake is more than its ingredients, it is how they are combined and processed; so chemical engineering is similarly a product of a balance of components and how they are brought together. Meanwhile, there are a range of cakes, different in specific ways but all cakes (except perhaps Jaffa cakes!), and so with chemical engineering; judgements about the legitimate nature of chemical engineering must understand these balances and interactions as well as embracing differences.

5 Laboratory and practical provision

Chemical engineering is inherently a practical subject and employers stress the importance of extensive hands-on experience among graduates. The cost implications for new providers are obvious: laboratories are expensive to build and equip, and proper supervision requires a much higher staff:student ratio than delivering lectures. Moreover, the breadth of the subject means that not all unit operations can be illustrated with experimental work: choices need to be made, providing students with experience of a broad range of operations and processes. Typically most experiments are at bench scale, though it is important that students do at some stage in their course experience operating at larger scale using industry-standard components – which can pose difficulties for new providers who are short of funds or of laboratory space of more than single-storey height. Accrediting bodies can strengthen the hand of academics by highlighting the need to invest in laboratory and experimental infrastructure.

To overcome difficulties such as the above, collaboration between geographically-close institutions is strongly to be encouraged. Partners may both be universities; or use can be made of facilities at a tertiary college (such as the partnership between the University of Huddersfield and Kirklees College's

ACCEPTED MANUSCRIPT

new Process Manufacturing Centre) or at a technical training facility such as CATCH[ii] in northern England, utilised by Hull.

Existing departments also need to invest to ensure their students' experience is abreast of developments in the subject and in instrumentation, that novel aspects of chemical and biochemical engineering are covered, and that facilities are of a quality to attract undergraduates in a competitive market (and to impress employers). A good example, enabled by a move to a new campus, is that of Swansea University, described in the case study below.

Case Study – Swansea University

Chemical Engineering at Swansea University is well-established and has a long history, dating back to the 1950s. The well-known Coulson and Richardson *Chemical Engineering* series of undergraduate textbooks were co-authored by the late Jack Richardson, former head of Chemical Engineering at Swansea University, and his colleague John Coulson (Newcastle University). One distinctive feature of the Chemical Engineering courses at Swansea is the significant practical and lab work students undertake as part of their degrees. In 2015, Chemical Engineering has moved along with the all other engineering disciplines at Swansea University to the Bay Campus which is a purpose built beach-front brand new campus of a value of £450M. As part of this move, and given the significant increase in student numbers (about 500% within a six year period), chemical engineering laboratories were redesigned and newly equipped. This contribution outlines our experiences in setting up the new labs and provides some insights that may be useful to other colleagues involved in similar projects.

The approach we undertook was to provide students with practical experiences in a wide range of chemical engineering related experiments as soon as they embark in their course using bench top scale, and to expand the scale to a larger pilot plant as they progress in their degree. Students could also carry out practical research and summer projects. Based on this approach, students undertake in the first year practicals to demonstrate and gain cognitive skills in fundamental principles of relevance to chemical engineering using a series of bench-top experiments in areas such as physical chemistry, heat transfer, mass transfer, fluid and particle mechanics, and separation techniques as well as instrumentation and analytical techniques. As students embark on the second year of the programme, they undertake pilot plant labs on a wide range of unit operations such as distillation, gas/liquid absorption, heat transfer, liquid fluidisation, evaporation, reactor engineering, process control, heat pump, liquid mixing, and water purification operations. Although we aim that all students experiment with this wide range of experimental rigs, this can be difficult, particularly for large classes. However, students have other opportunities to have exposure to the rigs other than through the formal modules assigned to the labs, via for example research projects or a summer placement. We also operate the labs in groups and rotate the students to maximise exposure.

In the setting up of our labs at the new Bay Campus, it was essential to involve all key academic and technical staff as well as the project manager. The meetings were formally recorded and progress against action points is checked regularly. In addition, informal meetings and discussions with various stakeholders were held on an ad-hoc basis. The design of the labs was done by professional designers with input from the chemical engineering team via the project manager. As a team, we developed a list of lab equipment to purchase and this was based on the academic approach discussed above as well as being mindful of constraints such as budget, safety and floor space. Although the procurement process was manged by the finance department, we contributed to the preparation of the tender documents for example via setting up the technical specifications of equipment and evaluation. As the equipment were delivered, sited where they should be, and commissioned by the supplier, academic and

ACCEPTED MANUSCRIPT

technical staff responsible for the delivery of the labs have received training on the safe use of each rig and have prepared risk assessments and student-proof operating instructions. Given the large size and complexity of the project, pitfalls were inevitable including for example undersized services (e.g. chilled water and steam). Close collaboration and constant communication with the university Estates department was essential to resolve such issues.

Although this project was complex, challenging and time consuming, Swansea University has now one of the best modern laboratories for teaching chemical engineering in the country. Defining the approach for setting up the labs early on was essential to guide further decisions in the process. It was also essential to involve all key academic and technical staff, making sure they understood the seriousness of the project so to minimise the risk of mistakes and any potential pitfalls. Procurement is a time-consuming process that should be considered carefully in the overall planning, particularly when the time is limited between the commissioning of equipment, training, purchase of consumables, lab notes preparation, and the effective starting date of the labs. A contingency plan should be in place to mitigate any unforeseen circumstances; for example swap teaching lab semesters to accommodate for any delays in equipment delivery or commissioning. It is also essential to have strong representation and communication with the various stakeholders involved in the project including designers, estates, suppliers and even at the building stage. Site visits during the building stage should be carried out regularly to rectify any issues that were not picked up during the design stage or as a result of changes made without notification. Finally, be ready for surprises but, after all, you are an engineer, keep calm and solve any problem.

Figure 2 here

Case Study – University of Greenwich

The Faculty of Engineering and Science at the University of Greenwich, UK opened a new chemical engineering laboratory at the university's Medway Campus in Kent. The lab is located in the Hawke building, a multidisciplinary facility belonging to the Faculty of Engineering and Science. Pablo García-Triñanes, head of the chemical engineering division, explains that *"the new lab is fitted with equipment to facilitate student learning and give them hands-on experience to complement their theoretical studies and prepare them for careers in industry". "There's no possibility of developing a programme in chemical engineering without practical experiments"*.

The new chemical engineering programme started in the 2017/2018 academic year, and In their first year the 2017/18 cohort used existing labs common to all engineering students before the new lab opened at the beginning of the 2018/19 academic year. García-Triñanes says that engineering students at Greenwich University experience a common first year, and there are laboratories available which include some equipment for chemical engineering content such as fluid mechanics, heat transfer or pumps. However, before the chemical engineering students started their second year, staff felt it was really important to get a teaching laboratory in which they could gain more specialised experience. García-Triñanes comments:

"The new equipment arrived mid 2018 summer and includes continuous distillation, reverse osmosis, heat transfer in fluidised beds, and multivariable control or reactor engineering kits, all manufactured by GUNT. These experiments are designed specifically to support our curriculum … with a responsive technical team of experts, and in the vicinity of industrial-scale pilot plant units for the study of bulk solids handling and separation processes."

ACCEPTED MANUSCRIPT

Figure 3 here

The new equipment includes items that will help students to understand fundamental modules of the chemical engineering programme as well as modules more specific to the curriculum at Greenwich - included to add some “personality” to the programme, such as process safety and chemical plant design, and materials handling. Consulting with employers helped shape the curriculum, ensuring that it addresses issues needed to create well-rounded students and prepare them for the “real world”, with a recognition that chemical and manufacturing plant layout, commissioning and process safety or sustainability are key in ensuring that all systems and components of an industrial plant are designed, installed, tested, operated, maintained and are safe according to operational requirements.

The breadth of chemical engineering, one of the attractions of the subject, allows it to complement other fields of engineering. The chemical engineering division has relationships with other research units on campus, and those relationships can benefit the students by contributing to its curriculum. For example, particle technology -- included in the chemical engineering curriculum -- is an area of expertise for the Greenwich’s Wolfson Centre for Bulk Solids Handing Technology, one of very few in the world that work with powders on an industrial scale and spanning a range of industries including chemicals, pharmaceuticals, and mining.

External collaboration with industry and through conferences and meetings has helped inform the programme, provided visiting lecturers, placements for students, and led to research collaboration. Meanwhile, next steps include adding a research lab for chemical engineering students who move on to doing Masters and PhD projects, and which could also be shared with other faculties at the university.

6 Use of software tools

In many ways computer-aided process engineering (CAPE) can be considered a microcosm of chemical engineering. There is a wide range of software tools supporting nearly every aspect of the discipline (Puigjaner and Heyen, 2006). Furthermore, to understand the correct application of these tools it is essential to understanding the underpinning fundamentals in order for software tools to be applied appropriately. Without this understanding there is danger that CAPE tools will used like black box with the associated drawbacks. As such, to gain full mastery of CAPE software requires the development of chemical engineering knowledge at degree level and beyond. This raises the question, should we introduce CAPE tools at all in a degree programme if such advanced knowledge is needed to appropriately use them? We would argue that there is a synergy in learning the fundamentals and developing software skills in parallel. The key is to make students aware of the limitations of software tools, to situate students’ current level of proficiency within a stratified journey of skill acquisition, and to emphasise the maxim “rubbish in equals rubbish out” (Belton, 2016).

One of the most prominent software tools taught in chemical engineering degree courses is steady-state process simulation. And this is a good place to start, since it deals with the many of the introductory concepts and principles, such as unit operations, mass and energy balances and thermodynamics. Here, university departments often pick one of the two market leaders, PRO/II or Aspen, and this is true of the new providers, as shown in Table 1. However, there is often a drive from industry for undergraduate courses to broaden the range and scope of software tools they cover. The need for such breadth has also been recognised in the literature. For example, Dahm et al. (2002) pointed out that process simulation should not be taught to the exclusion of other industrially relevant software tools.

ACCEPTED MANUSCRIPT

Alternative software tools include spreadsheets (e.g. Microsoft® Excel®), numerical computing environments (e.g. MathWorks MATLAB) and computer programming languages. For example, Microsoft® Excel® can be utilised to solve systems of linear equations, perform statistical tests, act as a database for physical property information, numerically integrate and differentiate, handle problems involving ordinary and partial differential equations, carry out linear and nonlinear regression analysis, and tackle optimization problems (Billo, 2011; Law, 2013). Simulink, a graphical programming environment within MathWorks MATLAB, has been used to illustrate the simulation and tuning of process control loops in taught courses (Li and Huang, 2017; Love, 2007). Others have advocated the teaching of computer programming skills within chemical engineering courses, using languages such as Visual Basic for Applications (VBA) to extend the power of Microsoft® Excel® (Chambers, 2006; Wong and Barford, 2010) or by combining courses in structured programming and object-oriented programming to develop problem solving skills needed for Industry 4.0 (dos Santos et al., 2018).

The increasing demands and diversification of computational tools in chemical engineering are also being driven by the arrival new conceptual frameworks and technologies, including Industry 4.0, virtual reality (VR) and Big Data. For example, VR environments have been developed for support operator training and allow students to explore real chemical plants with reduced logistical and safety constraints (Norton et al., 2008; Schofield, 2012). Big Data and Industry 4.0 are leading the charge in terms of improved process analytics (Qin, 2014), smart manufacturing (Yuan et al., 2017) and accelerated innovation (Beck et al., 2016). This is all set alongside the continued development of the vast array of existing CAPE tools, including steady-state and dynamic simulation tools, which continue to advance and evolve (Kravanja, 2016). Chemical Engineers must be at the forefront of these advances, in order to take full advantage of the opportunities presented. As such, the role of CAPE tools in Chemical Engineering education and training must continue to advance and evolve.

At the extreme, it could be mused that the entire chemical engineering curriculum could exclusively be taught through the use of CAPE tools. Whilst this approach could be tempting from a cost and resourcing perspective, it would be in danger of missing the point. Software tools should be used to support and enhance a rich and diverse educational experience, not to replace it. Hubert and Stuart Dreyfus support this view in their seminal book 'Mind over machine: the power of human intuition and expertise in the era of the computer' (Dreyfus et al., 1986):

"Since learning skills requires concrete cases, it seems only common sense to stick to the real objects when there is no compelling reason to use simulations."

However, this is not to say that CAPE tools cannot permeate all areas of the curriculum. In fact, it has been suggested previously that chemical engineering software tools should be integrated into the wider curriculum (Lewin et al., 2002). This also allows a broader scope of tools to be covered within a degree course, as often called for by industry and previously acknowledged to be desirable in the literature (Dahm et al., 2002).

New providers are taking the opportunity to explore and re-examine how process simulation should be taught. For example, the University of Chester has developed an interactive online simulator to introduce the basic concepts involved in modelling a process (https://virtualprocesslab.thorntonresearch.org). Belton (2016) investigated the teaching of process simulation using videos and inquiry/discovery-based learning. It was found that videos were well suited to supporting basic skill development and that the inquiry/discovery element of the teaching approach supported higher-order skill development. Beyond this, there exist excellent guidelines for the use and development of CAPE tools written by the IChemE CAPE Special Interest Group ("Use of

ACCEPTED MANUSCRIPT

Computers by Chemical Engineers", 1999). This guide provides a well-considered overview of how CAPE tools should be utilised in a professional engineering context, along with supplementary notes for managers, training providers and other stakeholders. Readers are referred to this guide and the wider literature for further information on this important and ever-growing area (Belton, 2016; Chemmangattuvalappil et al., 2017; Kravanja, 2016; Puigjaner and Heyen, 2006).

7 Design projects

The capstone Design Project is probably the most daunting aspect of a chemical engineering degree programme for both students and staff. It features prominently in the Accreditation Guidance, which obliges at least 10 European Credits of Chemical Engineering Design Practice and Design Projects that *"must include a major design exercise which addresses the complexity issues arising from the interaction and integration of the different parts of a process or system. It is expected that this major project will be undertaken by teams of students and that this will contribute significantly to the development of the students' transferable skills such as communication and team working."* (Accreditation Guidance, p30). Campbell and Belton (2016) identify three broad models by which group Design Projects tend to be delivered:

1. A single design task undertaken by all groups, possibly with variations in the details, with a core supervisor or (preferably multidisciplinary) supervisory team with detailed knowledge of the technical design, which usually varies from year to year;
2. Different design tasks undertaken by different groups, decided by the individual group supervisor according to their own competence and limitations, usually based on previous well-trodden designs that may stay much the same from year to year;
3. Different design tasks initiated and proposed by the students themselves (the "Manchester model"), with the supervisor not expected to have detailed technical knowledge of the design task, but able to assess the submission in the more authentic role of a boss.

Hybrids and other models exist, including in at least one place the authors are aware of, a single (very busy!) academic undertaking sole supervision of five different projects. Campbell and Belton (2016) discuss the various advantages and disadvantages of these models with respect to the balance between the open-endedness of the task relative to the technical depth of the design, and robustness against collusion and plagiarism.

As well as the model of delivery, the other issue is access to sufficient technical expertise to deliver the Design Project. Within the new providers, thus far Lancaster, Hull, Huddersfield and Chester have got as far as having to deliver design projects; the other new providers have not got to that stage yet. In all cases, the new providers have drawn on external help to develop and deliver their design projects, as summarised in Table 1. In Hull, the Design Project is sponsored by a local company, with engineers providing introduction to the task and judging final project presentations, while four ex-industry engineers have been appointed as part-time staff to support and guide the Design Project; Greenwich has similar intentions. In Huddersfield a retired academic with a long experience of leading Design Projects has been appointed, with the specific brief to develop staff technical and supervisory competence alongside supporting students, in order to establish a basis of Design Project supervision competence for the future. In Chester similarly a highly-experienced person has been brought in to support the Design Project.

Meanwhile, initiatives and consultations to understand and support the specific requirements of Design Project delivery are ongoing, including a recent (May 2015) Design Project "Checklist" issued

ACCEPTED MANUSCRIPT

by the IChemE Education and Accreditation Forum. A common difference in expectation is between industrialists (including members of assessor panels) who observe that Design Project tasks in undergraduate programmes are "not how it is done in reality", against academics who accept this while recognising the artificial nature of the Design Project task as an educational activity undertaken within the constraints of a university programme and context. The new Checklist acknowledges this tension by noting *"a full commercial design would encompass all elements of the Design Portfolio Checklist and this is not expected for an academic programme."* The Checklist offers a helpful basis for formulating learning outcomes for Design Projects and for placing them into the wider context of commercial design; it remains to be seen how this new Checklist is exploited and interpreted in practice.

8 Industry engagement

The central importance of industry exposure and industry engagement in engineering education is self-evident from the nature of the subject, but rarely are relationships between companies and universities as effective as they could be. Discussions with employers on a bilateral basis and through the IChemE Industry Panel convened by one of us (DB) reveal three characteristic concerns among employers of chemical engineering graduates:

- Lack of practical skills – especially for a generation that has spent its childhood years on social media instead of making things
- Lack of interpersonal / transferable skills such as team working, formal and informal verbal communication, time discipline
- Limited awareness of industry – often reflecting poor or outdated understanding among teachers and parents

Although there are various ways of tackling these issues, all three are very effectively addressed by a well-designed and well-supervised industrial placement – which is why increasing the supply of such placements is probably priority number one for the discipline in the UK, and why guidance now available[iii] is of such value to employers, students and universities alike. Unsurprisingly, industry placement experience is an important factor affecting employability of engineering graduates, as noted for example by Atkinson et al (2012). Obtaining placements can be difficult, especially for students who do not have useful personal or family connections: Wilson (2016) reports that employers would welcome targeted support for students from less-advantaged backgrounds to help them secure work experience, thus widening industry's potential talent pool and improving social mobility.

The measure of any engineering course is the level to which graduates enter their chosen industry and thrive there. The long established courses within the UK have generated substantial links with chemical process industries and many of their alumni are embedded into significant companies in a range of positions. Thus, the new courses need to address two fundamental and difficult problems. Firstly we need to raise our students' awareness of the industry that is out there waiting for them and to make them ready to explore this potential world. So without doubt our students need to understand the objectives and associated challenges of large scale manufacture, but at the same time have the academic/practical/personal skills that make them attractive to the employer. The second challenge is for the industry to recognise the new courses and be willing to take on the students from them. The accreditation process should provide assurance to employers that although these students may have differing backgrounds and characteristics from their counterparts from longer-established courses, they will possess similar core competencies and in the case of MEng graduates, will meet the

ACCEPTED MANUSCRIPT

full academic formation requirements to become fully qualified (and with experience, in due course Chartered) engineers.

During their university careers we need to expose our students to industrial practice. The simplest way to do this is for all students to take meaningful industrial placements, either as part of the course or during vacations. However, such placements are hard to secure and impossible to guarantee, partly due to the rise in the number of students, and for the more well known companies have become fantastically competitive. Students look at their lecturers aghast when told in the first couple of weeks of a course that they need to look and apply for placements and they may already be too late for some. The second shock to their system comes when they see the level of competition within and between universities. For students on the smaller/newer courses this can be quite bewildering as staff constantly try to orientate the students to how their new world works. An interesting experiment is to ask a cohort of students from new and old universities how many have relatives that are chemical engineers and influenced the students to follow them. In the older establishment very large numbers will have had a strongly influential mentor, for the new departments much less so. Typically the departments need to supply “old friends”, for example to give careers talks to try to show what roles and opportunities there are; plus the IChemE has very helpfully found some excellent speakers who have helped several of the new departments recently. A special mention should be given to the Frank Morton sports day – an annual, UK wide gathering of chemical engineering students. Here students socialise, play sport and engage with a trade fair of likely employers. For students from newer courses this can be quite the eye opener. They finally see the potential that their degree studies can deliver; but also they see the competition going for these exciting careers. Anecdotally, when students from one of the newer courses went to Frank Morton for the first time their overall response to the experience was “Ok we get it now”. But “getting it” also requires universities to ensure the interpersonal skills of their students match the expectations. Thus, presentation/interpersonal skills and a confidence in expressing their thoughts and ideas have to be developed, particularly when under pressure, but this needs to be achieved without compromise to the core subjects or laboratory practice time.

Whilst the new Universities ensure that they push their students towards industry with a confidence that they are valued and will succeed, there needs to be a pull from the industry with a recognition of the new sources of student talent. It appears this is happening and undoubtedly has been helped by the economic upturn. The larger question that remains is whether the graduates from the newer universities will be competitive for selection for permanent posts when placed alongside students from the older courses. The feedback that has currently been received, and this may well change, is that it may follow the old idiom of “horses for courses” and job specifications may well attract the appropriate students to them. In recent discussions with industrialists there does appear to be a focussed pull for the new students. Older university graduates, especially at MEng level, have had an extensive and rigorous training and this has involved exposure to the potential destinations within the profession and the lure of research. Thus, these graduates tend to be upwardly mobile and/or wish to pursue management or research careers across a number of companies in their early career years. By contrast, the more regional nature for recruitment and a less developed research base from the new courses might yield process operators/supervisors with the hope that they may become the long service employees of the future. Obviously, there can be no one size fits all approach here and indeed, once given exposure to the supportive university environment of the new departments, many students flourish in a way they didn’t think possible, and aspirations grow. Looking more broadly to the competitive job market more generally, the nature of a chemical engineering education is likely to serve graduates better than alternative degrees, such that it is to be expected, and not lamented, that

ACCEPTED MANUSCRIPT

many graduates from the new programmes will take their chemical engineering education into other areas, as is already the case from the established providers.

Thus, to satisfy the push and pull of the new university students and the potential employers requires conversation and growth between both groups. The universities need to listen closely to the employers to ensure that course content has a relevance to industrial practice. This is best achieved by contextualising problems and emphasising the interrelation of course components to describe whole processes. This is, of course, the aim of the Design Project. Indeed the Design Project should, and to be fair almost always is, industrially relevant. Chemical engineering benefits from a lifelong commitment from many of its graduates; just look at IChemE activities and the way people give back to the profession. An exceptional way to achieve this is for companies to set design challenges and be involved in the delivery and approaches to assessment. In this way a project might be set by an interested company, supporting lectures given, visits arranged to provide context and help offered to the students looking for inspiration or direction. A quid pro quo is the raising of the company's profile in the minds of the students when they choose possible career paths. Understandably, this is the ideal but in the main it seems to be happening across the new courses.

The two halves of the student and industry relationship are briefly described above. However, there should be a glue that binds the pieces. As noted above, academics need to know the industries that might take their students; and equally industrialists need to know who can supply their raw talent. Obviously communication and interaction are the keys. The vehicles for achieving this might then be reciprocal visits and design challenges for instance, but also involvement via industrial advisory boards and steering groups, as well as the obvious value of guest lectures.

All that said, many employers and individual practising and retired professionals are more than willing to assist university engineering departments, once given an appreciation of how to do so effectively. For example, Chester has benefited from the support of experienced individuals living locally (reflecting the local industry base) while in Huddersfield, local industry proved very supportive, with three companies being keen to provide prizes for the graduating cohort (something that costs them very little but raises their own profile with the university and assists their own marketing).

Industry advisory boards are widely utilised, in some cases specific to chemical engineering and in others covering a broad range of engineering disciplines. They vary in effectiveness, and some providers find 1:1 interactions with industrial practitioners to be more fruitful than advisory boards. Common pitfalls include a tendency to invite industrialists to 'come and be talked at'; inconsistent attendance by industry delegates, or delegation from senior to less senior individuals; and failure to assign specific tasks to sub-groups. Participation is most likely to be sustained if those present feel they are contributing something tangible and are not simply being an appreciative audience! A study of good practice in the scoping, composition, operation and impact of industrial advisory boards would be of value.

For links to be truly effective, whether on a bilateral basis or through an advisory board, will require some form of broker to make introductions or at least increase the awareness of each of the groups to the other; perhaps this is a role for IChemE, IET, IMechE and similar bodies. Additionally, the Chemical Engineers should also look to their colleagues in our allied departments. As engineers we are inexorably linked to industry and moving students into technical jobs, but alongside us are chemists, increasingly physicists, mathematicians and colleagues from other disciplines that are also of value in process industries and may not always have an industrially facing outlook; thus ensuring we are "ecumenical" in our approach is probably best for all parties.

ACCEPTED MANUSCRIPT

9 Accreditation

For those seeking to introduce new chemical engineering programmes and get them accredited, the IChemE Accreditation Guidance is of course essential reading (available at http://www.icheme.org/membership/accreditation.aspx). IChemE currently accredits courses at some sixty departments in 14 countries, and the guidance ensures that courses meet needs identified by employers as well as academics, including understanding of process safety and sustainability together with experience of teamwork, design and presentation. Of the new UK providers, Lancaster was accredited in 2016, while Chester, Huddersfield and Hull were all accredited in 2017. In all cases the programme leaders found the accreditation guidance and process invaluable in constructing programmes and giving leverage to ensure appropriate content and practices could be achieved within the constraints of the general university context. For graduates and their employers, accreditation offers international comparability and enhances employability.

There remain challenges in relation to courses that combine chemical engineering with aspects of other disciplines, whether subjects such as other sciences or economics, or other areas of engineering – for example the industrially important field of food process engineering is arguably a blend of chemical and mechanical engineering, while process control brings chemical engineering, electronics and software engineering together. Taking the food example, it would be possible for a set of learning outcomes to equip someone to be an engineer, meeting the requirements of the agreed UK-SPEC standard, while being neither quite a chemical nor a mechanical engineer. Accrediting bodies may need to be more imaginative and co-operative to cater for such cases. In this respect, the non-negotiable requirement to achieve accreditation is likely to have made the new providers cautious in constructing their programmes, perhaps perceiving themselves already to be on the back foot in persuading assessors of the solidity of their chemical engineering content and delivery, in the face of the challenges elaborated above, and hence unwilling to push their luck by being too creative. McLeish (2014, p246) notes Thomas Bender's "strong" and "weak" academic disciplines, in the sense not of a pejorative connotation of weakness but rather the "openness to new movements and ideas that change the character in disciplines", then observes, "The 'strength' (in Bender's sense of 'inflexibility') of the engineering disciplines, by contrast [with physics], reinforced by the prescriptive demands of professional accrediting bodies (at least in the UK), has impeded their development in such new directions." While acknowledging the need to preserve the rigorous strength of engineering disciplines, the observation and warning in relation to ossification are relevant to the discipline of chemical engineering as a whole, and to the role of new providers in moving it in new directions.

Linking back to the previous section, accreditation can be of benefit to universities in relation to the key area of industry engagement, involving as it does academics and industrial practitioners working together on accreditation panels and professional body accreditation committees. The recent Wakeham Review (Wakeham 2016) observes: "We have, for example, been able to identify that accreditation offers one of the most important mechanisms for structured engagement between HE and employers and that it should be taken seriously as a means to engender closer cooperation and a better fit between employer requirements and the skills and knowledge that the HE system has the capability to deliver."

The accreditation guidance was thoroughly revised in 2015, following a consultation that was ongoing at the same time as several of the new providers were starting up, giving for a while a degree of

ACCEPTED MANUSCRIPT

changing of goalposts! However, the revised guidance[1] and process appear to be simpler and fit for purpose. The approach is based on evaluating the learning outcomes achieved by students on the programme (rather than, for example, an approach based on inputs such as entry standards) and on a philosophy of continuous improvement, such that the expectation is that programmes will have improved in tangible ways on subsequent accreditation visits; the submission form opens with a comment on developments following the previous accreditation visit, and ends with Future plans.

The process starts with appointment of a panel comprising an experienced Lead Assessor, an Industry assessor and a third assessor, all experienced professional engineers, who between them represent both academic and industrial perspectives as well as both national and international perspectives. Having established a panel and a date for the 2-day visit, the submission documentation is prepared, comprising two main forms and the Credit Analysis spreadsheet (which facilitates allocation and aggregation of taught credits against the components of Underpinning Maths, Science and Engineering, Core Chemical Engineering, Chemical Engineering Practice, and Chemical Engineering Design and Design Projects), along with supporting evidence including examination papers and scripts, assessment schemes, coursework examples, design and research project reports, and the CVs of the academic staff delivering the programme. The submission documentation and evidence are delivered three months before the visit and scrutinised in advance by the panel: ample time should be allowed to assemble the necessary material. During the visit, aspects of the submission are scrutinised in more detail in dialogue with staff and students at the institution seeking accreditation, and put into the context of the physical and support infrastructures of the institution. The panel submits a report and recommendation to the IChemE's Education and Accreditation Forum (EAF), which makes the final decision about whether to accredit and whether to impose conditions or make recommendations.

The submission documentation rightly covers numerous contextual elements in relation to student support, quality assurance systems, culture and practice, alongside an essential focus on the core of the chemical engineering education being delivered. It is this latter point that perhaps most exercises designers and deliverers of programmes, and the scrutiny of assessors, given the inherent breadth of chemical engineering as a discipline, and the IChemE's desire to promote a diversity of provision while retaining a recognisable core. There is anecdotal evidence that assessor panels tend to take a stricter view than the EAF, which reflects the robustness of the two-tier system that averts the risk of excessively narrow priorities, expectations and interpretations from panels, while allowing the EAF to accommodate the aim of promoting a diversity of provision. Nevertheless, as noted above, there is an understandable inclination towards cautiousness rather than creative new interpretations and implementations of chemical engineering.

The guidance allows both for those universities that follow a common first year for the different engineering disciplines and for those that do not: the former approach underlines the integrated and multidisciplinary nature of engineering, but can be open to criticism regarding the low content of chemistry.

Points of difference or debate can arise from interpretations over to what extent the wording of parts of the guidance is intended to be illustrative or prescriptive. For example, for the Learning Outcomes described under Underpinning Maths, Science and associated Engineering Disciplines, the final learning outcome states:

[1] At the time of writing the latest update is from August 2017.

ACCEPTED MANUSCRIPT

"Students graduating from an accredited programme will: Have a basic understanding of relevant elements from engineering disciplines commonly associated with chemical engineering, such as electrical power and motors; microelectronics; mechanics of pressure vessels; structural mechanics."

It is a matter of interpretation as to whether the components following the words "such as" are illustrative or prescriptive, whether all of these components (but only these components and not alternative equivalents) would be required, and to what extent, in order for a programme to be accredited. Elsewhere, the use of the words "such as" appears to be intended as minimally illustrative, such that the list that follows is intended to be included, but not intended to be exhaustive. Thus, for example, elsewhere in the guidance requirements are made for students to have mastery of things "such as dimensional analysis and mathematical modelling… such as reactors, exchangers and columns…", things that might reasonably be expected in all chemical engineering programmes, but developed beyond this minimally illustrative list. In other cases the guidance is more explicit in its use of "for example", but even there, it remains a matter of interpretation and judgement as to how many of a list of examples might be reasonably expected (one, two, a majority of the list?).

However, making judgements is what engineers do. To quote Dearden (2009) in his article *Judgement Call*: *"It is the role of a professional engineer, having acquired the appropriate competencies, to exercise professional judgement with due regard to pertinent guidance"*; this applies to the range of activities of the chemical engineer including judgement of educational programmes. Elsewhere, commenting on academic judgement, Lamont (2009, pp8, 50) observes *"evaluation is a process that is deeply emotional and interactional… face-to-face conversations are seen as leading to better decisions… debating is important for the emergence of shared standards about fairness and for developing trust."* The consultative aspect of the accreditation visit reflects this and is embodied in the line from the Guidance documentation that accreditation *"… is a joint enterprise in which the IChemE panel and the university department seek understanding through mutually respectful discussion of the available evidence."* (Accreditation Guidance, p2) In this respect, in general both assessor panels and university departments tend to find the experience a constructive one that serves to strengthen programmes and to *"benefit the university, students, employers, IChemE and the wider public."* (Accreditation Guidance, p2).

10 Conclusions

Increased provision of chemical engineering degrees in the UK is coinciding with a fall-off in university applications unprecedented in recent years, thus creating real challenges for new degree providers. Nevertheless, opportunities remain real and with attention to the findings below, the future remains promising for the subject.

1. Growth in the number of providers paves the way for greater diversity in style and content of courses, improved choice for students, and a wider range of types of graduate for those employers prepared to familiarise themselves with the field instead of going to the same few institutions. However, accreditation requirements, while constructive in numerous ways, may also tend to make new providers conservative in conceiving and constructing their programmes.

ACCEPTED MANUSCRIPT

ACCEPTED MANUSCRIPT

2. The same growth also allows more students to study 'close to home', thus constraining costs in a period where university education has become extremely expensive, but providers should be aware that students living 'at home' may be at risk of poorer learning outcomes.
3. Broader approaches to student recruitment, made more necessary (as well as desirable) by a downward trend in applications, include the introduction of 'chemical engineering with…' options, acceptance of students with creative rather than scientific and mathematical strengths, and the possible introduction of degree apprenticeships combining work with study.
4. There is a pressing need for better information on the differentiating features of the various universities and courses to be made available and accessible to prospective students, their influencers, and employers.
5. New course providers need to consider three dilemmas: covering the basics while also embracing novel areas of the subject; combining the skills wanted by employers in the short term with the generic competencies to support a long term career; and ensuring adequate industry exposure for students and industry experience for staff.
6. Current and future generations of chemical engineering students will require greater understanding of underlying science, just as scientists will need to understand scale-up, manufacturability and process economics; the aim will be for engineers and scientists to be able to speak each other's language and work together, not (usually) to create hybrid scientists-engineers.
7. The need for extensive practical experience is driving co-operation among institutions, and between universities and third parties such as colleges and industrial training facilities.
8. The Design Project, for which several models are in use, continues to have a central place but successful delivery requires strong engagement from industry.
9. Opportunities for industry exposure have not kept pace with student numbers. Increased attention should be paid to growing the number of industrial placements and ensuring their quality; to increasing the engagement of industry practitioners in teaching, for example in connection with design projects; and to providing opportunities for academic staff to gain greater industry awareness for example through secondments, interaction with companies on a 1:1 basis, and the effective use of industry advisory boards.
10. Providers and professional bodies should conduct a study of good practice in relation to industrial advisory boards, based on the experience of a range of universities and employers.
11. The accreditation process continues to add much value for universities, students and employers, provided it is not treated as simply prescriptive or used as an excuse not to innovate. It can strengthen the case for necessary investment in staff and infrastructure. However, further evolution is required if interdisciplinary course offerings and novel types of engineering, attractive to students and important to industry, are to be well served.

ACCEPTED MANUSCRIPT

ACCEPTED MANUSCRIPT

Acknowledgements

The authors are grateful to staff members from all the new providers listed in Table 1[2] and referred to in the text, for open exchanges and information sharing in relation to the status, challenges and directions of their new programmes. They include:

Abhishek Asthana, Sheffield Hallam University, Howard Street, Sheffield, S1 1WB, UK
Henri Huijberts, Queen Mary University of London, Mile End Rd, London E1 4NS, UK
Alastair Martin, University of Lancaster, Lancaster LA1 4YW, UK
Anne Nortcliffe, Canterbury Christ Church University, Canterbury CT1 1QU, UK
Raj Patel, University of Bradford, Richmond Rd, Bradford BD7 1DP, UK
Philip Rubini, University of Hull, Cottingham Road, Hull HU6 7RX, UK
Stefaan Simons, Brunel University London, Uxbridge UB8 3PH, UK
Stephen Wilkinson, University of Chester, Thornton Science Park, Pool Lane, Pool Ln, Chester CH2 4NU, UK

ACCEPTED MANUSCRIPT

ACCEPTED MANUSCRIPT

References

The use of computers by chemical engineers: Good practice guidelines, IChemE CAPE subject group report, July 1999, http://www.icheme.org/~/media/Documents/Subject%20Groups/CAPE/TheUseofComputersbyChemicalEngineersGuidelines1999.pdf Accessed 16/09/2017

Atkinson, H., Pennington, M. 2012. Unemployment of Engineering Graduates: the Key Issues. Engineering Education 7, 7-15.

Beck, D.A.C., Carothers, J.M., Subramanian, V.R., Pfaendtner, J., 2016. Data science: Accelerating innovation and discovery in chemical engineering. AIChE J. 62, 1402-1416.

Belton, D.J., 2016. Teaching process simulation using video-enhanced and discovery/inquiry-based learning: methodology and analysis within a theoretical framework for skill acquisition. Educ. Chem. Eng. 17, 54-64.

Billo, E.J., 2011. Excel for chemists: a comprehensive guide, 3rd ed. Wiley.

Campbell, G.M., Belton, D.J, 2016. Setting up new chemical engineering degree programmes: Exercises in design and retrofit within constraints. Education for Chemical Engineers 17, 1-13.

Chambers, T.L., 2006. Teaching engineering analysis using VBA for Excel, Proceedings of the 2006 ASEE Gulf-Southwest Annual Conference, Baton Rouge.

Chemmangattuvalappil, N., Chon, C., Sum, D.N.K., Elyas, R., Chen, C.-L., Chien, I.L., Lee, H.-Y., Elms, R., 2017. Chemical Engineering Process Simulation. Elsevier, Amsterdam.

Dahm, K.D., Hesketh, R.P., Savelski, M.J., 2002. Is process simulation used effectively in ChE courses? Chem. Eng. Educ. 36, 192-197.

David, I., Bogle, L. 1996. An introductory course in computer aided process engineering (CAPE). Computers & chemical engineering, 20, S1323-S1327.

Dearden, H. 2009. Judgement Call. The Chemical Engineer 814, 18-19.

dos Santos, M.T., Vianna Jr, A.S., Le Roux, G.A.C., 2018. Programming skills in the industry 4.0: are chemical engineering students able to face new problems? Educ. Chem. Eng. 22, 69-76.

Dreyfus, H.L., Dreyfus, S.E., Athanasiou, T., 1986. Mind Over Machine: The Power of Human Intuition and Expertise in the Era of the Computer. Free Press, New York.

Kravanja, Z., 2016. 26th European Symposium on Computer Aided Process Engineering: Part A and B. Elsevier.

Lamont, M. 2009. How Professors Think: Inside the Curious World of Academic Judgment. Harvard University Press, Cambridge, Massachusetts, USA.

Law, V.J., 2013. Numerical methods for chemical engineers using Excel, VBA, and MATLAB. CRC Press.

Lewin, D.R., Seider, W.D., Seader, J.D., 2002. Integrated process design instruction. Comput. Chem. Eng. 26, 295-306.

Li, X., Huang, Z.J., 2017. An inverted classroom approach to educate MATLAB in chemical process control. Educ. Chem. Eng. 19, 1-12.

Love, J., 2007. Process automation handbook: a guide to theory and practice. Springer, London.

ACCEPTED MANUSCRIPT

ACCEPTED MANUSCRIPT

Norton, C., Cameron, I., Crosthwaite, C., Balliu, N., Tade, M., Shallcross, D., Hoadley, A., Barton, G., Kavanagh, J., 2008. Development and deployment of an immersive learning environment for enhancing process systems engineering concepts. Educ. Chem. Eng. 3, e75-e83.

McLeish, T. 2014. Faith and Wisdom in Science. Oxford University Press, UK.

National HE STEM Programme Regional Action Plan, available at http://epc.ac.uk/wp-content/uploads/2012/11/HE-STEM-Engineering-Grad-Unemployment-2012.pdf.

Neves, J., Hillman, N. 2017a. 2017 Student Academic Experience Survey, Higher Education Academy, York, and Higher Education Policy Institute, Oxford, p.12.

Neves, J. and Hillman, N, 2017b. Op.cit, p.25-26.

Puigjaner, L., Heyen, G., 2006. CAPE: computer aided process and product engineering. Wiley-VCH, Weinheim.

Qin, S.J., 2014. Process data analytics in the era of big data. AIChE J. 60, 3092-3100.

Rodrigues, A., Cussler, E.L. 2016. Teaching chemical product design. Education for Chemical Engineers 14, 43-48.

Russell, A.W., Dolnicar, S. and Ayoub, M. 2007. Double degrees: double the trouble or twice the return?. Higher Education 55 (5), 575-591.

Schofield, D., 2012. Mass effect: A chemical engineering education application of virtual reality simulator technology. J. Online Learn. Teach. 8, 63-78.

Shott, I., Titchener-Hooker, N., Seville, J., 2015. Pick a Mix. The Chemical Engineer 894, 35-36.

Wakeham, W. 2016. Wakeham Review of STEM Degree Provision and Graduate Employability. Prepared for the Department of Business, Innovation and Skills, London.

Wankat, P., 2017. Perspective: Teaching Professional Skills, AIChE Journal 63, No. 7.

Wilson, J. 2016. Work experience as a gateway to talent in the UK: Assessing business views. National Council for Universities and Business, London.

Wong, K.W.W., Barford, J.P., 2010. Teaching Excel VBA as a problem solving tool for chemical engineering core courses. Educ. Chem. Eng. 5, e72-e77.

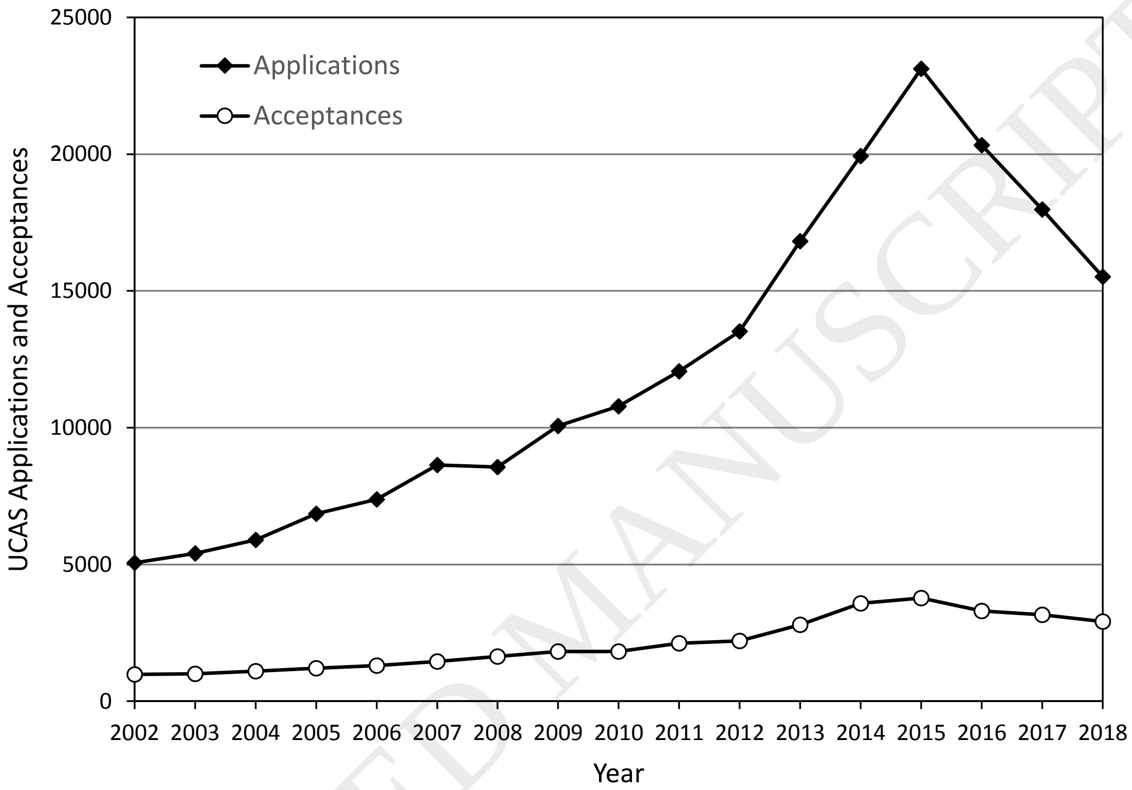
Yuan, Z., Qin, W., Zhao, J., 2017. Smart manufacturing for the oil refining and petrochemical industry. Eng. 3, 179-182.

ACCEPTED MANUSCRIPT

ACCEPTED MANUSCRIPT

---

[i] see www.whynotchemeng.com
[ii] See http://hcfcatch.com/
[iii] See for example https://www.icheme.org/~/media/Documents/Subject%20Groups/Education/1041_14%20Industrial%20placement%20GuidanceLR.pdf , https://workwith.online/ and http://epc.ac.uk/contextual-learning-toolkits/



ACCEPTED MANUSCRIPT

Figure 2 Laboratory equipment at Swansea: the value of going beyond bench scale

Figure 3 Laboratory layout and equipment at Greenwich

ACCEPTED MANUSCRIPT

ACCEPTED MANUSCRIPT

*Table 1 Features of new chemical engineering programmes**

University: **Programmes**	**Date of first BEng graduating cohort;** **Approximate student cohorts (2018-19)**	**Distinctive emphases or specialisms**	**Location; links, shared teaching**	**Context for developing a new programme; major new infrastructure requirements**	**Use of external facilities; Use of virtual environments and simulation**	**Industry panel, industry input; Design Project model, support and delivery.**
Bradford: BEng, MEng Chemical Engineering	First BEng graduation, 2012 Current cohorts: 1st year: 89 2nd year: 57 3rd year: 59 4th year: 35	1) Food and Pharmaceutical Engineering 2) Desalination Technology 3) Polymer Processing 4) Petroleum Engineering 5) Upstream Production & Refinery Operations	Chemical Engineering Department, Faculty of Engineering & Informatics. All taught from within the faculty, except for 'Chemistry for Engineers' which is taught by Faculty of Life Sciences.	Bradford ceased delivery of Chem Eng in 2002. Due to demand we relaunched in Sept 2010. New lab with bench-top equipment.	Aspen Plus and MATLAB used throughout the years. gPROMS, HydraFlash, Aspen Hysys, gSOLID and EDEM used at Level 7.	Industrial Advisory Board set up in 2015 & meets twice a year. Guest lectures for all core chemical engineering modules.
Hull: BEng, MEng Chemical Engineering, MEng Chemical	First BEng graduation, 2015 Current cohort 1st year - 110	Research emphasis on Biofuels and Biomaterials	School of Engineering and Computer Science All modules taught within the	Initiative from VC to develop course to reflect concentration of chemical and process industry in the region.	CATCH - Apprentice training centre with process plant, and simulator. 1st Year students visit for 2 days as part of Process Safety.	Original industry panel during design of programmes. New School reorganisation currently setting up a School wide

ACCEPTED MANUSCRIPT

ACCEPTED MANUSCRIPT

Engineering and Energy	2nd year - 100 3rd year - 96 4th year - 40		School. Maths common for all engineers (Mech/Elec/Chem) Chemistry teaching labs used, ChemEng academics		Plan to extend to later years. MATLAB, Aspen HYSYS all years. Aspen Plus, gPROMS, Ansys used in Level 7, especially for final year projects Virtual Control Room with real time dynamic simulation and 3D VR capability currently being installed.	Industry Panel. Process safety training for Year 1 and Year 4 provided by external process safety training company. The Year 4 module provides students with an additional IOSH qualification Design project sponsored by local company, with engineers providing introduction to the task and judging final project presentations. Guest lectures and site visits coordinated under auspices of local IChemE member group.
Lancaster: BEng, MEng Chemical Engineering	First BEng graduation, 2015 Current cohorts: 1st year: 29 2nd year: 35	1) Energy (Nuclear) 2) Bio-processing 3) Electrochemical engineering	Engineering department, Faculty of Science and Technology. Links to chemistry for lab resources, Maths teaching delivered by maths departmen	University strategic opportunity. Complimentary to existing Nuclear engineering programme. New chemical engineering lab, micro-pilot equipment.	Site visits. MATLAB throughout course, Aspen engineering suite used from year 2 onwards, ANSYS and COMSOL in 3rd and 4th years in project contexts	Engineering Industrial Advisory Board meets twice a year. Group design project in year 3. Whole process design, diverse range of products. Partial peer assessment by following cohort. Lead academic with

ACCEPTED MANUSCRIPT

ACCEPTED MANUSCRIPT

	3rd year: 31 4th year: 11		t to all engineers			50:50 industry academia experience. Guest lectures from industry/contracting. Yr3-yr4 collaborative bridging project with industry and international partners (clients).
Huddersfield: BEng, MEng Chemical Engineering; BSc Chemical Engineering and Chemistry	First BEng graduation, 2017; Current cohorts: 1st year: 39 2nd year: 28 3rd year: 52 4th year: 14	Distinctive emphases: Chemistry, Systems thinking tools, practical laboratory skills, process simulation skills	Department of Chemical Sciences, School of Applied Sciences. All taught from within the Dept, except a 1st year maths module taught from the School of Computing and Engineering, and 2nd and 3rd year optional modules from that School.	Natural outgrowth from teaching chemical engineering in a chemistry context for >50 years. Existing chemical engineering lab, just needed a more focussed selection of rigs (with multiple units).	Kirklees College Process Manufacturing Training Centre (1 day as part of 3rd year Process Control and Safety Engineering module); Pro II used throughout the three years, Matlab and DynSim used in 3rd year Process Control, gPROMS in 4th year Computer-Aided Product and Process Design	No industry panel. Industry input to developing programme. Industry input as guest lectures on several modules, covering management, process control, safety. Design Project supported by a retired academic with long experience in teaching chemical engineering design, and with the brief to enhance staff technical and supervisory competence for the future. Design projects are specified, with different groups doing broadly the same task, with central support (Model 1).

ACCEPTED MANUSCRIPT

ACCEPTED MANUSCRIPT

Chester: BEng, MEng Chemical Engineering.	First BEng graduation, 2017; Current cohorts: 1st year: 31 2nd year: 31 3rd year: 45 4th year:12	Distinctive emphases: Employability embedded into teaching. 1st year placements for 4 weeks in June and 2nd year placements in May. Location on Science Park shared with small companies.	Department of Chemical Engineering, Faculty of Science at the university's Thornton Science Park. Shared modules and teaching across Faculty e.g. 50-75% of 1st year shared with Mech Eng (heat transfer, fluids, thermo, maths) and Natural Sciences (maths, chemistry, biotech).	New Faculty of Science and Engineering established at former Shell Thornton Research Park in Sept 2013, New Depts of Chemical, Mechanical, Electronic & Electrical Engineering, as well as Natural Sciences were joined by existing Depts of Maths and Computer Science.	Half day Field Trips to neighbouring Stanlow oil refinery and CF Fertilisers Ammonia plant early in 1st year form part of assessment in Professional Skills module. Pro II used throughout the three years, Matlab used in 1st and 2nd years in Professional Skills and Maths.	Industrial steering group established to provide some input that was acted upon – e.g. produce graduates who can use Excel! Industry led lectures on process safety, legislation.
Wolverhampton:	First graduation 2018 1st year: 15 2nd year: 24 3rd year: 34 Graduated: 15 Forthcoming intake: 61	Food/energy	Engineering but located alongside physics, maths and chemistry. Petroleum engineering management in associated school	Previous VC had seen the worth of chem eng. Regional competitors should have been fishing in other ponds, giving us a regional USP.	Series of external visits arranged, and industrial speakers. Use of Matlab and ProII In all years. Hope to get suite of CFD packages next year	Yes along with sciences. Ex-head of design for a major redbrick dept. is consultant for design studies. Direct input from growing number of industrialists - e.g. for control

ACCEPTED MANUSCRIPT

ACCEPTED MANUSCRIPT

Sheffield Hallam (SHU):	First BEng graduation 2019 Current cohorts: 1st year: 37 2nd year: 30 3rd year: 30	Emphasis on employability and provision of placements	Hosts the National Centre of Excellence for Food Engineering with strong ties to the food and drink sector. Not many chemical industries in the region. Maths and Chemistry modules shared with other engineering disciplines.	New HOD appointed for Engineering Department in 2014 with previous experience of establishing Chemical Engineering Department at another university. Market survey confirmed the need for Chemical Engineering programmes. A substantial part of £5.5 million grant from HEFCE (+5.5 million match funding) used for developing new lab facilities for the course.	Apsen Plus licence acquired, Matlab and Ansys Fluent available already. Sophisticated research equipment additionally available at Materials and Engineering Research Institute at SHU for final year projects.	Industrial Advisory Board, senior academics from other universities and IChemE input into the design development of the programmes. Regular industry visits and guest lectures organised.
Greenwich: BEng, Ext, MEng in Chemical Engineering	First cohort of students (Sept 2017). Second year of recruitment, with promising numbers. Singular participation of women and London & South East student	Particle technology, Food Science and Technology, Pharma & Biotechnology. Desalination technology and Water Waste & Environmental Engineering.	New structure with Faculty of Engineering and Science, divided into two schools: Science and Engineering. 1st year is common to all engineering students. Entry points from both Engineering and Chemistry routes.	Brand new specialist lab using a blend of experiments such as heat transfer, rectification, thermodynamics, multivariable control or particle technology. Also incorporating world-leading research expertise: Wolfson Centre for bulk solids handling, NRI and School of Pharmacy.	Current use of Fluent, Comsol, Simulink, Labview. AspenTech academic license. Faculty believes in learning by doing, though. Several virtual lab environments based on Matlab tools and Virtual Formulation Lab for advanced solid formulations.	Several industrial panels – at the Faculty and Engineering level. Several leading companies involved in the programme development and IChemE consulted extensively. Senior engineers (mentors) will support the guidance of design projects..

ACCEPTED MANUSCRIPT

	s plus a combination of international students					
Queen Mary University of London BEng/MEng Chemical Engineering BEng/MEng Chemical Engineering with Industrial Experience BEng/MEng Chemical Engineering with Year Abroad	First BEng graduation: 2020. 2017 intake: 42 2018 intake: 48	Distinctive emphases: Thermofluids, Materials Chemistry and Processing, Energy Materials	School of Engineering and Materials Science, Division of Chemical Engineering and Renewable Energy. All taught from the School, ~40% shared with other Engineering programmes (Aero, Mech, Biomed)	Completely new in response to student interest and gap in portfolio. Chemical Engineering considered to be an integrator of research strengths within the School.	No use of external facilities planned currently. Matlab used throughout. Virtual environments and simulations used throughout.	Industrial Advisory Boards for Aerospace Engineering & Fluid Mechanics; Biomedical Engineering & Biomaterials; Materials Engineering; Mechanical Engineering, Robotics & Design; Chemical Engineering and Renewable Energy.
Brunel: BEng, MEng Chemical Engineering; MSc Bioprocess	2019/2020 start	Technology/Engineering based courses, Creative design; Resource efficiency; Emerging low carbon technologies; Practical laboratory skills; Cyber security	College of Engineering, Design & Physical Sciences. Engineering college-based courses with all specific	Chem eng 4 (inc HOD), chemistry/materials 5 Gaps: Technician & Further Chem Eng recruitments as	TBC	Brunel has strong industrial links and therefore, industrial guest lecturers is a normal practice. An industrial advisory panel

ACCEPTED MANUSCRIPT

ACCEPTED MANUSCRIPT

Engineering			and shared modules within the college	approaching L2,3 & 5.		is to be considered.
Canterbury Christ Church: MEng Chemical Engineering BEng Chemical Engineering BEng Chemical Engineering with Foundation Year	Validated 6th June 2018 2018 Sept' intake to BEng Chemical Engineering with Foundation Year: Foundation Year: 7 MEng/ BEng Chemical Engineering	Industry co-design curriculum to support over 30 pharmaceutical/cosmetic/food and drink/water utilities companies who require a curriculum design that embeds and integrates chemistry and biochemistry with respect to chemical engineering. Also, adopting Conceive, Design, Implement and Operate (CDIO) pedagogy, CDIO projects where possible sourced from industry.	The programmes reside in New School of Engineering, Technology and Design. Chemistry, Biology, and Maths related modules are supported by School of Life Sciences.	The Chemical Engineering programmes are part of innovative initiative led by Pro-VC Professor Helen James to create Kent and Medway EDGE (Engineering, Design, Growth and Enterprise) Hub to support and grow local economy. Initiative secured £13.1M from National and Local Government	The Life Sciences Industry Liaison Labs at Discovery Park as provides the academics and students access to first class facilities for science and research, also the opportunity to network with industry. Matlab, LabView, and seeking Aspen License.	Curriculum co-designed and developed with local Pharmaceutical/ Food and Drink/Water Utilities/ Automation Suppliers to chemical industry. Local Pharmaceutical company providing industrial field trips, company conference opportunities, guest lectures, placements and CDIO projects. Currently working with employers to co-design SIPPE Apprenticeship Degree programme.

Table 2 Challenges and advantages for new and established providers.

	Large / established providers	New providers

ACCEPTED MANUSCRIPT

Challenges	• Staff / infrastructure fails to keep pace with student numbers • Impersonal teaching • Maintaining reputation while student numbers have risen • Demanding financial targets • 'The only way is down'	• Too few staff to cover a broad subject • Lack of reputation • Limited industrial links • Limited range of practical equipment • Securing industrialist participation e.g. in advisory boards • Accreditation of innovative / interdisciplinary courses
Advantages	• Existing course content • Established reputation • Alumni network • Established industry / employer links • Labs and facilities • Wide range of staff	• Little academic inertia • Free to innovate • Close personal contact with a small student cohort • Co-create with students • Increased interest in studying close to home • 'The only way is up'

ACCEPTED MANUSCRIPT