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New Chemical Engineering Provision: Quality in Diversity

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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

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29 1 Introduction

30 Chemical engineering is a university subject that has seen considerable increases in undergraduate
31 student numbers since the turn of the millennium. UK applications almost quadrupled between
32 2001 and 2015 (though the most recent data show a slight fall – see Figure 1) and aggregate intake
33 has grown by almost the same amount. These trends, mirrored to a greater or lesser extent in other
34 parts of the world, have driven growth in established university departments and the introduction of
35 new chemical engineering degree courses in several universities not previously offering the subject.

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

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

50 *Figure 1 here*

51

52 2 A diversity of provision

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

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

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

72 a benefit of the university experience for young people, changes in UK student finance in recent
73 years mean that it is for many becoming a financial impossibility or a prospect that carries the
74 spectre of a debt mountain of >£50,000. The ability to study a subject of one's choice near
75 home has therefore assumed far greater importance than in the past.

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

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

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

109 Table 1 presents a snapshot of the recent and forthcoming additions to the list of UK universities
110 offering chemical engineering, in chronological order of entry onto the scene. Thus the University of
111 Bradford, having closed its chemical engineering programmes in 2002, reopened them in 2010 and
112 graduated its first cohort in 2012. Hull followed shortly after, with Chester and Huddersfield not far
113 behind and graduating their first BEng students earlier in 2017, and Wolverhampton and Sheffield
114 Hallam due to graduate their first cohorts in 2019. These new providers currently have first year
115 entry numbers mostly in the range 30-100 students. Meanwhile, Greenwich, Queen Mary, Brunel,
116 Canterbury Christ Church and Derby all have started or plan soon to start chemical engineering
117 programmes notwithstanding the dip in applications shown in Figure 1. In all cases, degrees are

118 offered at both Bachelors level (typically three years) and MEng level (the Integrated Masters model,
119 typically four years in duration but widely – though not universally – viewed as corresponding to a
120 combined first cycle + second cycle qualification). Where a year-long industrial placement is
121 included – and employability is much enhanced if it is – it extends the degree duration by a year (this
122 is true at most, though not all, universities, but is currently true for all of the new chemical
123 engineering providers).

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

135

136

Table 1 here

137

138 **3 Student recruitment**

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

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

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

158 The rise in emphasis on apprenticeships, including degree apprenticeships, is a significant feature of
159 the current UK higher education landscape, with students viewing degree apprenticeships as a route
160 to a degree combined with work experience and without the debt implications of a conventional

161 degree. No longer are apprenticeships largely confined to less able students. From an employer
162 perspective too, apprenticeships offer an 'extended interview', allowing employer and individual to
163 assess each other and leading to improved graduate retention. While degree apprenticeship
164 provision in chemical engineering has yet to be developed, the model is one for which a number of
165 the new providers are well suited. As apprenticeships have to be led by employers, dialogue with
166 companies is an essential first step.

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

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

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

194

195 **4 Course content**

196 Most of the newer degree programmes are located within Engineering schools, with some located in
197 Science schools, giving potentially different emphases for programmes and experiences for students
198 (chemical engineering can look very different if taught predominantly alongside other engineering
199 disciplines compared with taught alongside chemistry or in isolation). The programmes aim, to a
200 greater or lesser degree of overtness, to draw on and promote distinctive strengths in, for example,
201 food, pharmaceuticals, biofuels, energy, chemistry, or particle technology. Most new programmes
202 have been initiated to fill a gap in provision in the light of the increased student interest in recent
203 years up to 2016, sometimes drawing on a natural context such as existing relevant teaching and
204 labs, or in the case of Chester, the creation of an entire new Faculty of Science and Engineering at

205 the former Shell site in Thornton. Table 1 also attempts to capture a flavour of how these new
206 providers are dealing with issues of infrastructure, industrial input and the delivery of design project
207 teaching, while Table 2 summarises some of the pros and cons of new providers in comparison to
208 established and generally larger providers.

209

210 *Table 2 here*

211

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

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

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

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

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

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

245 There is a fashion in the UK for tertiary education and training to be ‘employer-led’. This is
246 all very well, providing the employers recognise that the purpose of education is to equip

247 students for lifelong careers, perhaps taking them into jobs and careers that have yet to be
248 invented. Unfortunately, many employers don't. The solution is for employers and
249 academics to work *together*, just as they do in the accreditation processes of the major
250 professional engineering institutions, to achieve the difficult balance of "skills for today" and
251 "versatile competent graduates for tomorrow and beyond". That means some content, dear
252 to the hearts of some, will have to be left out of any given degree course – but across the
253 range of course providers, the full rich breadth of chemical engineering should be catered
254 for. New providers should consider carefully how they contribute to this mix,
255 complementing rather than duplicating what is available elsewhere, while having the
256 confidence not to aim to cover everything.

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

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

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

283 Overall, the new degree provision is adding useful diversity to higher education in chemical
284 engineering. However, some areas would merit greater attention. Arguably those areas of the
285 subject interfacing with the life sciences, such as industrial biotechnology, bioprocessing and the
286 analysis of biological and biomedical systems in chemical engineering terms, are among examples
287 that might be better served, as argued by Shott et al (2015). Application of chemical engineering
288 principles to materials, or to the design and development of chemical products (e.g. Rodrigues and
289 Cussler 2016) as distinct from chemical processes, may also deserve fuller attention, while process
290 instrumentation, automation and control is an aspect that is still under-served in UK courses. The
291 latter is a topic bridging chemical and electronic/software engineering, which may be one reason
292 why it is less fully addressed than it might be – given the tendency of academic disciplines and

293 accrediting bodies to remain focused on the traditional disciplinary 'silos', i.e. separate branches of
294 engineering. The boundaries between those specialisms should be more fluid, recognising that
295 technology challenges, user needs and indeed careers can embrace several of them.

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

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

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

324

325 **5 Laboratory and practical provision**

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

337 To overcome difficulties such as the above, collaboration between geographically-close institutions
338 is strongly to be encouraged. Partners may both be universities; or use can be made of facilities at a
339 tertiary college (such as the partnership between the University of Huddersfield and Kirklees
340 College's new Process Manufacturing Centre) or at a technical training facility such as CATCHⁱⁱ in
341 northern England, utilised by Hull.

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

347 **Case Study – Swansea University**

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

361
362 The approach we undertook was to provide students with practical experiences in a wide
363 range of chemical engineering related experiments as soon as they embark in their course
364 using bench top scale, and to expand the scale to a larger pilot plant as they progress in their
365 degree. Students could also carry out practical research and summer projects. Based on this
366 approach, students undertake in the first year practicals to demonstrate and gain cognitive
367 skills in fundamental principles of relevance to chemical engineering using a series of bench-
368 top experiments in areas such as physical chemistry, heat transfer, mass transfer, fluid and
369 particle mechanics, and separation techniques as well as instrumentation and analytical
370 techniques. As students embark on the second year of the programme, they undertake pilot
371 plant labs on a wide range of unit operations such as distillation, gas/liquid absorption, heat
372 transfer, liquid fluidisation, evaporation, reactor engineering, process control, heat pump,
373 liquid mixing, and water purification operations. Although we aim that all students
374 experiment with this wide range of experimental rigs, this can be difficult, particularly for
375 large classes. However, students have other opportunities to have exposure to the rigs other
376 than through the formal modules assigned to the labs, via for example research projects or a
377 summer placement. We also operate the labs in groups and rotate the students to maximise
378 exposure.

379
380 In the setting up of our labs at the new Bay Campus, it was essential to involve all key
381 academic and technical staff as well as the project manager. The meetings were formally
382 recorded and progress against action points is checked regularly. In addition, informal
383 meetings and discussions with various stakeholders were held on an ad-hoc basis. The
384 design of the labs was done by professional designers with input from the chemical
385 engineering team via the project manager. As a team, we developed a list of lab equipment

386 to purchase and this was based on the academic approach discussed above as well as being
387 mindful of constraints such as budget, safety and floor space. Although the procurement
388 process was managed by the finance department, we contributed to the preparation of the
389 tender documents for example via setting up the technical specifications of equipment and
390 evaluation. As the equipment were delivered, sited where they should be, and
391 commissioned by the supplier, academic and technical staff responsible for the delivery of
392 the labs have received training on the safe use of each rig and have prepared risk
393 assessments and student-proof operating instructions. Given the large size and complexity
394 of the project, pitfalls were inevitable including for example undersized services (e.g. chilled
395 water and steam). Close collaboration and constant communication with the university
396 Estates department was essential to resolve such issues.

397
398 Although this project was complex, challenging and time consuming, Swansea University has
399 now one of the best modern laboratories for teaching chemical engineering in the country.
400 Defining the approach for setting up the labs early on was essential to guide further
401 decisions in the process. It was also essential to involve all key academic and technical staff,
402 making sure they understood the seriousness of the project so to minimise the risk of
403 mistakes and any potential pitfalls. Procurement is a time-consuming process that should be
404 considered carefully in the overall planning, particularly when the time is limited between
405 the commissioning of equipment, training, purchase of consumables, lab notes preparation,
406 and the effective starting date of the labs. A contingency plan should be in place to mitigate
407 any unforeseen circumstances; for example swap teaching lab semesters to accommodate
408 for any delays in equipment delivery or commissioning. It is also essential to have strong
409 representation and communication with the various stakeholders involved in the project
410 including designers, estates, suppliers and even at the building stage. Site visits during the
411 building stage should be carried out regularly to rectify any issues that were not picked up
412 during the design stage or as a result of changes made without notification. Finally, be ready
413 for surprises but, after all, you are an engineer, keep calm and solve any problem.

414
415 *Figure 2 here*

416 417 418 **6 Use of software tools**

419 In many ways computer-aided process engineering (CAPE) can be considered a microcosm of
420 chemical engineering. There is a wide range of software tools supporting nearly every aspect of the
421 discipline (Puigjaner and Heyen, 2006). Furthermore, to understand the correct application of these
422 tools it is essential to understanding the underpinning fundamentals in order for software tools to
423 be applied appropriately. Without this understanding there is danger that CAPE tools will used like
424 black box with the associated drawbacks. As such, to gain full mastery of CAPE software requires the
425 development of chemical engineering knowledge at degree level and beyond. This raises the
426 question, should we introduce CAPE tools at all in a degree programme if such advanced knowledge
427 is needed to appropriately use them? We would argue that there is a synergy in learning the
428 fundamentals and developing software skills in parallel. The key is to make students aware of the
429 limitations of software tools, to situate students' current level of proficiency within a stratified
430 journey of skill acquisition, and to emphasise the maxim "rubbish in equals rubbish out" (Belton,
431 2016).

432 One of the most prominent software tools taught in chemical engineering degree courses is steady-
433 state process simulation. And this is a good place to start, since it deals with the many of the
434 introductory concepts and principles, such as unit operations, mass and energy balances and

435 thermodynamics. Here, university departments often pick one of the two market leaders, PRO/II or
436 Aspen, and this is true of the new providers, as shown in Table 1. However, there is often a drive
437 from industry for undergraduate courses to broaden the range and scope of software tools they
438 cover. The need for such breadth has also been recognised in the literature. For example, Dahm et
439 al. (2002) pointed out that process simulation should not be taught to the exclusion of other
440 industrially relevant software tools.

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

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

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

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

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

478 New providers are taking the opportunity to explore and re-examine how process simulation should
479 be taught. For example, the University of Chester has developed an interactive online simulator to
480 introduce the basic concepts involved in modelling a process
481 (<https://virtualprocesslab.thorntonresearch.org>). Belton (2016) investigated the teaching of process
482 simulation using videos and inquiry/discovery-based learning. It was found that videos were well
483 suited to supporting basic skill development and that the inquiry/discovery element of the teaching
484 approach supported higher-order skill development. Beyond this, there exist excellent guidelines for
485 the use and development of CAPE tools written by the IChemE CAPE Special Interest Group (“Use of
486 Computers by Chemical Engineers”, 1999). This guide provides a well-considered overview of how
487 CAPE tools should be utilised in a professional engineering context, along with supplementary notes
488 for managers, training providers and other stakeholders. Readers are referred to this guide and the
489 wider literature for further information on this important and ever-growing area (Belton, 2016;
490 Chemmangattuvalappil et al., 2017; Kravanja, 2016; Puigjaner and Heyen, 2006).

491

492 **7 Design projects**

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

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

511 Hybrids and other models exist, including in at least one place the authors are aware of, a single
512 (very busy!) academic undertaking sole supervision of five different projects. Campbell and Belton
513 (2016) discuss the various advantages and disadvantages of these models with respect to the
514 balance between the open-endedness of the task relative to the technical depth of the design, and
515 robustness against collusion and plagiarism.

516 As well as the model of delivery, the other issue is access to sufficient technical expertise to deliver
517 the Design Project. Within the new providers, thus far Lancaster, Hull, Huddersfield and Chester
518 have got as far as having to deliver design projects; the other new providers have not got to that
519 stage yet. In all cases, the new providers have drawn on external help to develop and deliver their
520 design projects, as summarised in Table 1. In Hull, the Design Project is sponsored by a local
521 company, with engineers providing introduction to the task and judging final project presentations,
522 while four ex-industry engineers have been appointed as part-time staff to support and guide the

523 Design Project; Greenwich has similar intentions. In Huddersfield a retired academic with a long
524 experience of leading Design Projects has been appointed, with the specific brief to develop staff
525 technical and supervisory competence alongside supporting students, in order to establish a basis of
526 Design Project supervision competence for the future. In Chester similarly a highly-experienced
527 person has been brought in to support the Design Project.

528 Meanwhile, initiatives and consultations to understand and support the specific requirements of
529 Design Project delivery are ongoing, including a recent (May 2015) Design Project “Checklist” issued
530 by the IChemE Education and Accreditation Forum. A common difference in expectation is between
531 industrialists (including members of assessor panels) who observe that Design Project tasks in
532 undergraduate programmes are “not how it is done in reality”, against academics who accept this
533 while recognising the artificial nature of the Design Project task as an educational activity
534 undertaken within the constraints of a university programme and context. The new Checklist
535 acknowledges this tension by noting *“a full commercial design would encompass all elements of the
536 Design Portfolio Checklist and this is not expected for an academic programme.”* The Checklist offers
537 a helpful basis for formulating learning outcomes for Design Projects and for placing them into the
538 wider context of commercial design; it remains to be seen how this new Checklist is exploited and
539 interpreted in practice.

540

541 **8 Industry engagement**

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

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

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

563 The measure of any engineering course is the level to which graduates enter their chosen industry
564 and thrive there. The long established courses within the UK have generated substantial links with
565 chemical process industries and many of their alumni are embedded into significant companies in a
566 range of positions. Thus, the new courses need to address two fundamental and difficult problems.

567 Firstly we need to raise our students' awareness of the industry that is out there waiting for them
568 and to make them ready to explore this potential world. So without doubt our students need to
569 understand the objectives and associated challenges of large scale manufacture, but at the same
570 time have the academic/practical/personal skills that make them attractive to the employer. The
571 second challenge is for the industry to recognise the new courses and be willing to take on the
572 students from them. The accreditation process should provide assurance to employers that
573 although these students may have differing backgrounds and characteristics from their counterparts
574 from longer-established courses, they will possess similar core competencies and in the case of
575 MEng graduates, will meet the full academic formation requirements to become fully qualified (and
576 with experience, in due course Chartered) engineers.

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

602 Whilst the new Universities ensure that they push their students towards industry with a confidence
603 that they are valued and will succeed, there needs to be a pull from the industry with a recognition
604 of the new sources of student talent. It appears this is happening and undoubtedly has been helped
605 by the economic upturn. The larger question that remains is whether the graduates from the newer
606 universities will be competitive for selection for permanent posts when placed alongside students
607 from the older courses. The feedback that has currently been received, and this may well change, is
608 that it may follow the old idiom of "horses for courses" and job specifications may well attract the
609 appropriate students to them. In recent discussions with industrialists there does appear to be a
610 focussed pull for the new students. Older university graduates, especially at MEng level, have had
611 an extensive and rigorous training and this has involved exposure to the potential destinations
612 within the profession and the lure of research. Thus, these graduates tend to be upwardly mobile
613 and/or wish to pursue management or research careers across a number of companies in their early

614 career years. By contrast, the more regional nature for recruitment and a less developed research
615 base from the new courses might yield process operators/supervisors with the hope that they may
616 become the long service employees of the future. Obviously, there can be no one size fits all
617 approach here and indeed, once given exposure to the supportive university environment of the
618 new departments, many students flourish in a way they didn't think possible, and aspirations grow.
619 Looking more broadly to the competitive job market more generally, the nature of a chemical
620 engineering education is likely to serve graduates better than alternative degrees, such that it is to
621 be expected, and not lamented, that many graduates from the new programmes will take their
622 chemical engineering education into other areas, as is already the case from the established
623 providers.

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

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

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

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

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

667

668 **9 Accreditation**

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

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

702 Linking back to the previous section, accreditation can be of benefit to universities in relation to the
703 key area of industry engagement, involving as it does academics and industrial practitioners working

704 together on accreditation panels and professional body accreditation committees. The recent
705 Wakeham Review (Wakeham 2016) observes: “We have, for example, been able to identify that
706 accreditation offers one of the most important mechanisms for structured engagement between HE
707 and employers and that it should be taken seriously as a means to engender closer cooperation and
708 a better fit between employer requirements and the skills and knowledge that the HE system has
709 the capability to deliver.”

710 The accreditation guidance was thoroughly revised in 2015, following a consultation that was
711 ongoing at the same time as several of the new providers were starting up, giving for a while a
712 degree of changing of goalposts! However, the revised guidance⁶ and process appear to be simpler
713 and fit for purpose. The approach is based on evaluating the learning outcomes achieved by
714 students on the programme (rather than, for example, an approach based on inputs such as entry
715 standards) and on a philosophy of continuous improvement, such that the expectation is that
716 programmes will have improved in tangible ways on subsequent accreditation visits; the submission
717 form opens with a comment on developments following the previous accreditation visit, and ends
718 with Future plans.

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

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

⁶ At the time of writing the latest update is from August 2017.

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

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

755

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

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

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

785

786 **10 Conclusions**

787 Increased provision of chemical engineering degrees in the UK is coinciding with a fall-off in
788 university applications unprecedented in recent years, thus creating real challenges for new degree

789 providers. Nevertheless, opportunities remain real and with attention to the findings below, the
790 future remains promising for the subject.

791

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

798 2. The same growth also allows more students to study 'close to home', thus constraining costs
799 in a period where university education has become extremely expensive, but providers
800 should be aware that students living 'at home' may be at risk of poorer learning outcomes.

801 3. Broader approaches to student recruitment, made more necessary (as well as desirable) by a
802 downward trend in applications, include the introduction of 'chemical engineering with...'
803 options, acceptance of students with creative rather than scientific and mathematical
804 strengths, and the possible introduction of degree apprenticeships combining work with
805 study.

806 4. There is a pressing need for better information on the differentiating features of the various
807 universities and courses to be made available and accessible to prospective students, their
808 influencers, and employers.

809 5. New course providers need to consider three dilemmas: covering the basics while also
810 embracing novel areas of the subject; combining the skills wanted by employers in the short
811 term with the generic competencies to support a long term career; and ensuring adequate
812 industry exposure for students and industry experience for staff.

813 6. Current and future generations of chemical engineering students will require greater
814 understanding of underlying science, just as scientists will need to understand scale-up,
815 manufacturability and process economics; the aim will be for engineers and scientists to be
816 able to speak each other's language and work together, not (usually) to create hybrid
817 scientists-engineers.

818 7. The need for extensive practical experience is driving co-operation among institutions, and
819 between universities and third parties such as colleges and industrial training facilities.

820 8. The Design Project, for which several models are in use, continues to have a central place
821 but successful delivery requires strong engagement from industry.

822 9. Opportunities for industry exposure have not kept pace with student numbers. Increased
823 attention should be paid to growing the number of industrial placements and ensuring their
824 quality; to increasing the engagement of industry practitioners in teaching, for example in
825 connection with design projects; and to providing opportunities for academic staff to gain
826 greater industry awareness for example through secondments, interaction with companies
827 on a 1:1 basis, and the effective use of industry advisory boards.

828 10. Providers and professional bodies should conduct a study of good practice in relation to
829 industrial advisory boards, based on the experience of a range of universities and employers.

830 11. The accreditation process continues to add much value for universities, students and
831 employers, provided it is not treated as simply prescriptive or used as an excuse not to
832 innovate. It can strengthen the case for necessary investment in staff and infrastructure.
833 However, further evolution is required if interdisciplinary course offerings and novel types of
834 engineering, attractive to students and important to industry, are to be well served.

835

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