Upskilling student engineers: The role of design in meeting employers' needs

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Abstract

Integrated learning makes use of group work to develop students' professional competencies in tandem with their transferable skills. This paper looks at the skills required to undertake a fourth year chemical engineering "capstone design project" (*Design*) and the skills developed therein. Staff and students were surveyed about their perceived skills abilities, both before and after the project; the results of which showed agreement as to the skills necessary to undertake *Design:* these were grouped under personal effectiveness skills, communication skills or research skills. Students described a number of extra-curricular activities that contributed to skills development but sometimes failed to appreciate their transference to academic arenas. The surveyed students indicated that their confidence in all skills areas was increased by *Design* but there were instances where some individual sub-set devaluing occurred. There is a link between experiential practice, predominantly as a result of producing assessed components, and high skills confidence; hence, it is recommended that students are encouraged to reflect on their project experience and that integrated learning be promoted to develop all skills effectively.

Keywords: Employability; Mixed-methods; Engineering, Undergraduate; Industry; Transferable skills.

1. Introduction

1.1 Skills development in chemical engineering degree cohorts

UK Higher Education has seen an enormous increase in interest in chemical engineering degrees; in 2015, there was a record 3,775 enrolments on chemical, process and energy engineering courses across the UK, compared to just 750 in 2007 (UCAS 2015). Many institutions have increased their entry grades, in alignment with higher demand, and there has been a move towards greater gender population balance. It is imperative that these well-qualified cohorts are provided with a high quality, inclusive education, which both challenges them to their full potential and attains industrial and postgraduate standards, so equipping students to enter the workplace, or further education, upon graduation.

It is true of all disciplines that a professional body will accredit university courses for quality assurance, however, it should be appreciated that such accreditation processes alone may not perfectly capture the success, or otherwise, of 'latent' skills development. The global professional body of membership for chemical engineers is the Institution of Chemical Engineers (IChemE), who provide accreditation of university degree courses, as well as company training and continuing professional development courses. IChemE also awards qualifying members with chartered chemical engineer status, as well as a range of membership categories that reflect achievement and experience (IChemE 2015). It is one of IChemE's aims to ensure that the chemical engineering workforce maintains its skill levels, by assessing institutions and chartership against their experiences of best global practice (IChemE 2015).

IChemE's guidance focusses on a learning outcomes based approach, rather than being content-driven, and this is the general paradigm shift that has occurred across the whole of engineering education in recent years (Fitzpatrick, Byrne, and Kennedy

2009). Learning outcomes focus on the student, highlighting expected skills or capabilities, but not necessarily the method or content by which it must be achieved, thereby giving academics greater flexibility in their teaching. However, it can subsequently be difficult to explain the exact subset of skills developed on particular courses for specific cohorts, while assessing some outcomes can prove challenging.

1.2 Design projects in chemical engineering

Following the inception of chemical engineering as a discipline in its own right, *Design* has been an integral part of chemical engineering studies and, as part of all accredited chemical engineering degrees within the UK, students are expected to complete a chemical engineering design project towards the culmination of their studies, as part of their professional training.

The *Design* syllabus is defined as '*the design project is organised and run the way the Institution of Chemical Engineers recommends, to cause the student to apply knowledge of chemical engineering principles to the design of a process' and 'to demonstrate creativity and critical powers in making choices and decisions in some areas of uncertainty'. With additional elements that extend the students experience of; process evaluation and selection; safety and environment; control and operability; costing and economic evaluation*'. Hence, students are expected to undertake a project that simulates the real life demands facing a chemical engineer and to utilise knowledge gained from a range of previous courses.

At the time of survey, *Design* ran as two separate projects, one covering core chemical engineering principles (detailed design) and the other focussing on the aspects of innovation and validation (conceptual design).

Successful completion of *Design* allows students to apply for prestigious (and financially rewarding) chartered status (CEng) from IChemE, upon graduation and attainment of a minimum period of professional experience. Failure to complete *Design* results in the non-award of honours status with the degree classification, and thus an extended period of proof, from relevant experience and additional study, is required to gain chartered status. Hence, *Design* is viewed as highly desirable by students and industry alike, thus it is imperative that the required skills are developed therein.

Design gives students excellent learning opportunities through common intellectual challenges, working in learning communities, collaborative project work and, importantly, experiencing 'Engineering as Engineering is done' (Kuh 2008). As part of *Design* students have to meet with project supervisors each week to discuss progress to date and their targets for the future. The learning outcomes place emphasis on the consideration of a process as a unified system rather than individual parts, and to undertake creative development of a process design while at the same time considering economic viability, and environmental and safety issues. Most notably, two of the specified learning outcomes are to '*appreciate the benefits and difficulties of working in a small group as well as an individual*' and '*have deployed a reasonable selection of the skills and techniques acquired during the course (such as process design, equipment design, plant design, control and more general theory) in completing a substantial and coherent piece of work*'.

Many students experience theoretical difficulties with *Design*, which is partly attributable to the lack of engagement with key concepts in core modules. Another factor is that there is often no one definitive right answer, and the supervising academics may themselves not necessarily know what the best solution would be -this is especially true for the conceptual component of the project.

It is possible that, for some students*,* *Design* requires the revisiting of troublesome knowledge - a consequence of not previously engaging with key concepts earlier in the course - while for others it may present a new threshold concept (Meyer and Land 2003), namely *Design* as a process in its own right, with many students unable to overcome their issues.

1.3 Employers' perceptions of chemical engineering graduates

The Confederation of British Industry (CBI) education and skills conducts an annual survey, in 2016, they collated the views of nearly 500 employers, representing approximately 32% of the science, engineering, manufacturing, energy and water sectors with a combined workforce of ~3.2m (Confederation of British Industry 2016). All employers were asked to rate their satisfaction with graduates' employability skills as either '*very satisfied*', '*satisfied*' or '*not satisfied*', ranking seven key employability skills identified by CBI as valued by employers. It is notable that five of the seven key graduate employability skills have increasing levels of dissatisfaction amongst employers, while graduates' relevant work experience also scores highly in terms of employer dissatisfaction. In 2004, the World Chemical Engineering Council (WCEC) surveyed 2,158 participants from 63 countries, to investigate '*how does chemical engineering education meet the requirements of employment?*'(World Chemical Engineering Council 2004), ranking 26 preselected skills on a Likert scale (1: very low to 5: very high) according to the respondents' perceived views of the quality of their education and the relevance of each skill to their work. One critique of using the mean deviation to rank skills is that participants may have been comparative rather than subjective in their evaluation of each skill, using other skills as comparators and skewing the expected evaluation of educational quality and work importance; this is refuted by the authors' validation that both of the perceptions considered in determining the deviation represent the changing views of work and education priorities. An interesting result of this analysis is that the mean deviation rank assigned to '*apply knowledge and basic chemical engineering fundamentals*' is 25th out of 26, compared to the World ranking of 14th; being one of only two skills from the survey to exceed the perceived employment requirement from the education perspective, indicating that the IChemE's learning outcome for students (IChemE 2015) to be knowledgeable in '*essential facts, concept, theories and principles of chemical engineering and its underpinning mathematics and sciences*' has not only been met, but exceeded. By contrast, many of the skills identified by the survey to be highly important for employment, such as '*ability to solve problems'*, '*ability to work effectively in a team'* and '*self-learning abilities'* demonstrate a competency gap (a negative mean deviation), which indicates that educational institutions are not yet sufficiently addressing the need to develop these skills in their graduates.

Grant and Dickson (Grant and Dickson 2006) have also reviewed employment skills, including a thorough investigation of a range of accreditation guides, including the IChemE, and associated bodies for graduate recruitment; their resulting classification of the main transferable skills for employment are summarised as:

- Good at communicating in a variety of forms (written, oral and so on)
- Able to work well in teams
- Able to solve problems (pro-actively and with initiative)
- Numerate and IT literate
- Able to manage themselves and continue to learn

which align with the 6 skills identified as most important in employment by the WCEC (World Chemical Engineering Council 2004), and in line with IChemE's Learning outcomes that '*graduates must possess skills such as communication, time* *management, team working, inter-personal, effective use of IT including information retrieval [considered] valuable in a wide range of situations'* (The Institution of Chemical Engineers 2012). Agreement also exists between the WCEC survey results (World Chemical Engineering Council 2004) and CBI findings (Confederation of British Industry 2016). Here, skills perceived as under-taught in universities by current employees are similar to those towards which employers have expressed dissatisfaction, most notably business and management skills, suggesting measures are required to promote these skills.

Thus, there is significant evidence that the most important skills for work are those that are typically considered transferrable, and significant deficiencies exist for some skills, which are recognised by both employers and employees.

1.4 Skills development

1.4.1 Transferable Skills

The definition of transferable skills is situation dependent but often the language is vague; for example the Department for Skills and Education's (1995) definition is *'cognitive and interpersonal skills (application of number, communication, information technology, problem-solving, personal skills, working with others and improving own learning and performance) which are central to occupational competence in all sectors and at all levels'*. It is notable that subject specific knowledge and technical skills are omitted from this definition, despite being crucial to student academic advancement, practically delineating the two aspects of development (Chadha and Nicholls 2006).

While technical skills and knowledge can be formally assessed, for example via examinations, and some forms of transferable skill may be a conduit for assessed content, transferable skills are predominantly experiential, through educational and social experiences, and not formally assessed. Hence, students need to develop their own methods of evaluating their development in these areas. This difference in appraisal is manifest in the dichotomy that transferable skills competencies are not universal, nor are they an indication of academic success.

A recommendation of the Dearing report (Dearing 1997) was to enhance skills outwith the ‘normal’ teaching curriculum, which was underpinned by identified employer needs, including greater graduate independence (also related to responsibility for career development and autonomous learning). Such skills development can be realised by one of three methods:

(1) embedded teaching, which involves latent skills development, allowing students to become independent learners (Fieldhouse 1998). Students can sometimes fail to appreciate the applicability of taught content to transferable skills development (Chadha and Nicholls 2006).

(2) integrated teaching, which places equal emphasis on co-curriculum strands of technical knowledge and transferable skills, hence students work on group projects or presentations that require knowledge application, often more closely simulating real-life working scenarios (Humphreys, Greenan, and McIlveen 1997). *Design* at Strathclyde attempts to utilise integrated teaching.

(3). bolted-on teaching, which sees transferable skills taught outwith the core curriculum as stand-alone modules. While this emphasises skills development, it has been questioned whether this allows effective teaching as a separate entity (Drummond, Nixon, and Wiltshire 1998), as the importance of the skills themselves is often diminished (Chadha and Nicholls 2006).

Hence, the Department of Chemical and Process Engineering (CPE) is attempting to utilise integrated teaching to simulate the real-life scenario of the design process for its students, however, the development of the underpinning teaching strategy and resulting students' engagement has never been previously evaluated.

1.4.2 Previous evaluation of design teaching

A previous study within CPE has looked at the effect of curriculum changes in *Design* teaching (implemented in 2008-2009) on student academic performance, without any detailed investigation of student skills development (Fletcher and Boon 2013). One of the major changes found for the new delivery of *Design* was that BEng Chemical Engineering students seemed to now be integrated fully into the two design teams that were in operation, potentially raising BEng students' aspirations by allowing them to work closely with students achieving MEng grades. Additionally, the removal of process design to a dedicated module, making *Design* a completely coursework driven process, may have allowed BEng students to demonstrate strengths in that particular mode of assessment.

Post-2008 results showed a highly positive correlation of marks awarded for *Design* and overall performance, both final degree mark and the years preceding *Design* (i.e. years 2 and 3); this is in contrast to pre-2008 results where BEng students showed a decrease in performance for *Design*, possibly related to group dynamics or assessment mode changes (Fletcher and Boon 2013). Hence the revised teaching structure allows all students to perform in line with their previous performances and this levelling of *Design* performance, irrespective of degree programme, allows direct comparison of data accrued over the three main streams taught within CPE.

2. Methodology

2.1. Study objectives

CPE offers a range of full-time degree courses, comprising the qualifications of BEng Chemical Engineering and MEng Chemical Engineering, as well as MSci Applied Chemistry and Chemical Engineering, jointly run with, but administered by, Pure and Applied Chemistry. All three degrees are accredited by IChemE, and the MSci is jointly accredited by IChemE and the Royal Society of Chemistry.

Chemical Engineering is a versatile discipline, both in education and employment; as a result the taught curriculum is varied, offering problem solving, design, control, management, materials science, safety, economics and environmental impact, in tandem with chemical engineering fundamentals, all of which prepare students for the gamut of roles offered within industry and further education. This accrual of knowledge is, in itself, only part of the whole training process, which should, ideally, also allow students to develop key transferable skills that will be required within the chemical and engineering industries. To facilitate this process, students are encouraged to engage with professional development activities, allowing reflection on their engagement and progress. However, it is also essential for the teaching staff that provide such student training to similarly understand at what times and by which mechanisms these transferable skills are being developed, providing evidence for further curriculum development or to validate course accreditation.

As detailed in the previous sections, employers are increasingly dissatisfied with the transferable skill set offered by their recruited graduate students. A fine balance exists in academia to ensure that the accredited curriculum is taught to the highest level while affording students opportunities to develop skill sets that may be useful in their final employment. In an ideal situation the two would be symbiotic, and there are instances, in CPE's degree programmes, where this happens; however, the non-explicit nature of skills development means that students may not appreciate the development taking place and may then fail to capitalise on their new skills, thereby reducing future recognition and impact.

The perceptions of skills development by undergraduate students, undertaking *Design* within CPE, was investigated in order to more fully understand both staff perceptions of student development and students' views of their own skills progression, with a view to evaluate this teaching instance as an exemplar for other years and courses. This was achieved by considering the following research questions:

1. What skills do staff and undergraduate students think are developed during *Design*?
2. Is there agreement between the expectations of staff, regarding project learning outcomes, and undergraduate students undertaking design?
3. How do students' perceptions of their abilities in selected skills change during design?
4. What other external experiences have contributed to undergraduate students' skills development?

Question 1 was addressed in the scoping surveys of staff and students; Question 2 correlates the information obtained in both sets of surveys; finally, Questions 2 and 3 were probed in the student surveys conducted pre- and post-*Design*. In all cases, the questionnaires were distributed online to increase accessibility for participants, providing a spreadsheet of data and responses on completion. To eliminate bias in the collected results, data were obtained from all available student demographics, including full-time BEng, MEng and MSci students, and part-time distance learning

BEng students, providing a representation of the different attitudes that degree focus and experience bring to a chemical engineer's views about their work and education.

2.2 Composition of the study

16 CPE staff were sampled in the design scoping survey (see Supporting Information), constituting the whole teaching team for *Design* at the time of the survey (January 2014). This included staff at a number of grades, from lecturer to professor, and teaching fellows.

The undergraduate student scoping survey was run in January 2014, prior to the semester-long design project (13 weeks), and had 31 respondents: 27 men and 4 women; it is appreciated that the number of women respondents is lower than the proportion within the sampled cohort (25%, which is in line with previously reported demographics (Carter and Kirkup 1990)) but their responses may give important points for discussion so gender differences have been probed. This cohort also included students from the distance-learning cohort (composed predominantly of men, which skews the relative proportion by gender, and all 4 distance learning respondents were men) and this provides insight from mature students (age range 24-40) and those already employed in related industries.

The undergraduate student population sampled in the pre-*Design* survey was composed of a total of 56 students: 38 men and 18 women, giving an over-representation of women students but again allowing a comparison on the basis of gender. Students were encouraged to take the survey to assist in the development of future design teaching, thereby removing skewed responses from students who felt that they were coerced or forced into answering the survey.

A total of 25 undergraduate students: 20 men and 5 women took part in the post-design survey in May 2014 after submission of all design assessment components. Registration numbers allowed student responses between to be collated between the two phases and a total of 22 students answered both surveys, providing a basis for pre- and post-design comparisons (gender breakdown was 17 men students and 5 women students, which exactly mirrors the gender balance for the cohort sampled at 30%). Comparison of the mean responses given by the sub-group that answered both surveys and the respective global groups showed that the views of the sub-group were representative of the whole and vice-versa.

2.3 Scoping survey of skills development

Addressing Question 1: *What skills do staff and undergraduate students think are developed during Design?*, two scoping surveys were developed in-house, one aimed at staff teaching design and the second targeting students in the 2013-14 design cohort to better understand their expectations of the design process. Validation was provided for the student survey by colleagues to ensure clarity, readability and clear layout; reliability could not be tested due to the small cohort and anticipated low response rate (which was realised in the number of responses obtained).

Two questionnaires on skills expectations were devised to gain qualitative insight into the expectations of (1) teaching staff and (2) undergraduate students with regards to prior skills requirements and skills developments in *Design*. All teaching staff were encouraged to complete the staff survey; while undergraduates were offered the opportunity to express their expectations for *Design*, with a view to course redevelopment based on their responses.

The staff questionnaire requested:

- ***demographic information***: job grade, normal role within *Design* teaching and amount of experience teaching *Design*;
- ***prior skills***: skills brought to *Design* by students, whether such skills are commonplace, effect of mode of learning i.e. full-time or distance-learning, difference in skills required for conceptual and detailed *Design* components.
- ***skills development:*** which skills are developed and which skills are expanded upon during *Design*;
- ***industrial alignment:*** if alignment is merited, which skills should be aligned.

The student questionnaire requested:

- ***demographic information***: registration number (to allow collation of data pre- and post-*Design*), gender, age, and degree stream;
- ***prior skills***: skills needed and brought to *Design*, which skills differ in undertaking conceptual and detailed *Design*;
- ***skills development***: expectation of which skills need to be developed or expanded;
- ***industrial alignment:*** industrial experience; if alignment is merited, which skills should be aligned.

An open response textbox allowed participants to comment on concerns and/or aspirations related to undertaking *Design*.

2.4 Evaluation of skills and abilities by questionnaire

2.4.1 Survey structure

Question 2: *Is there agreement between the expectations of staff, regarding project learning outcomes, and undergraduate students undertaking design?*, was probed by two surveys of students undertaking *Design* in the 2014-15 cohort, one directly before they started (January 2015), and a second upon completion of *Design* (April 2015).

Two questionnaires on personal employability skills attainment were developed in-house to gain quantitative insight into the attitudes of participants, allowing a large sample size for statistical consideration, hence, representation of the perceptions of the full cohort. Validation was again provided by colleagues and reliability was not tested due to the limited cohort and response rate.

The questionnaire requested:

- ***demographic information***: registration number (to allow collation of data pre- and post-design), gender, age, and degree stream;
- ***skill set***: type of experience (summer placement, current employment etc.), area of experience, area of interests and offer for graduate employment;
- ***perceived skills attainment***: utilising the generic skills/abilities identified by the scoping surveys to both staff and students. Participants rated each skill on a 7-point Likert scale, firstly with respect to how prepared they felt before undertaking design and latterly once they had completed the design process. It is important to note that all ratings are based on individual perceptions;
- Open response textboxes allowed participants: (a) In the pre-design survey to comment on which of their past experiences had developed the skills surveyed and what additional skills, other than those surveyed, that they may develop during design; (b) In the post-design survey to comment on how design has helped development of the surveyed skills, whether they developed any additional skills other than those surveyed, and space for further comments.

2.4.2 Data analysis

The questions employing a Likert scale were analysed by determining the arithmetic mean or mean, $\bar{x}$, from a population of *n* samples, where x_i is the value of sample *i*:

$$\bar{x} = \frac{1}{n}\sum_{i=1}^{n} x_i$$

The standard deviation of x_i, for sample *i*, from the mean ($\bar{x}$) was determined using:

$$\sigma = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(x_i - \bar{x})^2}$$

Likert scale questions are a form of ordinal measurement, i.e. there is no assurance that a linear relationship exists between '*above average* (6)' to '*slightly above average* (5)', hence, a mean of 5.6 does not necessarily indicate that the result is closer to '*slightly above average* (5)'. The misuse of Likert scale means have been reported in the literature (Jamieson 2004), where it has instead been recommended to use the most frequent response i.e. the mode; hence both statistical quantities have been determined and compared here.

3. Results and Discussion

3.1 Scoping survey indicators for student surveys

The scoping surveys were used to provide information on the overall perceptions of skills development in the 'as then' process, by staff and students engaged in *Design*. The data obtained (see Supporting Information), underpinned the individual skills on which students were latterly surveyed, in depth, in *Design* 2014-15. It is evident that both staff and students agree that *Design* both requires and further develops key skills. Although *creativity* and *criticality* were identified as desirable skills, it is difficult for students to assess their abilities in these fields as they are very subjective concepts; it is also recognised, especially by observation of the student scoping survey results, that these skills are specific to one aspect of design i.e. conceptual, hence, they were discounted, along with *technical knowledge* and *ability for application* as these are assigned as skills primarily used in detailed design. The remainder of the skills fall into three main themes and these are discussed in detail with their respective skills subsets.

It was decided to deconstruct ***communication skills*** to provide more detail, especially as the term was often used extensively by both groups as a catch-all in the student scoping survey, by asking students about the specific skills of *verbal communication*, *written communication*, o*ral presentations, minute taking* and *listening*; skills that underpin effective meetings. A second core area was ***personal effectiveness*** and it was decided to probe this in greater depth, by asking students to consider *time management*, *project management*, *leadership*, *decision making* and *working with others*. Lastly, ***research skills***, which allow students to collate, evaluate and present their work were assessed by asking about *word processing*, *data analysis*, *IT* and *research of literature*. The results are discussed both in terms of the individual skills and also the overarching themes.

3.2 Student data

3.2.1 Communication skills

Verbal Communication: Possibly the most obvious communication skill is that of verbal communication, where information is transmitted by discourse. The students surveyed indicated that before undertaking design they had an *above average* ability (by mode) with the majority of responses in the *average* to *above average* range (Table 1, responses are presented as a percentage to allow ease of comparison between the two different populations of respondents). Numerically representing the Likert response as the values 1 to 7 (with 1 being *well below average* and 7 being *well above average*), pre-design the responses mean was 4.95, increasing to 5.24 post-design (+0.29, 5.9%); a marginal increase and, post design, it can also be seen that the overall mode response is unchanged at *above average* but there is a significant increase in the proportion of students answering *well above average* (in real terms, an increase from 1 respondent to 5).

This improvement is slightly tempered by the fact that a greater proportion of students identify as *below average* post-design, representing an increase from 3 to 5 students. This is not insignificant, despite the small numbers involved, as it indicates that, in addition to not improving the lot of three students, design has potentially reduced the perceived abilities of a further two students.

Figure 1 shows a bubble plot of the responses provided by the 22 students answering both surveys, two of whom indicated below average ability both pre- and post-design, with no numerical change in their responses, indicating that the design process has not enhanced their verbal communication, despite the fact that they have had to talk to their peers and supervisors at regular meetings across the 14 weeks. It may be that such students are inherently shy, possibly being ‘hidden’ or even intimidated by more outgoing students within their groups, which could have impacted on their skill perception or confidence.

It is interesting to consider the change in perceived verbal communication ability with respect to gender, where men students increase from a mean of 4.84 to 5.16 (+0.32, 6.5%) also increasing the mode from *slightly above average* to *above average*, which brings them to the same level as pre-design women. Post-design women gave a mean of 5.50 (+0.34, 6.6%), hence, the mode was unchanged at *above average* both preand post-design. So, although they demonstrate the same incremental change in perceived ability, it is the higher starting baseline for women that sets them apart and sees them finish at a much higher level than their men peers. Such a gender imbalance is contrary to previous studies (Tannen 1995) and may result from a long-term socialisation of the peer group, which is fairly demographically homogeneous and without an evident hierarchy.

Listening: In conjunction to verbal communication, it is important that team members are able to actively listen to each other, allowing information to be shared effectively and for ideas to be fully aired and considered. Overall, students felt well prepared for design, averaging 5.19 for listening and recording a mode response of *above average* (Table 1); this was unchanged post-design but the mean had increased to 5.40 (+0.21, 4.0%). Similarly to verbal communication, men students started design with a lower perception (5.11) of their listening skills than women students (5.37) and, although the men see a marked increase in perceived ability at the conclusion of design (5.32, representing a +0.21 (4.1%) increase), the women students see a greater increase and end design with a perceived ability of 5.67 (+0.30, 5.6%). This comparable trend with verbal communications may be related to the similar nature of these skills; however, it is interesting to note that the *above average* mode for all groupings, both pre- and post-design, is moderated by the large number of students who responded *average* and *slightly above average*, which are almost unchanged by the process and it is the increase in the proportion of respondents answering *well above average* that increases the mean for both genders and overall.

Oral Presentations: Given the students' responses to verbal communication ability, the responses received for oral presentations were surprisingly low by comparison. Overall the pre-design mean was only 3.93 (mode *average*, Table 1) and the split by gender showed that this lack of confidence was evident for men (4.16) but most noticeably for women (3.47). This is in stark contrast to the relative perception of ability shown for verbal communication and may be more reflective of the task i.e. in that it is more formal and assessed, compared to other types of verbal communication.

Despite the fact that students only undertake one presentation during the design process, where they must present their conceptual *Design* findings to their supervisor and another staff member, the perceived ability is increased significantly, by this one instance, to a mean of 5.16, representing an increase of +1.23 (31.3%). Very few students indicate a less than average ability post-design (Table 1) and there is a clear increase in individual perception, as evinced by the sub-group of 22 respondents and shown in the bubble lot of their responses in Figure 2. There is only one respondent who does not stay at the same perceived level or increase their perception, as a result of undergoing design, but this decrease is only marginal, moving from *above average* to *slightly above average*, which could easily be subjective for any individual on a day-by-day basis.

Men indicate that their abilities are increased to a mode of *above average* (5.37, an increase of+1.21 (29.1%)), while the mean perception ability of women increases by a comparable amount (4.50, an increase of +1.03 (29.5%)) also with a mode of *above average* but they still lag significantly behind men (-0.87 post design).

Written Communication: Students are required to communicate by writing in a number of summative and formative tasks throughout their degree courses, hence, it would be expected that they should feel some level of confidence in their abilities in written communication.

This was seemingly true for women students (5.16, mode *above average*) but wide of the mark for men (4.66, mode *average*); the gender dominance of men students means that the global mean is 4.82 (mode *average*). Design involves students contributing to, and authoring individual sections of, two 100 page reports; the report for detailed design also includes appendices and it is not unusual for these reports to reach total page counts in excess of 400 pages. This requires students to (i) each produce a large amount of written text, (ii) manage their individual work and integrate it into the collated main report, and (iii) format each report to read as a single document rather than a collection of individual texts. As a consequence, students demonstrate to themselves and their peers, both their capabilities and limitations, but the project works such that often a group will help an individual overcome a weakness. Hence, there is significant scope for development, and this is shown by an increase in the mean to 5.12 (+0.30, 6.1%), with 7.3% and 6.6% increases for men and women, respectively. These improvements in perceived ability mean the whole cohort, irrespective of gender, complete design with a mode response of *above average* (Table 1).

Minute Taking: The chemical engineering degree at Strathclyde requires students to work in teams from the very first week, recording the details of their meetings and receiving feedback on their attempts at taking minutes appropriately. Despite this prior experience, and feedback, students demonstrated a low perceived ability to minute taking when surveyed (Table 1). Overall the mean was 4.14 (mode *average*) with a small difference between men (4.05) and women (4.32), which is somewhat at odds with the perceived abilities of women in written communication but in line with the responses by men.

Despite an increase of 8.2% to 4.48, most notably attributable to men (+0.42, 10.4%), the mode for both genders and the whole cohort remains at *average*, indicating that, while the students seem to have increased their written communication skills, they do not conceive minute taking to also be a form of written communication, the task may also not be rotated between group members. There is a relative cluster of students increasing their perception from *average*/*slightly above average* to one or two categories above (Figure 3), hence, there is little difference in the global distribution excepting the response rate for *above average* (Table 1).

It may also be that, as the minutes taken for the design meetings in CPE are not assessed and few supervisors offer any form of feedback on the minutes submitted, some of which may not even be constructive, this is evidence of students committing effort to the latent curriculum and failing, somewhat, to realise their own development outwith the tasks that accrue marks. While there have been calls for teachers to make the latent curriculum more explicit in their courses (Portelli 1993), there remains an underlying trend that most educators do not appreciate that a 'hidden' curriculum exists and need to acknowledge the fact (Xiao-dong 2003) before strategies can be put in place to assist students in its engagement. Such a situation currently exists in *Design* and the results presented here lend evidence to the need for both implicit and explicit curriculum development.

3.2.2 Personal effectiveness skills

Time Management: Students and staff both highlighted that time management was a key attribute to bring to design and, hopefully, develop further during the process. Students need to manage two concurrent projects over 14 weeks, with multiple submission dates, weekly supervisor meetings for each project and additional meetings with their groups as required. Surveys were conducted prior to *Design* (January 2015) and upon completion of the project (April 2015) and comparison of the

Likert responses at these two test points shows that pre-*Design* students perceive their time management skills to be *average* (mode for men) to *above average* (mode for women) with an interesting contrast post-design, where the majority of students suggest they are all now *above average* (+0.38 increase (7.8%), Table 2). Despite the mode for men changing by two categories (*average* to *above average*), and the fact that the mode for women students is unchanged, it is interesting to note that there is a 12.4% increase in female perception of ability, while men increase by 6.6%, falling behind the women overall (-0.39) and this stresses the importance of considering both the most common response and the mean for the global cohort as this accounts for significant proportions of outliers.

Project Management: The responses for students perception of their skills in project management are shown in Table 2 and show that students generally have a higher perception of their abilities post-*Design* (mode of *above average* compared to *slightly above average* pre-design). This is matched by the mean marks, which also see an increase in category from 4.61 to 5.16 (+0.55, 11.8%). This global trend, however, masks the fact that women students start *Design* believing themselves to be average at project management, one category below men, yet end with the same mode (and almost identical means).

One worrying fact of these results is that students enrolled on all three degree programmes undergo project management training as an explicit class, and have several opportunities to develop their skills in earlier projects, yet their pre-*Design* responses suggest low confidence in using this skill. It is possible that students have difficulty translating theory into practice prior to *Design* and that these two intense, concurrent, projects provide a structured opportunity for development, which shows in the post-design responses.

It is also of some concern that, after having been through *Design*, two students feel that their project management is now *below average,* their original responses to their abilities to manage projects being *average* and *slightly above average*. Figure 4 shows a bubble plot of the responses provided by the 22 students answering both surveys. Such a decline in perceived ability may be either a realisation, by these students, that they do not possess the skill to the level that they originally believed or their skill perception has been devalued by either their colleagues or the project itself. Either way, it is disappointing that, given that *Design* has a latent learning outcome to skill students and prepare them for the demands of the outside world, some students see a negative impact on ability or confidence, or even both.

Leadership: Students perceived their pre-*Design* abilities in leadership, overall, to be *average* (by mode) with a mean of 4.70. It was interesting to note that there was little variance in the men and women means at the beginning of *Design* (4.68 and 4.74, respectively); however, the 8.0% increase at the end (5.08) was largely due to the increased perceptions of men students, who had increased their mean by 10.1%, with women only gaining 2.0%. This is in line with the mode responses, by gender, post-*Design*, with women answering *slightly above average* and men most often responding above *average* (Table 2). Women may enter *Design* with a higher perception of their leadership skills as a result of external activities or adoption of similar roles in earlier projects; however, men students have a tendency to monopolise leadership roles in *Design*, possibly as a consequence of the large academic credit attached to the class.

Working with Others: Students within the department have myriad opportunities for group/team work activities over the first four years of their degree programmes, including group-based tutorials, team project work and laboratory groups, with cooperative work encouraged from their first day at induction. Hence, it is not surprising that students considered themselves to be *above average* with respect to teamwork pre-*Design* (5.44). However, as the question asks students to rank themselves against their peers it does seem that students may undervalue their colleagues and/or overvalue themselves.

Students' rankings of their teamwork skills increases by 6.6% over the course of *Design* (mode is again *above average*), with a significant increase in the number of students who responded *well above average*, but also an increase in the *slightly below average* category, which may be the result of self-evaluation by some students or potentially devaluing of their skill by peers (Table 2).

Decision Making: The role of the supervisor in *Design* is to guide students and to provide general advice regarding their proposed process and the guidelines for marking and submission criteria. Students, however, often begin *Design* with the notion that the staff member is there to assist in the decision making process and, consequently, students are advised that direct questions are not permitted (an issue that is frequently revisited during *Design*). It may be this reliance on staff expertise or it may be a consequence of students' failure to accept the threshold concept (Meyer and Land 2003) that there is not always a singular correct answer that causes issues in agreeing the direction of work, once within the *Design* process.

The survey results (Table 2) indicate that this trend may be underpinned by students' prior confidence in decision making with 39% of students reporting a less than average response. The mode response of *slightly above average* brings up the mean to 4.72 and there is a slight increase during *Design* to 5.08 (+0.36, 7.6%), driven primarily by the 12.8% increase for women, suggesting that they become more engaged with decision making, and resulting in a post-*Design* mode of *above average*. The *less than average* categories post-*Design* now account for only 16% of the surveyed group, indicating a significant increase in decision making confidence. It may be that students feel empowered by being forced to make decisions themselves and there may be an acceptance of the threshold concept mentioned above, which is a powerful transition if realised.

3.2.3 Research skills

Word Processing: Women students have struggled in the past with accepting the roles assigned to them, seemingly by consequence of gender, and have tried to avoid actively accepting tasks related to secretarial work (Flynn et al. 1991; Carter and Kirkup 1990). Hence, it is interesting to consider their development in word processing during *Design*.

The survey results for perception of word processing ability (Table 3) demonstrate the limitations of considering the mode as an isolated variable (Jamieson 2004), as the responses show a bimodal distribution for both pre- and post-design. There is a marginal change in all categories *average* and above, which results in a significant mode change from *average* to *above average*. This is influenced predominantly by women who responded *average* pre-*Design* but agreed with their men colleagues post-*Design* by responding *above average*, representing an increase of 21.5%. Women students have been described as being able to '*configure the world as a web rather than a hierarchy*' (Flynn et al., 1991). They are consequently more likely to work in a cooperative manner (Belenky et al. 1986; Flynn et al. 1991; Gilligan 1982), however, previous work has shown that women students can face negativity from their men peers (Carter and Kirkup 1990; Flynn et al. 1991), and this may result in the assignment of group secretarial responsibilities, as a consequence of gender related bias. Our previous research has shown that women students rebel against this in their early student life (Nisbet et al. 2016) but may reconfigure their later working practices to improve their potential attainment by increased time spent on task for report completion and drive to produce a more integrated final output.

Information Technology: Students undertake explicit classes in IT development in the first and third years, while also utilising IT for laboratory classes, project work and personal interests; yet students demonstrate a low perception (4.33 total cohort) of their IT ability pre-*Design* (mode of *average*). There is a correlation between the responses for word processing and IT, with only a handful of students answering more than one category differently between the two skills, and it may be an implication that in the act of word processing students require IT skills, hence, the similar scores.

It is important to remember that word processing can require students to use non-IT based systems as well as requiring organisation of information and formatting. Table 3 shows that there is a significant shift in perception with a post-*Design* mean of 5.12 (+0.79, 18.2%); however, the mode is unchanged, except for the gender allocated responses for men with a mode of *above average*, more akin to the mode for word processing. The large change in mean is mirrored by both genders, who each exhibit increases in the mean of +0.71; however, women students still finish design with a mode response of *average*, suggesting that although women engage with IT, potentially to improve their word processing skills, they remain less confident than their men colleagues in using IT.

Data Analysis: IT skills are required, in part, for data analysis, which also requires students to be able to evaluate and assemble data to support their work. It is evident from Table 3 that students have a similar perception of data analysis as word processing, and it may be the use of IT, rather than the concept of understanding how

IT works, that gives them greater confidence in this skill, with an overall pre-*Design* mean of 4.54.

Despite the significant number of responses in the greater than average categories, the mode is *average* (Figure 5), and remains so, even when the post-*Design* mean increases to 5.08 (+0.54, 11.8%). Gender makes little difference to students' perceptions of data analysis, except in absolute mean terms, with both genders seeing a significant increase in mean value but with no change in mode (average).

It is worth noting that three students' perceptions of their data analysis ability reduced after completing the design project; possibly as a result of self-realisation through experiential evaluation during design or that there perception was based on the operational aspects (e.g. IT) rather than the process itself.

Research of Literature: The basis of conceptual design is to scope a novel research area to determine a viable process that can be scaled to produce the material(s) of interest, and this requires students to engage with the open scientific and engineering literature. This is a skill that they have utilised, in part, in earlier projects but that is not explicitly taught and more often implied in the set remits for projects. Consequently, students may feel underprepared for the level of research work required by *Design*. In Table 3, it can be seen that some students feel they have a greater than average ability in researching the literature but the mode and mean (4.35) fall in the *average* range. The mean for women is less than men (-0.21) but their confidence, or practice of skill, is obviously marked in *Design* as they end the process with a mean +0.28 greater than men, representing a 26.7% change, and a mode of *above average*. This contributes to a post-*Design* mean of 5.12 (+0.77. 17.7%) and a shift in mode to *slightly above average*.

3.3 Rankings of surveyed skills

The overall rankings make for interesting reading. Pre-*Design*, men students rank ***personal effectiveness skills*** most highly as a grouping, with *working with others* the highest of all 14 skills surveyed. The same is true for women students, however there is a marked difference in the order of the ***personal effectiveness*** subset of skills, as well as the secondary overarching skill set of ***communication***. The top seven skills identified by women students are exclusively ***communication*** and ***personal effectiveness skills***, whereas men's responses are dominated by ***personal effectiveness*** but also rank one ***research skill*** in their top seven.

This contrasts markedly with the post-*Design* rankings, where men students still show a mixed overview in their top seven, but are now less influenced by ***personal effectiveness***, with ***communication skills*** becoming more dominant. There is significant 'shuffling' of the rankings with only the top ranked skill (*working with others*) retaining its position. Women students, on the other hand, now include two ***research skills*** in their top seven, however, these are at positions 6 and 7, as the top five skills are unchanged (even in order), indicating that the skills women students perceived to be well developed pre-*Design* as still highly developed compared with the other surveyed skills post-*Design*. It is worth noting that the scores for the majority of skills outwith the top five increased markedly, while four of the top five showed marginal increases, this demonstrates the very high scores originally assigned to these top ranked skills, allowing them to be retained as highest ranked skills despite the relatively small increase in perceived ability.

For men students, leadership was surprisingly low pre-*Design* in comparison to other ***personal effectiveness skills*** (time management, project management, working with others and decision making), especially as students have previously undertaken a variety of group work tasks with opportunities to adopt a range of roles. There is a higher confidence for women students pre-*Design*, and it is encouraging that female students feel they are able to adopt leadership roles in this instance; however, it is somewhat troublesome that women rank *leadership* lowest of all ***personal effectiveness*** skills post-*Design*, potentially at the expense of their male colleagues.

Initially, men also perceived *project management* less favourably than other **personal effectiveness skills**, while women students ranked it lowest in this area, despite a class devoted to the topic; however, it may be the opportunity to practice theoretical learning that results in *project management* featuring higher in rank for ***personal effectiveness*** post-*Design*, suggesting an enhancement of students perceptions and, thereby, confidence of their ability.

This improvement in men's perceptions of two ***personal effectiveness skills*** comes at the expense of the rank of *time management*, which may be a consequence of this skill not improving as much as *leadership* and *project management* despite students working for 14 weeks on task. It may also be possible that, when asked to reflect on their experiences, many students will relate their time management to the final few weeks of the project, where they are often in panic mode to complete to the deadline. Women students see no change in the rank of *time management*, possibly due to women students working more consistently across the project duration, so not entering the 'panic' period of their men colleagues; this is consistent with findings that women suffer greater anxiety associated with procrastination.

It is interesting that while working on an open-ended problem, as well as a clearly defined design, where decisions need to be made throughout the duration of the projects, both groups of students now rank *decision-making* amongst the lowest skills in ***personal effectiveness***. The mean score has increased for both genders but it seems that students do not feel more confident of this skill than the others in this category.

As discussed previously, IT scores were very low pre-*Design*, especially in comparison to other ***research skills*** (research of literature, word processing and data analysis), despite explicit classes in IT. It is interesting to see the post-*Design* contrast, where students now consider IT to be their most proficient ***research skill*** and *word processing* has dropped down the rankings. This indicates that independent practice of a skill, i.e. experiential learning, significantly increases a student's perception of their ability (Haycock, McCarthy, and Skay 1998). The project requires the production of two 100+ page reports, formatted to specific guidelines, and presented as single reports despite an authorship of six, hence, students' *word processing skills* have probably developed the most but, already being scored highly, see only a small perceived increase. *Written communication* ranks highly for women and this may be related to the high rank of *word processing*, which is also slightly true for men, who rank *written communication* third of the ***communication skills***. This is also at odds, for both genders, with their rankings of *minute taking*, which is low, yet is a form of written communication.

Oral presentations have been highlighted, anecdotally, as an issue outwith *Design* so it is not too surprising to see it ranked low for both genders pre-*Design*. Students finish their projects with a presentation to staff, bringing the experience and, hence, students' perception of having performed a task to equal a skill developed, to the fore. Again, experiential skills development may help in the increased ranking of oral presentation, for men students, post-*Design*. Women students rank *oral presentations* lowest in *effective meetings skills*, pre-*Design*, but they do not see an increase in rank post-*Design*, possibly as a consequence of the very low mean for oral presentations awarded pre-*Design*. Ironically both genders ranked *verbal communication* higher than *oral presentations* in the pre-*Design* survey, suggesting that specific demands of presenting cause issues for students as opposed to talking to peers and supervisors about the day-to-day working of their projects.

3.4 The contribution of external experiences

When asked to detail any past experiences that they felt had developed the skills surveyed pre-*Design*, several students cited academic projects, most notably the smaller design project in third year, and a few more stated aspects of individual classes, such as IT and use of software packages, that they felt would benefit *Design*. However, many gave examples of external activities that were instrumental in developing their skill sets (see Supporting Information).

It was interesting to see the common skills that were mentioned by students in relation to these experiences, especially to note that they predominantly fit into either the categories of ***communication*** or ***personal effectiveness***. ***Research skills*** were poorly represented and it may be for this reason that they feature so low on the overall rankings by students. One student also noted that, despite feeling that the experience of part-time work had developed their personal effectiveness and communication skills extensively, the relatively informal management of the role would reduce the transferability of their skills to a professional working environment.

As can be seen from the rankings discussed above, there is clear skills development and, free text responses in the post-design survey also show students feel that they have developed their full range of skills as a direct result of *Design*. Hence, it is hoped that students do feel prepared for the professional environment as a combination of *Design* and their myriad external activities.

4. Conclusions

The skills that staff and undergraduate students perceived as important in undertaking the capstone design project (*Design*) within the Department of Chemical and Process Engineering at the University of Strathclyde were similar, irrespective of the role of the respondent. Identified skills were covered by three overarching themes: ***personal effectiveness*** (time management, project management, leadership, working with others and decision making), ***communication*** (listening, verbal communication, oral presentations, written communication and minute taking), and ***research*** (word processing, information technology, data analysis and research of literature).

Students demonstrated an increase in perceived ability for all surveyed skills, and there was evidence of experiential practice increasing confidence, for example in IT, project management, written communication and oral presentations, often as a consequence of preparing assessed outputs. The significant academic merit associated with *Design* resulted in men adopting leadership roles, possibly devaluing women colleagues, however, women excelled in word processing, potentially as an acceptance of pre-defined feminine roles. By contrast, minute taking was not rewarded or formally assessed so students felt they had developed little in that area, possibly as a result of non-engagement or the lack of feedback to demonstrate their development; this was mirrored in verbal communication, where some students did not increase in confidence, which may be a result of negative group interactions. Finally, *Design* requires students to undertake open-ended problems, which is a threshold concept for many, and it was reassuring to see decision making abilities increase in their perceptions, as many were forced into the process of making a choice and may have found themselves to be more capable than previously thought.

It is worth noting that students do not need to fully appreciate the concept of design rationale nor overcome their troublesome knowledge in order to pass the course, as the project structure is such that as long as one team member can produce the required work the team will benefit as a unit, and students may continue with the troublesome knowledge acquired, as part of core modules and design, even into their chosen profession.

There is a vast range of external activities undertaken by the surveyed students and this contributes to their development, however, it is clear that there is some limitation to the explicit transference of these skills between students' different roles i.e. academic, social and employment. It may be advantageous to encourage students to undertake a skills analysis pre- and post-*Design* to capture the full gamut of their experiences and, while it is appreciated that the *Design* experience may meet the accreditation needs of IChemE, there may be significant value in asking students to undertake a facilitated reflection on *Design* so they can recognise and appreciate any skills development and identify areas where further improvements are required to meet the needs of prospective employers.

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Figure captions

Figure 1: Bubble plot collating Likert responses of the 22 students that answered both pre- design (x-axis) and post-design (y-axis) surveys for verbal communication ability.

Figure 2: Bubble plot collating Likert responses of the 22 students that answered both pre- design (x-axis) and post-design (y-axis) surveys for oral presentations ability.

Figure 3: Bubble plot collating Likert responses of the 22 students that answered both pre- design (x-axis) and post-design (y-axis) surveys for minutes taking ability.

Figure 4: Bubble plot collating Likert responses of the 22 students that answered both pre- design (x-axis) and post-design (y-axis) surveys for project management ability.

Figure 5: Bubble plot collating Likert responses of the 22 students that answered both pre- design (x-axis) and post-design (y-axis) surveys for data analysis ability.

Table captions

Table 1: Percentage respondents in each Likert category when asked about their relative ability in communication skills both pre- and post-design.

Table 2: Percentage respondents in each Likert category when asked about their relative personal effectiveness both pre- and post-design.

Table 3: Percentage respondents in each Likert category when asked about their relative ability in research skills both pre- and post-design.