Setting up new Chemical Engineering degree programmes: Exercises in design and retrofit within constraints

Grant M Campbell and Daniel J Belton

School of Applied Sciences, University of Huddersfield, Queensgate, Huddersfield, HD1 3DH, UK
*corresponding author: g.campbell@hud.ac.uk

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Abstract

The rise in popularity of chemical engineering among students entering university has prompted expansion of the UK provision, through increased intake into current degree programmes and with the rise of new providers. The former entails logistical challenges of processing larger numbers through existing infrastructures whilst maintaining the student experience. The latter entails challenges of designing and introducing programmes that build harmoniously on existing non-chemical engineering provision, within the constraints of university validation procedures and physical resources, and in the face of uncertainty around student and staff recruitment, while aspiring to implement best practice in chemical engineering content and pedagogy. Following a review of the UK chemical engineering landscape and a critique of literature guidance on the appropriate content of chemical engineering curricula, this paper illustrates the issues of new programme development through the approaches and experiences of a new provider, the University of Huddersfield, which introduced new chemical engineering programmes from academic year 2013-14. The paper addresses specifying the content of chemical engineering programmes to align with accreditation requirements and literature advice while maintaining distinctiveness. The constraints imposed by the need to specify and validate courses internally and to minimise substantive programme changes subsequently, whilst responding to the opportunities that arise as staff are recruited and to external developments and unplanned incidents, are highlighted and illustrated, in order to draw lessons that might help to guide other new entrants.

Keywords

programme design; curriculum; accreditation; validation; design project; laboratory infrastructure

1. Introduction

As all chemical engineers know, analysing and operating a process at steady state is orders of magnitude easier than dealing with a highly dynamic process or situation. Plant modification and minor retrofit are a constant part of the refinement of plants to enhance productivity and to respond to relatively minor internal upsets and external influences while continuing to produce much the same product. Plant commissioning or substantial retrofitting projects are, by contrast, much more demanding. The introduction of new degree programmes in universities is in some respects analogous to new plant commissioning or substantial retrofitting in terms of timescale and challenge, compared with tweaking a degree programme operating more or less at steady state. And the substantial increase in demand from students wanting to study chemical engineering has prompted increases in capacity from existing providers alongside new entrants into the market, injecting a challenging dynamism into chemical engineering provision in UK universities.

Following a concern in the late 1990s over the health of UK chemical engineering and a steady decrease in university applications to the extent that "departments [were] desperate to fill vacancies' (Molzahn, 2004), from around 2002 chemical engineering has been very much in the ascendancy, more than quadrupling by 2015 to around 23,000 applications, converting to over 3700 acceptances of Home students onto degree programmes (Figure 1). This success is attributed in part to IChemE initiatives such as the whynotchemeng campaign and the Roadmap, including success in conveying the message that chemical engineering aligns with prospective students' aspirations to make a positive difference to the world (Byrne, 2010); in part to the increase in university tuition fees focussing the minds of students and their parents on degree choices that promise a good return, with chemical engineering the most lucrative of the engineering professions and second only to dentistry for graduate earnings (Anon., 2015). Whatever the reasons, these plentiful conditions have made offering chemical engineering programmes attractive to universities, whether to boost student numbers and/or quality for existing providers, or for the entry of new providers. Thus, several well established chemical engineering departments in the UK have similarly quadrupled their first year intakes from typically 75 students in 2002 to over 300 in recent years, often while increasing entry grades. Meanwhile, other universities have introduced or resurrected chemical engineering programmes. The IChemE currently lists 23 universities offering accredited chemical engineering degrees in the UK, with Aberdeen the most recent to secure accreditation following the launch of its chemical engineering programmes in 2006. However at least half a dozen new entrants are emerging. The University of Bradford had closed its chemical engineering programmes in 2002 following a drop in intake to 16 students, but in 2010 it reopened chemical engineering within its School of Engineering. Hull took its first BEng chemical engineering students in 2013; in the same year Huddersfield introduced a 50:50 BSc in Chemical Engineering and Chemistry within its School of Applied Sciences then, encouraged by the uptake, brought in a full BEng in Chemical Engineering in 2014. The donation of Shell's former

R&D site at Thornton to the University of Chester in 2013 prompted the university to create the UK's first new Faculty of Science and Engineering in over 20 years; the new faculty took its first cohort of students in September 2014, with chemical engineering part of the suite of courses benefitting from the 48 science and engineering buildings on the 66-acre site – a unique situation that will undoubtedly deliver a distinctive and valuable student experience. The Universities of Lancaster and Wolverhampton are both currently investing £12M in new engineering facilities, including chemical, the latter taking its first entry in 2015. Sheffield Hallam University is listed on UCAS as offering chemical engineering programmes for 2016, with Brunel also planning to introduce chemical engineering. Thus the scale and scope of UK chemical engineering provision have expanded in response to the attractiveness of our discipline to students.

Interestingly, it appears the demand has not prompted a wider scope of chemical engineering specialisms within individual departments; on the contrary, some departments appear to have rationalised their provision into fewer programmes in order to cope with the larger student numbers, no longer needing to cast the net so widely. Thus, for example, Byrne (2006), noting the attractiveness of specialist programmes for enticing students, lists six specialist options from the University of Manchester on top of its straight MEng Chemical Engineering; for 2016 UCAS lists just three specialisms. Sheffield had six MEng specialisms and still does (albeit slightly different). Newcastle and Heriot-Watt both had four and now have three. Compared with the diversity of specialisms listed by Byrne (2006), the current offerings on UCAS appear somewhat streamlined, a retraction perhaps into undifferentiated commodity processing in the face of large student numbers, with breadth offered instead by a broader scope of providers each with narrower portfolios.

2. Designing, or retrofitting, a chemical engineering programme

To a chemical engineering educator, it is attractive to contemplate sitting down with a blank sheet and designing the "perfect" chemical engineering programme. But engineering is "design under constraint" – in this case, constraints of what prospective students are capable of mastering, of what staff are capable of delivering, of what the infrastructure is capable of servicing, of what content can be squeezed into 3- and 4-year programmes, of what employers and accrediting bodies demand, and of the underlying vision for the type of graduate the programme aims to cultivate. Judgements must be made based on appropriate objective external guidance, adapted to local context, and undoubtedly coloured by personal or collective preferences, principles and prejudices. In most cases a blank sheet scenario is unavailable, and design of a programme is either based on a rearrangement, possibly radical, of existing staffing and infrastructure resource (*e.g.* as described by Gomes et al., 2006), or retrofitting around a basis of material drawn from existing courses possibly in chemistry, biology, mechanical engineering, materials science or mathematics, or from a common Year 1 engineering intake. In some ways this is more helpful than complete blank-sheet freedom, as the presence of constraints is more conducive to creativity than their complete absence, and existing strengths and opportunities help in conceiving the distinctive features and emphases of a prospective new programme and in devising a feasible pathway to build it.

The blank-sheet designer might also find little consensus in the literature regarding the suitable curriculum for an undergraduate chemical engineering degree programme. Byrne (2006) reviews the literature debating how chemical engineering education should evolve and adapt, highlighting the range of views from those advocating substantial change towards enhanced scientific basics (particularly around biology and biotechnology, see also Shott et al. (2015)), business acumen and soft skills, with trimming of some of the more traditional material, to those who point to the evidence that the traditional core skills are highly valued by industry, as evidenced by the demand for such engineers, and cautioning against the rush "to gallop into these new areas" (Agnew et al., 2003). Looking to industry for advice on how to orient chemical engineering programmes is reasonable, and Byrne (2006) quotes, by way of example, Douglas Ruthven who observed from talking with former students now working in industry "When asked how the curriculum should be modified to better serve the demands of an industrial career the response was never for additional emphasis on modelling and mathematical analysis!" Against this one can argue that, while employability is a legitimate focus for all sorts of reasons, higher education is as much about education as employability and must protect this corner that is uniquely its responsibility, and that part of that unique responsibility is to "teach at university what cannot be taught elsewhere".

An educator at the sharp end of getting approval for and delivering a new chemical engineering programme could also become disheartened by the exhortations in the literature to squeeze ever more, and more challenging, material into an already overburdened discipline; one's grasp very quickly exceeds one's reach. Perkins (2003) describes chemical engineering as the broadest of the engineering disciplines, a feature that undoubtedly underpins the concern of overburdening curricula that is a theme of the literature. This daunting breadth is evident in the chemical engineering taxonomy developed by the Engineering and Physical Sciences Research Council and shown in Table 1 (Anon, 2015b). Molzhan (2004) urges "the courage not to try and cover everything" and reports a recommendation from the European Federation of Chemical Engineers' Working Party for a chemical engineering core curriculum that is quite traditional and trimmed down. Notably it omits the Sustainability emphasis that has become pressing in recent years (see for example Byrne and Fitzpatrick (2009) and Glassey and Haile (2012)) and the emphasis on process systems engineering promoted by Perkins (2002) and Stephanopoulos and Reklaitis (2011), both of whom highlight the need to balance a long-standing emphasis on analysis with a more distinctive emphasis on synthesis, while acknowledging that educational material for the latter is less readily available. (Note that the process systems engineering emphasis encompasses sustainability and strengthens it by emphasising synthesis alongside the more prominent (life cycle) analysis.) Shott et al. (2015) express concerns over "a high level of uniformity in terms of [chemical engineering syllabi in the UK], with a high degree of focus on the oil and gas industries" and urge "diversity of delivery for the decades to come", in particular urging some provision of "life science chemical engineering" including industrial biotechnology and synthetic biology.

In the conversation about curricula, it is important to acknowledge that not every student needs to master every component of the breadth of chemical engineering, not at the Masters level and even less at the Bachelor's level. The Engineering Council's Accreditation of Higher Education Programmes (AHEP) document, based on the UK Standard for Professional Engineering Competence (UK-SPEC) describes Integrated Masters (MEng) and other Masters (MSc) degrees as awarded to students who have demonstrated (italics added) "a *comprehensive* understanding of techniques applicable to their own research or advanced scholarship", "A *comprehensive* knowledge and understanding of scientific principles and methodology necessary to underpin their education in their engineering discipline", "A *comprehensive* knowledge and understanding of mathematical and computational models relevant to the engineering discipline" and "wide knowledge and *comprehensive* understanding of design processes and methodologies". Notwithstanding that it has never been resolved whether the descriptors in this document are to be viewed as minimal, modal or aspirational, not even full professors of chemical engineering or senior industrial practitioners would consider their knowledge of the discipline and its scientific, mathematical and computational underpinnings as "comprehensive". On a similar note, Stephanopoulos and Reklaitis (2011) argue that process systems engineering (PSE) is "the foundational underpinning of modern chemical engineering; the one that ensures the discipline's cohesiveness in the years to come" but that despite this, "a significant number of educational institutions do not recognise it as a foundational component of the chemical engineering curriculum". Byrne and Fitzpatrick (2009) argue similarly persuasively and more pressingly for Sustainability as a core integrating principle for chemical engineering curricula development and accreditation, acknowledging the perception of "yet another addition to an already overburdened programme", an addition that, in dealing with "wicked problems", stretches not just the programme but the abilities of what staff can deliver and students master within the constraints of an undergraduate programme. Chemical engineering suffers something of an identity crisis, with Stephanopoulos and Reklaitis (2011) arguing for PSE serving as the core glue as "chemical engineering tries to redefine its intellectual core and disciplinary cohesiveness, *and attempts to discipline centrifugal forces towards the interface with other disciplines*" (italics added). In the face of this internal struggle for the soul of the discipline at risk of disintegration towards an ever-wider scope and ever-deeper challenge, it is even less reasonable to expect graduates to have "comprehensive" knowledge and understanding of the discipline, or for a given programme to cover its breadth and depth anywhere near comprehensively.

However, a more comprehensive understanding of chemical engineering could be approached if graduates were to depart with a commitment to lifelong learning. The

United States' Accreditation Board for Engineering and Technology (ABET) includes in its criteria for the accreditation of university engineering programmes "a recognition of the need for, and an ability to engage in, life-long learning" (Spurlin et al., 2008, p. 73); the UK Standard for Professional Engineering Competence (UK-SPEC) similarly recognises the need for lifelong learning, and lists "ability to learn independently" as one of the distinctive outcomes expected from an MEng programme (Anon., 2004). Campbell et al. (2010) ask "on what basis might an engineering programme demonstrate that it is giving its graduates the ability to engage in lifelong learning?", and describe an initiative to do so via encouraging and empowering engineering graduates to engage in reading as the basis for lifelong learning.

In any case, some educators warn against an over-emphasis on curriculum as the defining component of an effective education, noting the dictum that "more is caught than taught". Learning is a social endeavour, and exposing students to highly educated, experienced and capable teachers is, arguably, of more value than the specific content. Ashwin et al (2015, p333) highlight the importance of teacher expertise in making a difference to the quality of student learning in terms of more integrated and coherent understanding of concepts. In this respect, a programme design that originates from personal passion (and prejudices), and that has as its basis the social interaction of a community of scholars, perhaps has greater power to inspire and educate than a curriculum that on paper is ambitiously comprehensive and objectively "perfect".

Beyond issues of curriculum content lie the even more fraught issues of effective delivery mechanisms. It seems wise to aspire to deliver a variety of teaching and learning experiences, appropriately ambitiously within the constraints of time and priority, and depending on the competence and commitment of the staff. Beyond that, a critique of the range of available options is outside the scope of the current paper; we acknowledge this important aspect of curriculum design without seeking to resolve it on this occasion. We note that there is scope and opportunity to inject distinctiveness into a programme through adopting and promoting some novel delivery methods. We also highlight, however, the importance of recognising that it is more the competence and commitment of the teacher than the inherent merits of the delivery method that most affect student learning (Thomas, 2013, pp40-41; Ashwin et al., 2015, p333).

At risk of appearing unambitious or uninspiring, it seems pragmatic for the designer of a new chemical engineering programme to be content to make a distinct, coherent offering that complements the scope of available programmes elsewhere, the only non-negotiable being to fulfil the requirements for accreditation. Meanwhile, accreditation bodies such as IChemE might be in a position to take an overview of the range of available programmes, in order to be satisfied that overall chemical engineering is covered adequately, while encouraging and facilitating new programmes to address weaknesses or opportunities, rather than exerting pressure for comprehensive coverage within each individual programme, beyond an agreed core. Perkins (2002) observes "It is unlikely that there is such a thing as a 'typical' chemical engineering course these days" and (like Shott et al. (2015)) encourages a healthy diversity of curricula, but advises, by way of maintaining a core identity and power, that "It is the combination of a strong and broad base in engineering science and the ability to synthesise as well as analyse complex systems that is the unique feature of chemical engineering." In devising new programmes, clarity around the unique features and power of chemical engineering seems a helpful starting point.

3. A natural outgrowth: Resurrecting chemical engineering at the University of Huddersfield

The University of Huddersfield is a post-1992 former polytechnic that traces its roots back to the Huddersfield Science and Mechanics Institute founded in 1825 in support of local industry (Tylecote, 1957). In 1843, chemistry was added to the curriculum, driven by the requirements of the local textile industry to dye and add value to its products, and colour chemistry remains a strength of the current School of Applied Sciences. Full-time courses in Chemical Engineering have been available in Huddersfield since 1964, when the institution began to offer a 2 year higher national diploma (HND). This was preceded by a part-time higher national certificate (HNC), which was taught from the early 1950s predominantly by Chemical Engineers from the local ICI site. Figure 2 shows a jacketed pan batch reactor that was donated by ICI and used by students for lab work from the 1950s to the early 2000s, and Figure 3 shows the chemical engineering lab in the 1960s. Links with local industry were also supported by Chemical Engineering summer schools. These were run by the first full-time member of chemical engineering staff, Stan Michell. Attempts were also made in the 1960s to introduce a full degree in Chemical Engineering that, whilst approved at regional level by the Yorkshire council for Further Education, was not given the go-ahead at a national level.

During the transition to a post-1992 university, the chemical engineering infrastructure continued to be enhanced and deployed in support of chemistry programmes, recognising the value to industry of chemistry graduates with some knowledge of chemical engineering. This included a major refurbishment of the lab in 2006. Having this history along with an excellent and well-resourced chemical engineering laboratory, it made sense, in the light of the increasing popularity of chemical engineering, for the university to reintroduce full chemical engineering programmes, this time at degree level. Daniel Belton, employed as a senior lecturer in analytical chemistry but originally a chemical engineering MEng and PhD graduate from the University of Manchester, was tasked with designing a programme for internal validation within the university.

The School already offered a BSc degree in Chemistry with Chemical Engineering, the latter comprising 1/3rd of the programme, or straight Chemistry BSc programmes with a few chemical engineering electives, these being of an overview nature rather than in depth. Its first step was to introduce in 2013-14 a 50:50 BSc in Chemical Engineering and Chemistry, to dip its toe in the water by seeing the response to giving the chemical engineering element first billing. This programme retained the core themes of Physical, Organic and Inorganic Chemistry (3×20 = 60 credits) throughout the three years plus the final year Chemistry Project, in order to retain the basis for RSC accreditation, and added modules covering key chemical engineering topics in proper chemical engineering depth: *Heat Transfer and Fluid Flow*, *Chemical Engineering Design*, a *Maths* module, *Transport Processes and Unit Operations* (distillation, gas absorption, liquid-liquid extraction and an exposure to the unifying paradigm of transport phenomena), *Chemical and Biochemical Reaction Engineering*, *Solid-Fluid Systems and Particle Technology* and a final year 20-credit *Design Project*. As this programme has evolved alongside the full BEng programme, the timing of these modules across the three years has been reordered to align more coherently with the BEng.

Encouraged by the uptake of the 50:50 BSc programme, the School proceeded to introduce a full BEng in 2014-15. (The University has a School of Computing and Engineering, but for the School of Applied Sciences this was its first foray into BEng territory. Chemical engineering often struggles to find a natural home in either Engineering or Science schools, and the School of Computing and Engineering may have been a more natural home, but the opportunity and indeed initiative to introduce chemical engineering arose from the School of Applied Sciences and, for better or worse, this is where chemical engineering sits.) Over the course of 2014 four new chemical engineering staff were recruited, at Professor, Reader, Senior Lecturer and Lecturer levels, in time to deliver the first year of the new BEng and second year of the BSc. At the same time the two existing chemical engineering staff retired, their legacy in the form of the excellent laboratory facility and technical support being most gratefully acknowledged. The chemical engineering laboratory was already equipped with an excellent range of teaching items for first and second year labs (distillation, gas absorption, liquid-liquid extraction, rotary vacuum filter, fluidised bed, cooling tower, mechanical heat pump, batch heating and tubular heat exchangers, CSTR and tubular reactors, along with a range of pharmaceutical science equipment as the lab also served the School's pharmacy programmes, and a large scale pulsed liquid-liquid extraction rig and climbing film evaporator), to which some new fluid flow and pump rigs were added.

Meanwhile, back at the IChemE, a working party and consultation were initiated in 2013 to revise the accreditation guidance. The Huddersfield programme had been constructed with close attention to the 2012 version of the accreditation requirements (Anon., 2012) and validated by the university, but these changing requirements, along with the input from the newly recruited staff, obliged a revisiting of the programme. Much of the rest of the story is of the ongoing evolution and refinement of the programme in response to this and other external influences, internal drivers, unexpected hiccups and welcome opportunities.

3.1. Programme structure: rationale and flavour

In conceiving a new programme, it is pragmatic to consider what existing teaching might be leveraged. In our case the strength of the School's chemistry teaching, with its already strong chemical engineering flavour, and the fact that this was the origin of the opportunity to introduce chemical engineering, made this a natural starting point. We recognised that other countries, notably the US, have a stronger chemistry bias in their chemical engineering programmes than does the UK (as noted, for example, by Rodrigues and Cussler, 2016), and that there is a legitimate employment market for chemical engineers with good chemistry knowledge and skills. We also recognised that the strong chemistry component could be attractive to prospective students. Byrne (2006) highlights that students at University College Cork overwhelmingly found chemistry the most interesting of the sciences and concludes "the key to attracting chemical engineering students would appear to be to tap into their liking of chemistry". (Alpay et al. (2008) report that successfully communicating that chemical engineering has the power "to make a difference to the world" through its unique power to address sustainability issues is also highly attractive to today's students, particularly females. This is reflected in the gender balance in chemical engineering degree programmes, typically around 26% female compared with less than 15% for most other engineering disciplines.) We were also aware from experience that students embarking on chemical engineering programmes can be surprised and disappointed to discover that the chemistry component of many programmes is quite small. We were resolved to maintain strength in chemistry as a distinctive and attractive feature of our programme.

Part of the chemistry culture in Huddersfield is a strong emphasis on lab skills, these featuring within most modules rather than as separate labs modules. Again, we were aware that chemical engineering programmes can be heavily mathematical and/or computer simulation based, and that this can be at the expense of (expensive) contact time in laboratories, exacerbated by the increases in student numbers. Although our entry requirements for the MEng include an A in A level Maths (dropping to a B for the BEng programme), we were also aware that the students we would be likely to attract may be less strong on the maths, and at the same time mindful of the quotation from Ruthven above that former students now in industry "never [requested] additional emphasis on modelling and mathematical analysis!". We resolved that, without neglecting adequate proficiency in the key mathematical elements of chemical engineering, a further feature of our programme would be a strong emphasis on practical skills. (As our numbers increase and we face the logistics of processing more students through labs, this may yet prove to be mistake!) We believe that there is a market for chemical engineering graduates with excellent practical skills, while this also aligns with students' desire for more practical work and skills training (Alpay et al., 2008; Glassey and Haile, 2012).

A 1st year Maths module from the University's School of Computing and Engineering was identified that was well suited to our programme. For the purposes of internal validation, some other plausible modules from that School were also identified for the later years of our programme, although in the end these have been replaced with our own more well targeted modules. Thus for each of the three years, 6×20-credit modules were specified that satisfied the university's validation procedures and had a plausible connection to the IChemE's accreditation requirements. The validation process included seeking valuable comments from four external reviewers, who were broadly positive while alerting to some potential weaknesses.

Having secured internal validation and got the BEng programme on the books, we took our first entry in September 2014, with several new staff members starting that same month and having to hit the ground running. That academic year we delivered 1st year 20-credit modules in *Chemical Engineering Design* and *Heat Transfer and Fluid Flow*, with the other four 1st year modules drawn from the existing provision. The 50:50 BSc programme was now entering its 2nd year, requiring us to also create and deliver 2nd year modules in *Chemical Engineering Design 2*, *Transport Processes and Unit Operations* and *Chemical and Biochemical Reaction Engineering*, the latter two also being offered as elective modules for chemistry students. In future the BSc programme will have *Heat Transfer and Fluid Flow* in its first year, but that module had not been available the previous year, so this cohort of 2nd year students took that module as well, instead of *Inorganic Chemistry 2*.

Having staff, students and a selection of early year modules in place, we now had to work quickly to revise the programme to address known weaknesses and to exploit the strengths and draw on the expert inputs of the new staff (including a new professor of chemical engineering to lead the activity, along with other staff with diverse experience and strong views). At this point the emphasis had to move from the broad strategy of introducing chemical engineering to the tactics of responding rapidly to events, opportunities and urgent priorities in the face of pressing deadlines. A major driver was that, although the programme had been designed to align with IChemE accreditation guidelines, at this moment those guidelines were in the process of revision, with early indications that our programme may no longer fit. Major pressures were around deadlines for internal revalidation procedures alongside the imperative of developing and delivering the new modules.

Alongside the early indications of the changing IChemE requirements, a major influence was the "Frontiers in Chemical Engineering Education" initiative driven by Professor Armstrong of MIT (http://web.mit.edu/che-curriculum/statements/NSF_proposal.pdf). This deep and systematic initiative, drawing on wide input, concluded that the distinctive heart of chemical engineering was encapsulated in three organising principles:

- ***Molecular Transformations***, broadly interpreted to include chemical and biological systems and physical as well as chemical structural changes;

- ***Multiscale Analysis***, from sub-molecular through super-macroscopic scales for physical, chemical and biological systems;

- a ***Systems Approach***, addressed to all scales and supplying tools to deal with dynamics, complexity, uncertainty and external factors.

The last two of these align with Perkins' (2002) "ability to synthesise as well as analyse" as at the heart of the distinctive power of chemical engineering, and resonated with us as a powerful structure against which to construct our programme; meanwhile, the first theme with its emphasis on molecular transformation aligned with our intention to make chemistry and chemical reaction engineering a strength of our programme. Also, several of us had experienced in some capacity or other chemical engineering at the University of Manchester; we recognised the quality of its programme and graduates (as evidenced by the accumulation of awards and prizes by its students and recent graduates and its teaching staff), and also recognised that the strength of the Manchester BEng programme derived from its alignment with the three "Frontiers" themes, as illustrated in Table 2(a). (Units as listed at http://www.ceas.manchester.ac.uk/study/undergraduate/courses/chemical-engineering-beng/, accessed 1/10/2015)

We undertook an exercise in aligning our own current and proposed modules against the three themes, in order to be clear about our coverage and emphases. Table 2(b) illustrates the alignment, alongside a fourth category of Supporting Competencies/ Engineering Practice. (**Bold** indicates modules delivered by chemical engineering staff; *italics* indicates that component of the module does not contribute to that column's theme. Note that Huddersfield operates 20-credit modules, Manchester 10-credit modules, the former forcing some unnatural groupings and obscuring the granularity of some of the content.) The placement of modules within themes is imperfect, with some straddling themes; in particular, the culture of including lab work within individual modules rather than as separate lab skills modules means that many of the modules have a portion of their credits in the Supporting Competencies theme. The table tries to indicate this by subtracting the supporting competencies components from the credit totals under each theme. However, for the purpose of accumulating the required balance of credits for accreditation, it may be appropriate to consider some laboratory activities to be primarily delivering core chemical engineering knowledge rather than engineering practice skills; the IChemE accreditation process allows some flexibility in interpretation of learning outcomes and appropriate assignment of credits.

(The School of Applied Sciences also operates an industrial placement scheme and encourages and supports students in taking a year in industry between their 2nd and 3rd years.)

Comparing the two programmes, the Molecular Transformation theme is developed in Manchester through the three years via 1st year *Engineering Chemistry*, *Thermodynamics* and *Introduction to Chemical Reaction Engineering*, 2nd year *Chemical Reaction Engineering* and *Chemical Thermodynamics* and 3rd year *Catalytic Reaction Engineering*, a total of 60 credits in this theme. Our Huddersfield programme has roughly twice this, with 118 credits plus practical chemistry labs across 1st year *Physical Chemistry 1*, *Organic Chemistry 1* and *Pharmaceutics*, 2nd year *Physical Chemistry 2*, *Chemical and Biochemical Reaction Engineering* and *Principles and Strategies for Fine Chemicals Route Selection*, and 3rd year *Targeted Synthesis of Organic Compounds* and the latter 10 credits of *Advanced Mass Transfer and Catalytic Reaction Engineerin*g.

The Multiscale Analysis theme is developed in Manchester through 20 credits of 1st year *Transport Phenomena* (equivalent to Huddersfield's *Heat Transfer and Fluid Flow*), 2nd year *Momentum, Heat and Mass Transfer* (10 credits, compared with around 5 credits on this topic within our *Transport Processes and Unit Operations* module), and 3rd year *Process Fluid Dynamics* (for which there is no equivalent in Huddersfield) and *Advanced Engineering Separations* (equivalent to our *Advanced Mass Transfer*). The Manchester programme has 10-credit Maths modules in each of the final two years, whereas Huddersfield does not explicitly develop maths beyond first year. Thus this theme totals 110 credits in Manchester, compared with 81 in Huddersfield.

(It is arguable whether Maths should appear under this theme or as a Supporting Competence. In the imbalance between analysis and synthesis identified above by Perkins (2002) and Stephanopoulos and Reklaitis (2011), "analysis" is strongly conceived as mathematical analysis; an emphasis on the type of Transport Phenomena analysis encouraged and empowered by Bird, Stewart and Lightfoot's 1960 book of the same name requires an accompanying emphasis on mathematics, as they themselves acknowledge in the Preface to the 2nd edition: "the language of transport phenomena is mathematics". Hence, in identifying themes and emphases of a chemical engineering programme, we consider mathematics modules to be correlated with an emphasis on the Multiscale Analysis theme, while acknowledging that maths does not only serve this theme.)

The Systems theme is developed in Manchester through strong Design, Integration, Simulation, Safety and Control modules running across the three years, leading to a substantial 60-credit final year Design Project (three times the IChemE requirement for 20 credits) and a total of 140 credits. In Huddersfield (with a 30-credit final year Design Project split across 2 20-credit modules alongside 10 credits of taught material) the Systems theme totals 110 credits, similar to Manchester with the exception of the size of the final Design Project. (During the IChemE accreditation consultation, an early indication was for an increase in both the Engineering Practice and Design Project components from 20 to 30 UK credits (i.e. from 10 to 15 ECTs), but in the end these were both retained at 20 credits.)

In terms of supporting competencies/engineering practice, the Manchester programme features 30 credits of lab skills (c.f. the IChemE's requirement of 20 credits of

Engineering Practice), while the Huddersfield programme has 43 credits, with lab skills developed across a wider range of modules. The Manchester programme features more computing skills and includes the optional Leadership in Action module.

The above comparison is not intended to imply that the depth and scope of similar modules are necessarily equivalent or that we view our course as of equivalent quality to the excellent and well-established course in Manchester. It is to illustrate that one of the strongest current UK programmes is well aligned with the "Frontiers" themes, confirming the relevance of those themes, and that these themes also served to inform the construction of the Huddersfield programme.

Using the Manchester programme as a benchmark, it becomes evident that our programme features more of the Molecular Scale Transformations theme, is weaker on the more mathematical Multiscale Analysis theme and associated computation, has a similar emphasis on Systems but with a smaller Design Project, and has greater exposure to practical lab work. This analysis reassures us that our programme is suitably aligned with the "Frontiers" themes as described in that document and as illustrated in an existing strong UK programme, while clarifying that our programme's distinctive emphases are in chemistry and practical skills, at the expense of a weakness in mathematical analysis. As the programme and staffing base develop, we may seek to rebalance the themes by removing some chemistry and adding more analysis. However, without seeking to cover within a BEng programme the full taxonomy presented in Table 1, we are satisfied that the programme gives sufficient of a basis for a graduating student to access more specialist education and an industrial career across the range of the taxonomy.

Our programme is largely delivered through relatively traditional lectures and tutorials supported, as noted, by a strong emphasis on practical lab work and an opportunity for a placement year in industry. Where appropriate we are drawing on innovations and best practice in relation to such things as personal response systems, problem-based learning, video-supported learning (particularly for introducing and developing process simulation skills; see Belton, 2016) and flipped classrooms. Our conscious emphasis, however, is on developing excellent educators rather than on specific methods. The University of Huddersfield prides itself on having all teaching staff recognised as Fellows of the Higher Education Academy and on its record in relation to teaching excellence (it has more National Teaching Fellows than any other university), and our recruitment and nurturing of academic staff in chemical engineering is aligned with this emphasis.

3.2. Revising and refining

The programme presented in Table 2(b) is different from that originally validated by the university, so further validation of the proposed changes was required. This had to be undertaken under a tight timescale, and encountered some resistance. In particular, we were keen to increase the proper chemical engineering content of the programme to be absolutely confident that, come accreditation, there could be no concern around the material counted as core chemical engineering. Thus, for example, a module originally listed was from the School of Computing and Engineering, entitled *Aerodynamics and Computational Fluid Dynamics*. While undoubtedly it could have imparted useful skills, its emphasis on sports cars would have looked out of place, while we had concerns about the preparedness of our students for its more mathematical and computational elements. Two other modules were from the Pharmacy Department of our own School, exploiting existing provision while also offering an opportunity to draw on that strength within the School. But one can't draw on too many peripheral "strengths" without weakening the core! We were already exploiting the strength in chemistry; to have strengths in pharmaceutical science as well would have weakened the core chemical engineering. However, our desire to increase the chemical engineering content was met with some resistance based on the understandable concern that this would require more chemical engineering staff, and that resource for this might not be forthcoming. Part of the reason to draw on existing provision as much as possible when introducing new programmes is to manage the risks around both staff and student recruitment. The university sector is also increasingly nervous of making changes to programmes that might fall foul of the Consumer Protection Act that requires programme changes to be minimised; in introducing our proposed changes, we had to consult with students already on the programme to give them an opportunity to comment or object (they didn't). Against this resistance we had the leverage that without making these changes, we would not meet the revised IChemE criteria for accreditation. On top of this resistance was the task of creating the specifications for the new modules alongside documented justifications, a straightforward task but time-consuming at an already busy time.

The indication that IChemE might increase its Design Project requirement aligned with our desire to increase our final year Design Project to 30 credits (although in the end IChemE retained the requirement at 20 UK credits). Huddersfield operates 20-credit modules, so the Design Project was split across two modules, with 10 credits of one of these comprising taught material. To make space for this in the 3rd year, a *Solid-Fluid Systems and Particle Technology* module was moved into 2nd year, displacing the *Formulation and Pharmaceutics* module, and renamed *Multiphase Systems* to cover a wider scope including gas-liquid systems and rheology.

We were also concerned at having insufficient material on Sustainability, so conceived a new module, *Sustainable Industrial Systems* (to replace the *Aerodynamics* module), drawing on the expertise of a new staff member while giving a better overall balance to the programme.

In introducing these refinements in order to strengthen the chemical engineering programme, a further constraint was the obligation to continue to deliver electives to chemistry students; this is, after all, why chemical engineering teaching existed at

Huddersfield in the first place, and in creating the new programme we must be careful not to deprive the existing chemistry programmes of their valuable chemical engineering content. This has required some accommodation that is probably still not ideal; these electives in the past have been of an overview nature, a more superficial introduction to chemical engineering, but the new modules are more solid and focussed in their chemical engineering content. In future it may be that the chemistry electives can be more bespoke and better suited to the needs of the chemistry students, rather than having to fit in with the constraints of the chemical engineering programme to develop its themes to appropriate depth.

3.3. Labs and infrastructure

As noted above, the motivation and opportunity to introduce chemical engineering degrees to Huddersfield arose from the long history of teaching this subject and hence the existence of an excellent chemical engineering laboratory. This space was also used for Pharmacy teaching, which has now moved out such that chemical engineering can occupy the whole space. The lab is approximately 192 m^2 of double height space including a triple height "pit" that houses a 4.6 m tall QVF climbing film evaporator (Figure 3) and large Armfield distillation unit, with a further large QVF pulsed liquid-liquid extraction unit in the upper part of the lab. The facility already included an excellent range of chemical engineering teaching equipment. However, to cope with the increase in the number of students and to give a more comprehensive and coherent labs programme, careful thought was given to new equipment and to how to operate the labs.

Regarding equipment, we now have two of each of a range of mostly benchtop units to introduce fundamental principles in 1st year, covering heat transfer, fluid flow, mass and energy balances and reactions, with students in groups of two rotating through seven activities over the course of the year; a suitable range of rigs were identified and purchased to this end, to complement the existing rigs. For 2nd year the emphasis is to move to more problem-based learning involving larger groups and larger items of equipment. Third year labs activities are anticipated to involve more sophisticated rigs, the details of which not yet fully decided. Nearby Kirklees College is, at the time of writing, building the National Process Manufacturing Training Centre (https://www.kirkleescollege.ac.uk/processmanufacturing) which will encompass processing plant operating for training purposes under realistic environments. We plan to take the opportunity to use this facility to provide practical experience for our final year students, and have made a joint appointment with Kirklees College of a chemical engineer with significant industrial experience to facilitate the link while bringing that strength to our programme.

As noted above, the pattern in the School of Applied Sciences is to operate lab classes within each module rather than as a separate module. There is, however, a difference between doing a practical class on a heat exchanger in the context of a Heat Transfer module, and doing the same in the context of a labs module; to the student, in the former situation he or she is learning about heat transfer, in the latter they are learning lab skills, the heat transfer being somewhat incidental. Meanwhile, if labs are part of each module as part of the specific content of that module, then the responsibility for teaching generic lab skills, including report writing, easily falls between modules and can be missed. For these reasons, we were keen to create a distinct and coherent 1st year Chemical Engineering Laboratories activity, to ensure that at least this part of the activity addressed the specific lab skills we required of our chemical engineering students, even while chemistry lab skills were being practised elsewhere. But Huddersfield operates 20 credit modules, and we did not wish to deploy a full 20 credits of our first year towards chemical engineering labs. The solution was to replace the 50% (10 credit) labs component of the *Pharmaceutics 1* module with chemical engineering labs, while retaining the taught part of that module and hence some exposure to this worthwhile topic, and thus creating the awkwardly-named *Chemical Engineering Labs and Pharmaceutics* module.

In creating the *Chemical Engineering Labs* half-module, we were also keen that, as well as giving practical exposure to rigs, this module should develop the specific components of lab skills, including reporting, in a targeted and coherent way. Chemical engineering graduates are sometimes criticised for poor writing skills, and indeed developing excellent written communication is a challenging task that requires systematic nurturing. In a separate exercise we had identified the "desirable attributes of a Huddersfield chemical engineering graduate", and excellent communication skills were one that we were keen to cultivate. To this end, against each lab activity a specific task was identified to be practised in relation to that particular task, such as writing a good summary, effective graphical presentation, error analysis, introducing and discussing figures, writing in the past tense, appropriate significant figures and explicit use of equations. The students are specifically told that in 1st year they are not being taught all the components of technical report writing, instead they are practising some of the component skills (in line with the advice of Ambrose et al. (2010) that "Mastery requires the development and integration of component skills"). In 2nd year, chemical engineering labs take place across three modules, and full report writing skills are explicitly developed across the activities for the three modules, the first emphasising referencing, the second literature surveys and data analysis, and the final module bringing the component skills together fully for a final, large scale group- and problem-based activity.

3.4. Design Project

The key considerations in constructing and delivering a chemical engineering degree programme can be divided into: Design Project (nature and delivery); practical laboratory work (intent, infrastructure and logistics); core chemical engineering (content and pedagogy); underpinning science and maths (is this best taught "in house" to allow control and integration with the core chemical engineering (and by chemical engineers), or outsourced?); transferrable skills; and industrial links. Of these, delivering the capstone Design Project is arguably the most challenging. (The challenges as perceived in the UK were identified and discussed in an IChemE Education Special Interest Group meeting in Reading in January 2015, along with some of the approaches adopted in different departments; presentations can be viewed at http://www.icheme.org/communities/special-interest-groups/education/resources/workshop%20presentations/design%20teaching%20workshop%20-%2016%20january%202015.aspx.)

The Design Project in a chemical engineering programme typically involves a large group activity with individual components, taking place in one of the later years of a programme and intended to be integrative in nature. Students frequently consider it the most challenging and stressful component of their degree programme and ultimately the most rewarding. Staff similarly can find supervising and assessing the Design Project challenging to the extent of being daunting. The research focus of university departments often mitigates against practical design experience, and consequently diminishes or compromises the quality and relevance of this aspect of a chemical engineering education, a concern that is a persistent theme of the literature and the blogosphere. Thus departments can find themselves with few staff competent or keen to supervise the Design Project.

While there are numerous reports of experimentation and innovation with respect to the Design Project, including in recent years an emphasis on product design as an alternative to the more traditional process design (Favre et al., 2008; Seider and Widagdo, 2012; Rodrigues and Cussler, 2016), delivery of the Design Project probably largely follows three broad models:

1. A single design task undertaken by all groups, perhaps with variations of specifications or conditions, co-ordinated by a small group or single staff member (possibly one with, in the words of Rodrigues and Cussler (2016), “an evangelical commitment to the subject”) who knows the entire design, with groups supervised by a number of other staff who are less intimately familiar with all aspects of the design and who will defer to/rely on the expert(s) for some of the specifics. This model has the disadvantage that all groups are doing the same design; this gives students from different groups working on the same task the opportunity to work through problems together, which can be helpful, but brings risks of excessive collusion. It also gives limited scope for creativity. This model has the advantage that it keeps the delivery of the Design Project manageable in terms of demands on staff expertise and parity of experience for students; it can be run with only a single staff member cognisant of the entire design task. This model is often run with the aid of an industrial sponsor.

2. A number of staff members, each of whom has a particular design or two that they are comfortable and competent to supervise, which they run every year.

Compared with Model 1, this model needs a greater number of staff competent over an entire design task, and can be patchier in terms of quality of both the design and the supervision. It has the advantage that each group undertakes a different design, avoiding collusion, although year-on-year plagiarism can arise. This model is dominated, and constrained, by the individual supervisor – their competence and limitations dictate the design tasks to be performed. In both this model and the previous one, the scope for creativity is dampened by the need for the design to stay within the bounds of the known design "answers". Seider and Widagdo (2012) describe a design course at the University of Pennsylvania that broadly follows this model.

3. The student groups themselves propose, within guidance and oversight, and based on a review of markets and of technological opportunities, a product for which a process is to be designed. This is a more genuinely open-ended task, with greater scope for creativity. It is also a more authentic task. In Models 1 and 2, the task for the students is, to some extent, to "extract" from the supervisor the known design; in Model 3, the supervisor can genuinely declaim any knowledge of how to design this process, and instead plays the more authentic role of a boss who has instructed their team to undertake a design, and who has not secretly done the task themselves already (why would a boss do this when they have employed a team to do it?) – but they are perfectly capable of assessing the report that their team delivers – that's what bosses do. This clarification of expectations – that the supervisor does not have the answers and that the challenge is therefore to demonstrate chemical engineering skills and judgement rather than find the "right" answer – can be liberating for both students and supervisors. This model also has the advantage of averting internal plagiarism. It requires a fairly capable cohort of students and some nimble and confident supervising that is very clear on the intended learning outcomes and the assessment criteria. This model carries the risk that the depth and quality of the design, starting from scratch, may be less than for a well-trodden design. However, it is capable of delivering design projects of outstanding quality; this is the model operated at the University of Manchester in recent years, and it is notable that groups from this university won the IChemE's McNab-Lacey Design Project prize for the first two years of its inception (Anon., 2016).

At the time of writing, in Huddersfield in academic year 2015-16, we have run a 20-credit Design Project for a single group of eight BSc Chemical Engineering and Chemistry students. We are undertaking a relatively traditional design task, a 250000 tonne per annum methanol plant, for which we are grateful to have engaged the services of a retired chemical engineering academic who is very experienced in teaching design, complemented by the appointment of a staff member with substantial industrial design experience. As we contemplate running the full 30-credit Design Project for around 40 students next year, initially we intend to operate Model 1, using the opportunity explicitly to develop Design Project supervision experience for all our staff and to add an additional product to our collective competence. Looking ahead to around 90 students in 2017-18 and beyond, our ambition is to operate a version of Model 3 for the MEng students, while retaining Model 1 for the BEng students, as we believe Model 3 delivers a distinctively authentic and valuable Design Project experience for students strong enough to embrace it.

3.5. Adding an MEng year

Having successfully validated and recruited onto a BEng programme, the next step was to add a 4th year to give an MEng programme. This was validated in 2014 with a view to being run for the first time in 2018-19. The challenge here was to specify a suitable set of modules so far in advance, not knowing the specific expertise of the staff that might be recruited by that time. One can take the approach of specifying a programme and recruiting to meet the details of that programme, but to do so misses the opportunity to draw on unanticipated expertise of new staff; there is a strong rationale for wanting staff to deliver against their own expertise rather than to fit into content specified and validated by non-experts. We have attempted to future-proof our MEng by adopting relatively generic module titles including *Advanced Process Development* and *Recent Advances in Chemical Engineering*. The latter module is intended consciously to develop self-learning skills to promote an inclination to lifelong learning, and will include a version of the Book Module described by Campbell et al. (2010). As well as helping to make the 4th year qualitatively different by emphasising independent learning, the focus on recent advances builds in some future-proofing, although will require some fleetness of foot when the time comes.

The 4th year is also dominated by the 40-credit Research Project, which by its nature also injects some future-proofing into that year. However, alongside establishing excellent laboratory facilities for teaching, a further pressing challenge is to develop by 2018 a sufficiently strong chemical engineering research context from which to be able to offer a suitable number and range of projects.

4. Reflections

As we complete the second year of running the BEng programme, recruitment into the new 1st year has been very strong, indicating from our perspective that the attraction of chemical engineering continues unabated. Our MEng programme has now also been validated and students have entered onto that programme. As we move forward it makes sense to expand the range of MEng specialisms we might offer, possibly drawing further on the Pharmacy teaching in the School and also its strengths in Biology, alongside MSc provision.

In terms of evaluating our success so far, the first critical test will come when we apply for IChemE accreditation next year, while the second test will be the success of our graduates in securing chemical engineering jobs. Meanwhile, we scrutinise both our curriculum and its delivery on an ongoing basis, including via student feedback which thus far is generally positive, while many of our current students have secured industrial placements, which we also take to be a sign of success.

Creating new degree programmes is certainly an exercise in "design under constraint". In terms of lessons learned, a key message is that introducing a new programme is driven more by tactical response to opportunities and events than by a clear and careful "management of change"; this is the nature of universities. Of greatest importance is to manage risk against an evolving background, and managing university validation, purchasing and staff recruitment processes effectively in order to be responsive to events and opportunities. It is also important to have a clear vision for the type of chemical engineering programme one aims to create, drawing on a coherent fusion of the distinctive nature of chemical engineering as a discipline with the specific local opportunities. The above discussion has focussed on the specifics of our programme without touching on the important issues of recruitment, open days, brochures, etc. – here the message is that the university's support structures must be leveraged and engaged with – or of local and national industry engagement. We are aware that, while much has been done of value and a programme that we are proud of is in place, there is much that has been neglected thus far; a further message is that one cannot tackle everything at once, particularly with limited staff in the early days, and one must prioritise. On staffing, this remains an on-going vulnerability; the growth of chemical engineering across the UK makes recruiting and retaining staff something never to be taken for granted. In this respect, it is a good time to be a chemical engineering academic! It is also an exciting time to be able to respond to a market demand by creating new provision for a subject that we know, and increasingly others recognise, has the potential "to make a difference to the world".

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Table 1. EPSRC Chemical Engineering Taxonomy (adapted from Anon., 2015b)

Area	Subfields
1. Engineering Science of Physical Processes	a. Transport processes b. Thermodynamics c. Rheology d. Separations e. Particle technology
2. Engineering Sciences of Chemical Processes	a. Catalysis b. Kinetics and reaction engineering c. Polymerisation reaction engineering d. Electrochemical processes
3. Engineering Science of Biological Processes	a. Biocatalysis and protein engineering b. Cellular and metabolic engineering c. Bioprocess engineering d. Systems, computational and synthetic biology
4. Materials	a. Polymers b. Inorganic and ceramic materials c. Composites d. Nanostructured materials e. Food f. Molecular and interfacial science and engineering
5. Biomedical Products and Biomaterials	a. Drug targeting and delivery systems b. Biomaterials c. Materials for cell and tissue engineering
6. Energy	a. Fossil energy extraction and processing b. Fossil fuel utilisation c. Carbon capture, storage and utilisation d. Renewable energy e. Fuel cells and energy storage, including hydrogen f. Nuclear power engineering (fission and fusion)
7. Environmental Impact and Management	a. Air purification b. Water purification c. Aerosol science and engineering
8. Process Systems Development and Engineering	a. Process development and design b. Dynamics, control and operational optimisation c. Safety and operability of chemical plants d. Computational tools, numerical methods and information technology e. Sensors (chemical and biochemical)
9. Sustainability	a. Social and cultural domain b. Environmental domain c. Economic domain d. General and integrating concepts

Table 2(a). Breakdown of the Manchester BEng chemical engineering course

(Credit ratings in brackets. Most modules are taught in house within the School of Chemical Engineering and Analytical Science.)

	Molecular scale transformations (60 credits)	**Multi-scale analysis (110 credits)**	**Systems approach (140 credits)**	**Supporting competencies/ engineering practice (50 credits)**
Year 1 (120 credits)	Engineering Chemistry (10) Fundamentals of Thermodynamics (10) Introduction to Chemical Reaction Engineering (10)	Engineering Mathematics 1 and 2 (20) Transport Phenomena 1 and 2 (20)	Chemical Engineering Design 1 and 2 (20) Design Project (10)	Engineering Computation (10) Laboratory Projects 1 (10)
Year 2 (120 credits)	Chemical Reaction Engineering (10) Chemical Thermodynamics (10)	Mathematical Methods 2 (10) Momentum, Heat and Mass Transfer (10) Distillation and Absorption (10) Solid-Fluid Systems (10)	Heat Transfer and Process Integration (10) Process Design and Simulation (10) Safety and Reliability Engineering (10)	Laboratory Projects 2 (20) Biotechnology and Environmental Engineering *or* Leadership in Action (10)
Year 3 (120 credits)	Catalytic Reaction Engineering (10)	Mathematical Methods 3 (10) Process Fluid Dynamics (10) Advanced Engineering Separations (10)	Process Control (10) Design Appraisal (10) Design Project Parts 1, 2 and 3 (60)	Reporting, presentation and groupwork components of Design Project

Table 2(b). Breakdown of the Huddersfield BEng chemical engineering course
(**Bold** indicates modules delivered by chemical engineering staff;
italics indicates that component of the module does not contribute to that column's theme.)

	Molecular scale transformations (140 credits less 22 of supporting competencies = 118 credits)	**Multi-scale modelling (90 credits less 9 of supporting competencies = 81 credits)**	**Systems approach (120 credits less 12 of supporting competencies = 110 credits)**	**Supporting competencies/ engineering practice (51 credits)**
Year 1 (120 credits)	Organic Chemistry 1 (20) Physical Chemistry 1 (20) ***Chemical Engineering Labs (10)*** and Pharmaceutics (10)	Mathematics 1 (20) **Heat Transfer and Fluid Flow (20)**	**Chemical Engineering Design 1 (20)**	Computing component of Chemical Engineering Design 1 (6). Lab components of: Chemical Engineering Labs and Pharmaceutics (10), Organic Chemistry (4), Physical Chemistry (4) (= 18 credits in total)
Year 2 (120 credits)	Physical Chemistry 2 (20) **Chemical and Biochemical Reaction Engineering (20)** Principles and Strategies for Fine Chemicals Route Selection (20)	**Transport Processes and Unit Operations (20)** **Multiphase Systems (20)**	**Chemical Engineering Design 2 (20)**	Lab components of: Physical Chemistry 2 (4); Chemical and Biochemical Reaction Engineering (5); Transport Processes and Unit Operations (4); Multiphase Systems (5); Principles and Strategies for Fine Chemicals Route Selection (5) (= 23 credits in total) Groupwork and reporting components of Chemical and Biochemical Reaction Engineering, Transport Processes and Unit Operations, Multiphase Systems Computing component of Chemical Engineering Design 2 (2).
Year 3 (120 credits)	Targeted Synthesis of Organic Compounds (20) ***Advanced Mass Transfer (10)*** **and Catalytic Reactor Design (10)**	**Advanced Mass Transfer (10)** ***and Catalytic Reactor Design (10)***	**Design Project 1 and 2 (40)** **Safety Engineering and Process Control (20)** **Sustainable Industrial Systems (20)**	Lab components of: Sustainable Industrial Systems (2 credits) Reporting, presentation and groupwork components of Design Project

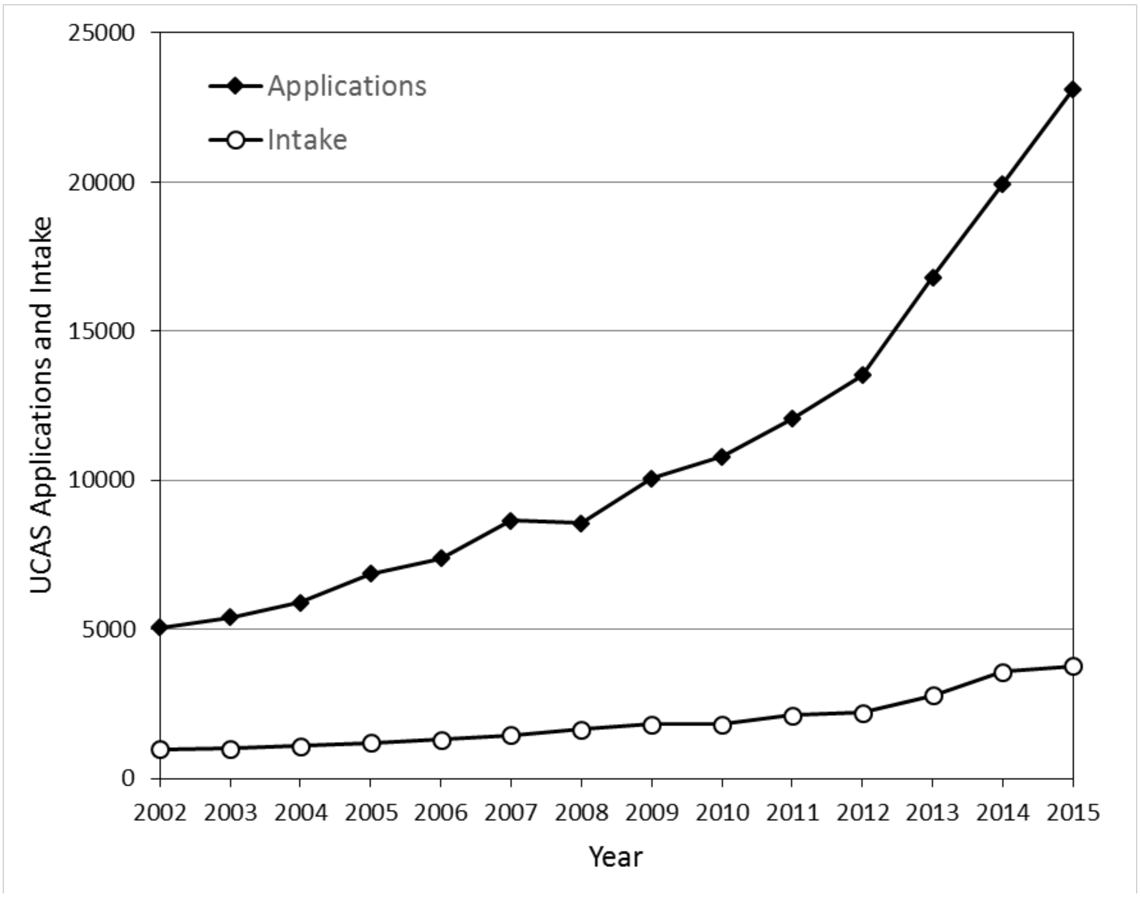

Figure 1: Applications and intake to UK chemical engineering programmes, 2002-2015. (Source: https://www.ucas.com/corporate/data-and-analysis/ucas-undergraduate-releases/ucas-undergraduate-end-cycle-data-resource-5)

Figure 2: Jacketed pan batch reactor donated by ICI and used in the Huddersfield teaching labs from the 1950s to early 2000s.

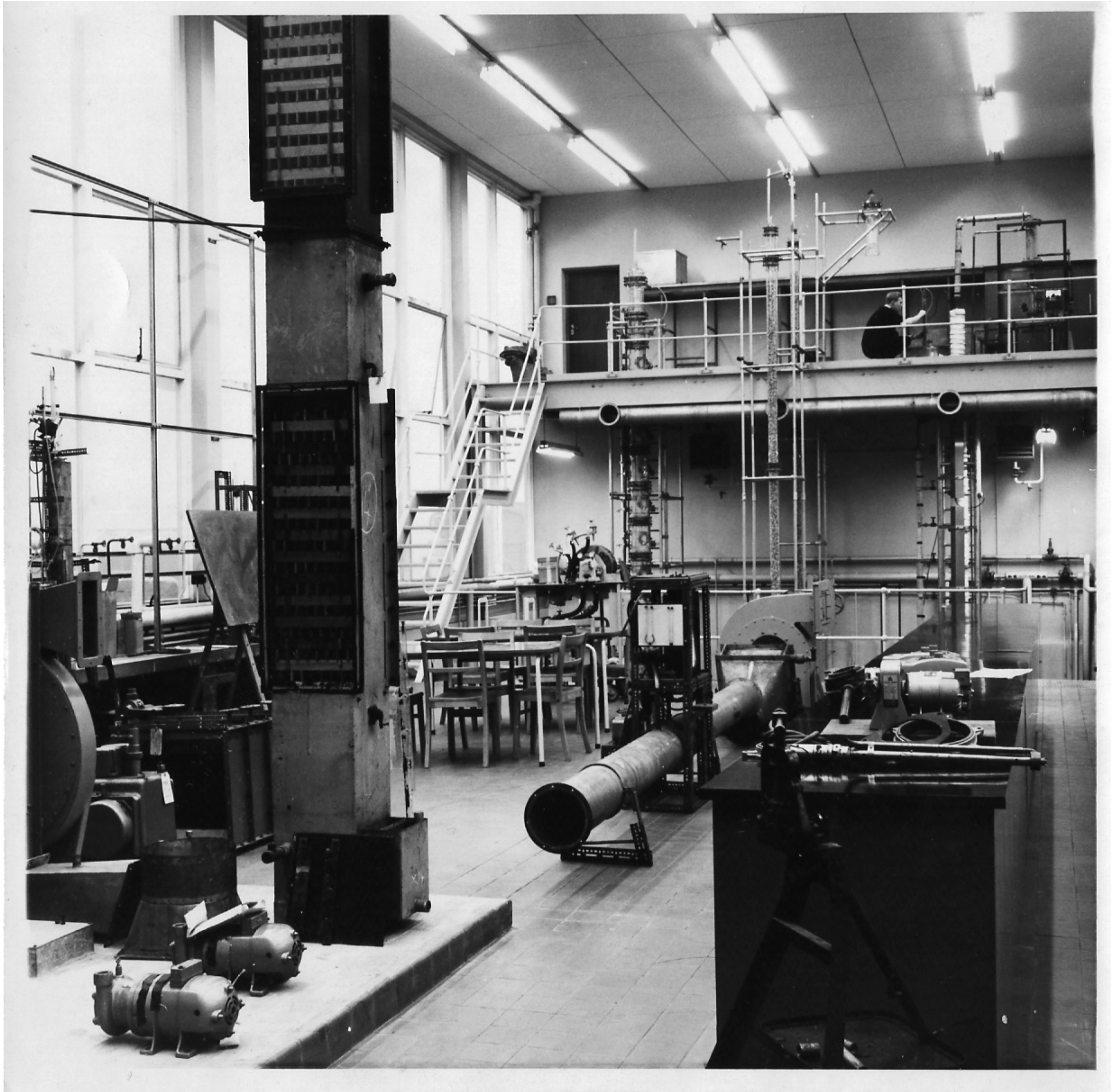

Figure 3: The Huddersfield chemical engineering teaching laboratory in the 1960s. The lab was substantially refurbished in 2006; the triple height pit at the far end with mezzanine above still remain.

Figure 4: Climbing film evaporator in the pit area of the chemical engineering lab.