Development and evaluation of open-ended learning activities to support chemical engineering students' development

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Declaration of authenticity and author's rights

'This thesis is the result of the author's original research. It has been composed by the author and has not been previously submitted for examination which has led to the award of a degree.'

Signed: A. Fletcher Date: 7 April 2020

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Contents

Abstract

There are myriad challenges in developing a stimulating yet supportive curriculum in many subject areas, and recent shifts in course entry demographics and employer expectations have made this especially challenging in chemical engineering. As a discipline, there has been a gender shift in recent years towards greater women student representation at undergraduate level and an increase in global industry sector demand for chemical engineering graduates. This has raised issues of inclusion, to allow women students to participate equally in learning activities and wider opportunities, as well as those of graduate skills development, tempered by reports from the Confederation of Business Industry, which indicate that employers are dissatisfied with the skill sets offered by graduates. This work sets out to address these concerns through evaluation of active learning and makes recommendations regarding integrated learning, where group work is used to develop students' professional competencies in tandem with their transferable skills. Engineering education has developed over the years to include many instances of group based working that focusses on problem based learning, however, the full extent of the impact that this may have on students' development is little understood or studied. This thesis explores the role of problem-based learning in facilitating students' engagement with specific components of a chemical engineering degree within UK Higher Education, including surveys of staff and student perceptions of group working and skills development, statistical evaluation of student attainment and appraisal of course (re)design.

Despite significant group work and problem based learning focussed on developing open-ended working, teaching staff identified issues with students' abilities to deal with such problems in chemical engineering and to accept open-endedness itself. By identifying open-endedness as a threshold concept, it has been possible to study the impact that the timeline of teaching has on student development and achievement. This work presents a strategy for vertical alignment of teaching within the chemical engineering degree to support student development and foster student confidence and autonomy. Within this context, the use of group working is key and the thesis also investigates the role of tutors within this educational framework and how such activities impact on the inclusion of women in engineering subjects. Additional work to redevelop early years teaching to address the identified threshold concept and, specifically, its role in the capstone design project is reported and students' perceptions of skills development has been investigated to understand the impact that working in such an environment has on the transferable skill sets of these cohorts.

The insights gained show that tutor supported problem based learning can be key in nurturing critical evaluation skills in students, often requiring them to explain their reasoning and work with unknown quantities. The role of women students in group working changes with their increased awareness of social expectations to adapt to normalised views of women's roles; this happens early in their University career and sets working parameters for the remainder of their degrees, so addresses the early imbalance in role assignment that may be observed. The successful incorporation of problem based learning activities in early years helps students overcome the liminality that results from open-ended working, with wider impact, beyond the classroom, in providing advanced skill sets and working practices that will enhance employability. Students demonstrate increased engagement, mitigated stress, bolstered confidence and reduced confusion, while student retention is also improved. By surveying current students and graduates, a link between experiential practice and high skills confidence is observed; hence, it is recommended that students are encouraged to reflect on their learning experiences and that integrated learning be promoted to develop all skills effectively. The work also indicates that using problem based learning in early year classes, to underpin advanced project working in later years, is worthy of consideration for chemical engineering teaching as well as the wider engineering discipline.

Chapter 1: introduction

The chemical engineering discipline

As a versatile discipline, chemical engineering offers students a wide scope both in terms of study material and graduate opportunities [1]; the knowledge gained unifies concepts across science and engineering, providing students with a range of modes of application, including laboratory sessions, problem solving and design, supporting increased student engagement [2] and enhancing performance [3]. This variety of subjects and delivery modes allows students to both deepen their understanding of everyday processes, while also providing a platform for the development of a range of industry relevant skills [4-10]. This makes chemical engineering a highly vocational study choice and it is essential to bridge the gap between the academic and practical components of such engineering disciplines [11], while keeping content relevant [12]. Recent years have seen a significant increase in matriculation to chemical engineering programmes [13], allowing entry grades to be increased in the main, and creating high-calibre cohorts of students.

Chemical engineering, at the University of Strathclyde has existed since 1888 [14], and the Department of Chemical and Process Engineering currently offers three qualifications: BEng Chemical Engineering, MEng Chemical Engineering, and MSci Applied Chemistry and Chemical Engineering, jointly run with, but administered by, the Department of Pure and Applied Chemistry. All three degrees are accredited by the Institution of Chemical Engineers (IChemE), and the MSci is jointly accredited by the Royal Society of Chemistry (RSC). Enrolled students generally enter directly from school and there is a predominance of Scottish nationals in the teaching group; recent years have seen an increase in recruitment of women students (from ~10% to > 33% over a 10 year period). The department engages heavily with industry, having appointed a number of Visiting Professors, several funded by the Royal Academy of Engineering, and our undergraduates have a range of opportunities to meet with industrialists and develop their networks. Students value this engagement as the motivation for many students enrolling on a chemical engineering programme is to secure a well-paid position in industry upon graduation [15] with the added attraction of gaining chartered status (CEng) as soon as possible after graduation. These drivers do not alter significantly during the students' periods of study.

Within all accredited chemical engineering degree programmes, students are required to undertake design components. At the University of Strathclyde, this is delivered in Y4 to allow all students, irrespective of their programme type and duration to undertake the capstone design project and meet the requirements of accreditation. The key purpose of the design project is to experience '*Engineering as Engineering is done*' [16, 17], within a structured and supportive framework, while allowing students to work on real-life problems, delivering creative and justified plant designs for a selected process. The are many variations in the way that design is delivered and managed across the discipline but the common goal is a project that allows students to unify their understanding and demonstrate their knowledge in pseudo-experiential activity.

It is important to ensure that students have a valued learning experience during their programme, irrespective of demograph, in association with the requirements of the accrediting body [18]. By utilising a range of group based activities throughout the programme, this allows all students to utilise their varied skill sets and backgrounds [19]. However, there are still differences of opinion in terms of the impact of group heterogeneity on performance [20-25], including the effect of gender balance [26-29], and these influences may well be subjective; in all cases it is imperative that staff strive to treat all students equally [25, 30, 31] and support them in diverse groupings. Prior educational experiences of this type may affect an individual's ability to contribute fully in future situations in the workplace.

Employer surveys, such as those run by the Confederation of British Industry (CBI) [4-10] and the World Chemical Engineering Council (WCEC) [32], showed that there are perceived competency gaps in key skills, such as problem solving and team working, which is concerning given the high level of such modes of learning within chemical engineering programmes. Additionally, 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. This mirrors academic studies undertaken in other countries, suggesting that this skills shortfall is a global issue [33, 34]. The skills of high importance are professional transferable skills, which are generally learned later when in post, or as other researchers have named it learning "soft skills the hard way" [35]. Such 'vocational drift' [36], can be seen as a dilution of academic standards, however, addressing these perceived skills deficits are crucial for future cohorts of graduates who face an increasing diversity of employment destinations [37-40].

It has been recognised that the development of transferable skills is imperative to develop fully-rounded engineers [37, 41, 42], yet represents a separate area of a students' educational growth than that of academic knowledge and technical skills [43]; the latter can be formally assessed, sometimes via the use of a transferable skill, but the former are not formally assessed, requiring students to reflect on their own development in these areas. The duality of academic attainment with transferable skills development can be achieved through embedded teaching [44, 45], integrated teaching [46, 47] or bolted-on teaching, the effectiveness of which has raised questions [43, 48, 49].

One mode of self-development for students is through engagement with integrated learning activities such as problem-based learning, which has proven to be effective across a range of disciplines [50-54], often helping students deal with threshold concepts [55, 56], where failure to master troublesome knowledge can have long-lasting effects on a student's individual progress. Problem-based learning focuses on active learning, independent enquiry, and developing proactive approaches to open-ended problems, and is well suited to examining troublesome aspects of core subjects [57-61], and may utilise alternative learning methodologies, for example flipped classroom [62-65]. Such approaches help in developing students' teamwork skills, critical thinking and problem-solving abilities [66].

Problem-based learning is also manifestly useful in teaching design where students are encouraged to develop new strategies and processes, and to incorporate new knowledge in solving open-ended problems [67]. Working on open-ended problems in a group context provides students with the opportunity to exchange ideas and to learn from other people [68-70], such as that facilitated by peer interaction; and early opportunities to work in this manner allows students to adapt their own working practices [71]. The view that open-endedness is a threshold concept is not new and has been explored in a range of disciplines [55, 72, 73], and previous researchers have reported on the concept of moving from "designing to specifications" to "designing the specifications", [73], which is crucial in defining the role of the engineer within this open-ended context i.e. one who creatively designs a process, including definition of process boundaries. This represents a key skill for the workplace upon graduation.

The design component of chemical engineering practice can be considered an example of advanced problem-solving, and gives students excellent learning opportunities through common intellectual challenges, working in learning communities, collaborative project work and, importantly, experiencing 'Engineering as Engineering is done' [16]. 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. In some cases, students are simply unable to overcome their issues and this impacts on their attainment in design, and their future career.

It is evident that threshold concepts exist in a range of subjects including engineering programmes, and are, therefore, likely to exist in chemical engineering; failure to overcome the issues associated with such concepts has potential to impact on final degree classification and employment prospects. Consequently, this thesis presents a structured approach to student engagement and development by:

1. Identifying threshold concepts that exist within the chemical engineering discipline with a view to supporting students in working through these concepts.
2. Developing vertically aligned problem-based learning approaches to more fully support students in their approaches to threshold concepts within their discipline.
3. Exploring the role of tutors in supporting students in such problem-based learning activities.
4. Evaluating the inclusivity of women students within tutorial and group project based learning environments.
5. Investigating the alignment of skills development in chemical engineering teaching with employers' expectations.
6. Understanding how open-ended learning activities can be used to develop students' abilities for problem solving and wider skills development to meet employers' needs.

Chapter 2: threshold concepts in chemical engineering

Threshold Concepts in Chemical Engineering Design

Ashleigh J. Fletcher and Stuart Boon, "Threshold Concepts in Chemical Engineering Design," In “Threshold Concepts in Problem-based Learning”, G. Tombs and M. Savin-Baden (Eds.), Sense Publishers, **2018**.

Introduction

This chapter explores the role of problem-based learning (PBL) in facilitating students’ engagement with design components of a chemical engineering degree at the University of Strathclyde (UoS), where students are required to plan and evaluate a manufacturing process. Teaching staff previously identified issues with students’ abilities to deal with open-ended problems in chemical engineering and to accept open-endedness itself, identifying open-endedness as a threshold concept in design. Work was subsequently undertaken to develop appropriate PBL content to address this threshold concept and associated drop-out rates. A longitudinal programme was engineered to support student learning via a dedicated PBL module, enhancing the students’ experience. The benefits of such a programme go beyond the students’ academic career and provide significant impact in achieving success in the real world. The chapter presents findings from this work and builds on the use of threshold concepts in PBL, as introduced in the works of Land and Savin-Baden, relating them to the engineering discipline and reporting on the successful incorporation of PBL activities in early years to help students overcome the liminality that results from open-ended working.

Literature

Since its incorporation in 1969 at McMaster University’s School of Medicine, PBL has found critically proven application in a wide variety of disciplinary contexts, including Chemical and Process Engineering (CPE) [50-53]. Here, we consider PBL to be a student-centred pedagogic activity that requires students to use reasoning and reflection to construct their own learning. As such, it focuses on active learning, independent enquiry, and developing proactive approaches to open-ended problems, and is well suited to examining troublesome aspects of core subjects, such as thermodynamics, process analysis, heat transfer, and fluid flow [57-60]. It is also manifestly useful in teaching design where students are encouraged to develop new strategies and processes, and to incorporate new knowledge in solving open-ended problems [67, 74].

The study and analysis of threshold concepts is less established in CPE, but has seen increasing critical attention and application over the last decade [75-78]. Here, we consider threshold concepts to be transformational in students' perception of chemical engineering and, while the majority of engineering teaching has been geared towards the acquisition of foundational knowledge [79], threshold concepts, i.e. core chemical engineering understanding, threshold concepts hold a particular power in the area of design, where open-endedness plays a larger role. Open-endedness has previously been identified as a threshold concept by Male *et al.*, who surveyed 435 first-year engineering students registered on an integrated engineering foundation course, concluding that open-ended problems were a threshold concept as a consequence of their *transformative* nature and *troublesome* features, including 'recursive solutions' and 'identifying which variables and constraints are significant' [80].

Seeing open-endedness as a threshold concept is not new; for example, previous work in teaching Liberal Education has suggested that '*Gaining a deep understanding that most problems are solvable with sustained effort we suggest marks a fundamental and irreversible threshold in students' development of problem-solving skills*' [72]. Similarly, the field of Architecture requires students to engage with ill-defined problems and open-ended situations [73], which is said to align with the framework of threshold concepts [55]. Finally, Land et al. reported on the concept of moving from designing to specifications to designing the specifications, where students engaged in design must '*make a plan for this*' or '*propose a solution to that*' and '*proactive knowledge is better served by engaging the learner in formulating some of the specifications or interpreting rather open-ended specifications*' [73]. This last work is particularly important in defining the role of the engineer within this open-ended context i.e. one who creatively designs a process, including definition of process boundaries.

As stated by McCartney *et al.*, liminality is 'the transitional period between beginning to learn a concept and fully mastering it' [81], such as the transition of student engineer to professional engineer. During a student's project to design a chemical engineering plant, it is this move towards professional working, where an end product or process is often unknown, requiring creative construction of new systems, which causes students most concern. Prior to design, students have predominantly attempted closed questions, i.e. problems that have a singular answer, requiring them to learn and apply fundamental principles, laws, standards, and other immutable elements to specific set tasks; even those problems that may be considered to be a move to open-endedness are structured and do not provide students with the reflective component required to work through the liminality of such a new mode of working. Design, therefore, requires students to 'breakaway' from their established learning constructs, requiring a completely different way of working, and the open-endedness of this mode of learning is, therefore, a threshold concept for CPE students.

Introducing students to open-ended scenarios earlier in their studies, via PBL methods, primes them for new, and often disquieting, thresholds and the liminal spaces between and should provide a progressive route to overcoming the threshold concept or open-endedness. PBL provides enhanced learning experiences where students encounter meaningful and challenging problems that bring about a re-examination of pre-existing knowledge and results in the generation of new hypotheses, processes, and understanding. The step or phase between pre-existing knowledge and new knowledge, between former and current understanding, is a liminal space that challenges students to make sense of the discordant incongruity, to re-evaluate, re-discover, and ultimately re-define the phenomenon or experience encountered. Such change does not come without cost, however, and many students struggle with threshold concepts and their concomitant liminality. From a CPE perspective, the open-endedness of the Year 4 (Y4) design, which requires students to work in a PBL setting, has proven to be a troublesome threshold. Below, this chapter looks in-depth at how staff in CPE articulated open-endedness as a threshold concept in the PBL design component and what means were put in place to support students to navigate liminality, negotiate new understandings, and benefit more meaningfully from the open-ended design experiences.

Problem-based learning in chemical and process engineering (CPE) at the University of Strathclyde

Design is undertaken by all students in Y4 of the Chemical Engineering degree at UoS, comprising approximately 80 students across all three degree cohorts within CPE, i.e. BEng/MEng Chemical Engineering and MSci Applied Chemistry and Chemical Engineering, and comprises 60 credits in the second semester of Y4. Current delivery of the module is the completion of one process design divided into three phases: scoping, detailed design, and evaluation and reflection. The whole cohort is distributed into teams of six students with each team assigned an academic supervisor. The group size allows assignment of a manageable number of groups per supervisor, while still permitting individual student engagement. Group composition covers a range of previous academic abilities with no positive bias for gender, ethnic origin or age. Overall, the project provides an opportunity to experience common intellectual experiences, work in learning communities on a collaborative project, hence, an experience of '*Engineering as Engineering is done*' [16, 17]. Students meet their supervisors weekly, and are responsible for managing their own schedule and workload in the remaining time. Team members must work together to create a coherent report from their individual contributions, hence, critical evaluation of the importance of information is crucial as each section must add value to the final report. The project provides an opportunity for students to gain experience of, and credit for demonstrating, leadership, collaborative working, critical analysis, creativity, and synthesis and integration of information. Supervisor meetings are not formally assessed, as is the case in some other Universities, however, CPE recognises that these provide students with opportunities to give oral feedback to their colleagues and supervisor, while the compilation of the final document requires critique and feedback on the work of other team members.

The open-endedness experienced in design is also a threshold concept, wherein students experience a transformative shift in mind-set towards the design question posed, iteratively evaluating and reconstructing their approach over time. Therefore we consider design a liminal process, whereby students must negotiate a troublesome pathway from previous perceptions of design and structured modes of design working to new modes of open-ended working, adopting a new understanding of the complexities of designing a novel process.

Previous offerings of the module highlighted issues that students were experiencing with the threshold concept of open-endedness, notably a significant drop-out rate and anecdotal confusion and stress throughout the cohort, as students grappled with the concept that there is not a pre-defined 'right answer' and that they are required to make assumptions or rationalise comparable data as and when required. In order to remedy the situation, academic staff incorporated a dedicated PBL module in the first semester of Y4. The intention of this new focus was to guide students through the liminal state often experienced in design projects, by working on discrete problems in preparation for tackling more complex tasks. Questions required students to draw on prior knowledge, apply concepts in new scenarios and make educated assumptions about missing data. While this enabled students to deal with the semester two design project more confidently and competently, it also highlighted the need for earlier embedding of PBL to support these later-year activities, as the liminality experienced in design was now shifted to the Y4 PBL module.

Teaching, across all years, focuses heavily on teamwork, thereby simulating real-life expectations of practising chemical engineers; these activities are designed so as to promote participant engagement for improved performance, including collaborative working and shared intellectual experiences. Previous research has identified several transferable skills, including communication, teamwork, problem-solving, numeracy, IT literacy and self-management, as key to enhancing employability; which aligns with the Institution of Chemical Engineers' learning outcome 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*. Certain skills within this list, including management, are considered under-taught in Universities, suggesting that teaching instances to enhance such skills development would be welcomed by both employers and prospective employees. Reviews of management practices within UK industry also suggest that graduate recruitment and progression is linked to the development and demonstration of group working skills. Hence, within CPE, students work in teams throughout all years, thereby experiencing many different groupings, thus, working practices.

As an engineering sub-discipline, chemical engineering focuses on designing, constructing, implementing, operating and managing process plants and systems. The curriculum consequently comprises a range of knowledge and skills preparing students to undertake the aforementioned tasks, with modules on fundamentals and core concepts in earlier years, and more specialist modules in later years. This breadth of the subject area requires diverse teaching and assessment methods to support students' development via increased engagement and enhanced performance. At UoS, this knowledge and skills development underpins the capstone design project within Y4 of chemical engineering, as described above, required for course accreditation and allowing students to subsequently apply for chartered status.

Identifying threshold concepts in chemical and process engineering problem-based learning

As outlined above, open-endedness is the core threshold concept in design, requiring students to act independently, trusting their own judgement in decision and assumption making, as well as accepting that there is no definitive answer for the problem set. After identifying the issues experienced in design and including a PBL module in first semester of Y4, discussion between staff involved in Y4 teaching identified that this action had only served to shift the issue to an earlier point in the same year, hence, the decision was taken to incorporate PBL in Y2-3 to support students in their journey towards design. Introduction of these components was evaluated for students undertaking PBL in Y2, using ethnographic observation and direct surveying of 86 students' opinions to assess the impact of this change. The former involved an MEng project student observing tutorials and synopsis lecture sessions to record student interactions with tutors and the class environment, while surveys, combining both Likert scale questions and free text answers, conducted at the mid and final points of the class provided feedback on students' perceptions of the new method of working.

As stated above, observations by staff teaching on the previous version of design, often within supervisor meetings, indicated that students frequently found the open-endedness of the design project to be problematic:

> *'They struggle to define the initial problem and also to accept that there are a range of answers that could work'.*
>
> *'Even the good ones (students) find it difficult to make assumptions and work towards an unknown outcome, it's hard then to explain that they need to be critical and evaluative rather than having a concrete 'right' answer.'*

Staff would face constant requests for affirmation, even from extremely able students, and the designs submitted would often be similar as students found it difficult to have confidence in alternative ideas; some students struggled with design for several weeks before withdrawing completely from their studies, admitting that they found it to be completely overwhelming. Whereas classes experienced in earlier years (Y1-3) had always required determination of set quantities, such that there was a definitive 'right' answer, the nature of design means that several solutions may be viable and there is not a single outcome expected. One student's reflection on design was:

> *'It's so different to everything we've done before. Sometimes I found it hard to get started as there seemed so much to do and I didn't want to get it wrong.'*

The students, therefore, were struggling with the liminalities associated with self-assessment and criticality, which are essential for personal and professional development. In addition to these threshold concepts [82], wherein students engage with and apply knowledge gained in core classes to assigned tasks, often revisiting, and maybe rationalising, troublesome knowledge as part of the process, further research, surveying 72 staff and student respondents, by a combination of Likert scale set questions and free-text boxes, into their perceptions of design identified several issues related to delivery of chemical engineering design at that time. The realisation there was no single 'right' answer came as a shock to students, who struggled to accept that their supervisors themselves might not know an absolute process for success or definite target to which the students should be working. Students commented that:

> *'You expect your supervisor to know what is needed but the feedback is often vague. I want to know for sure if I'm on the right track so we often compare working between groups as at least one of us are designing the same unit.'*

> *'It was a nice change to be creative but this did mean we were several weeks in with no clear plan of what to focus on. Our supervisor helped us see a path forward but it was sometimes still unclear till just before hand in.'*

Which demonstrates not only the students need for validation, but that they seek resolution by other means when they feel their supervisors are unable to categorically approve their working. This tension of guidance and affirmation is also felt by staff:

> *'It's evident that we are there to help the students by guiding their work but they also want us to tell them whether something is right or wrong, and to give them definite yes or no answers to their questions. Sometimes they ask the same thing in several ways just to try and get you to do that. I reflect the question back to them and ask them to discuss their options as a group but that often highlights the fact that they haven't been doing that in the time between meetings.'*

This last comment highlights further frustration that was born from high expectations both by staff and some students and the fact that many students found themselves insufficiently skilled to deliver. Coupled with a lack of group identity, understanding of team roles, project ownership, and resulting group cohesion: there was a tendency for students with poor exam performance in semester one to disengage from the design project once their exam results were released, which ultimately impacted the whole team. Hence, the introduction of PBL as a supportive pedagogic activity and this chapter presents evaluation of students' earlier experiences of this method of learning.

Managing threshold concepts in chemical and process engineering problem-based learning

Analysis of the previous delivery of design resulted in recommendations to enhance transferable skills development within the module, by establishing critical analysis and problem-solving abilities though alignment of embedded PBL activities. The introduction of such methods across all years of the degree program, with structured, increasing complexity, had been successful in other chemical engineering programmes. The programme at UoS aimed to increase students' skill sets, increase students' understanding of team roles and, therefore, their personal identity, so increasing student engagement on the project, thus, improving ownership of work, promoting reflection on past performance and experiences, and supporting students in their acceptance of the idea of open-ended problems, thereby reducing the stress experienced in design.

The first step taken was to introduce a problem-solving module, featuring open-ended problems that students were required to tackle in teams, to semester one of Y4, thereby providing some direct support for development of critical evaluation and reasoning. While successful in introducing students to the concept of open-ended problems, the module had significant failings. Firstly, the students taking the class had experienced four years of traditional, lecture-based teaching prior to and concurrently with the problem-solving module; consequently, the PBL delivery was a new concept and there was no transition period for the students to adjust to the requirements of this new mode of teaching and, therefore, learning. As a consequence of past experience, hence, prior familiarisation, this group of students were less likely to embrace PBL at that time. Secondly, students had not identified their role within the process: PBL contrasts starkly with traditional teaching modes, by requiring students to identify and state problems, before classifying information and learning goals, in order to produce a working plan; hence, the lack of structure in the former requires greater communication between teacher and student. A third issue was the students' perception of the class, in that it focussed on problem-solving and not PBL, primarily due to the lack of prior exposure but also as a result of the significant increase in difficulty of the problems posed compared to traditional tutorial questions from previous classes. Consequently, the students' initial experience was one of confusion and reduced engagement, indicating that Y4 was too late for this first instance of PBL.

Students perceptions of design

During the time of this initial introduction of PBL in Y4, students' perceptions of design were investigated as outlined above, by surveying students' views of the module, in order to determine the skills they expected to develop during the project and those that they thought were developed post module, including those relating to PBL.

Pre-design When asked about the skills that they expected to develop within design, students listed many of those outlined in the module learning outcomes and aligned with the skills identified earlier, such as teamwork, problem-solving, time management, self-management, innovation, leadership, project management and critical thinking. While some students recognized these as being particularly attractive for their future prospects:

> *'During this project I expect to develop and improve my group working skills and my*

ability to work as part of a team. Interpersonal and group working skills are core skills, essential in the modern day work place. The opportunity to improve these skills is advantageous in preparation for employment after university and this design project is the ideal opportunity to improve and exhibit the development of these skills to employers.'

Others expressed genuine concern for the process that they were about to undertake, which often related to the problem-solving aspects:

'I'm concerned with the design aspects we haven't been taught. I'm also concerned about what group I might be put in and that it won't have someone really good at problem solving because this is a skill I personally need to improve on so someone to help would be ideal for me.'

'Concern about not matching the pace of other group members who are able to create a specific goal to aim towards.'

It is interesting that students identify problem-solving as necessary and a skill to develop during design, while others are struggling with the idea of identifying a final objective on which to map their work plan. While problem-solving was highlighted, possibly as a result of having the embedded PBL module, none of the students identified working on unknown systems or emulating a professional workplace or project.

Post-design The same students were asked to identify how design had helped to develop their skills sets, and several mentioned increased criticality and decision-making, often without explicitly identifying it as such, and to do so within the required timescale:

'In previous coursework, I have always had a need to look over things excessively to ensure fine tuning. Whilst this has still been done to an acceptable standard in my design project, I have also developed the ability to decide when the work is of good

quality and move on when the time is right. Such is the demand of the projects.'

'My decision making skills, I believe, have been enhanced significantly.'

'Design has taught me to focus in on what is important and will add value to a project and what is extraneous detail that would be nice to include but is not essential. It has helped me learn when to move on from an idea and not spend too long on one particular task.'

This latter comment alludes to the, often observed, increase in confidence in their own assessment of a process, which students exhibit towards completion of the design project. This seems to provide students with an appreciation of applying their engineering knowledge to a real problem:

'I feel that I have significantly improved as a chemical engineer. This semi-practical work has really increased my knowledge and understanding of many key areas of the course, most of which I would not have learned simply from lectures.'

'I felt I learned more chemical engineering skills doing the design project than I have through any classes. The whole project means you self tech (sic) yourself all the necessary skills, with the aid of chem eng (sic) books.'

'Whilst the design project has ultimately been one of the most challenging tasks of my life, it has also been the most rewarding and I feel it sets me up very well for life in a professional chemical engineering environment.'

While criticality was valued, there seemed to be little reflection on the PBL aspects of design and it may well be that the prior exposure to open-ended learning offset their acceptance of such working. It is notable that this cohort saw a significant improvement in student retention rates compared with previous years.

Supporting design

These perceptions of design, and the concerns raised by the Y4 PBL class, indicated that a similar class structure in earlier years could help support students' development and provide a structured introduction to open-endedness and PBL in advance of their project year. Y4 design builds upon a more structured 20 credit class in Y3, Plant and Process Design, where students develop their design skills with significant tutoring and support; hence, the class is much less involved and less independent than Y4 design, but has been revised in recent years to provide further skills development. Again, students often experience theoretical difficulties with Y3 design, partly attributable to lack of engagement with key concepts in core classes but also related to the previously identified open-endedness and lack of a definitive right answer. Consequently, while Y3 design is now used to assess skills development within this year of teaching, it does not offer a suitable platform for exposure to open-endedness and the support of PBL prior to design in Y4. Subsequently, Y2 was identified as the most appropriate for introduction to PBL. To this end, the 20-credit Mathematics module has been split to contain 10 credits of Mathematics and 10 credits of problem-solving, while the 20 credit Chemical Principles and Thermodynamics module has been overhauled to use PBL principles throughout. This latter class offers a combination of highly numerical working and conceptual development, very much akin to design, making it an ideal candidate for learning style development.

Hybrid problem based learning in Thermodynamics and Chemical Principles

While embracing the tenets of PBL, to promote active learning and encourage peer teaching, the class is not entirely PBL based but rather uses a hybrid problem based learning (HPBL) approach. Such methods have been shown to be statistically insignificant with respect to students' acquisition of factual knowledge, compared to traditional teaching methods [83]; however, it does offer increased learning satisfaction [84] and improved critical thinking [85]. Students receive formal teaching and guidance into the areas highlighting concepts that must be understood to tackle problems presented in associated workshop sessions; many of these concepts are open-ended. However, for most elements, closed questions are designed to allow students to develop confidence in their knowledge and abilities prior to attempting the open-ended problems. In this module, students are expected to read notes and watch extended video lectures in advance of synopsis lectures, which highlight key concepts required for associated tutorials. Adopting a HPBL approach, as a precursor to Y4, allows students to develop critical thinking skills, mitigating the possible risks of a lack of previous PBL experience and issues relating to group dynamics, while also providing the benefits of teamwork, communication, self-motivation and closing the feedback loop [86]. It still places students firmly at the centre of the learning process, with an increasing level of control of their own learning, and opportunities to experience and articulate their learning within their groups.

Class redesign

The module was redesigned in 2015 and there have been two successive evaluations of the changes made, with feedback into the on-going development of the module. Student opinions were sought by survey and in the second year of offering, students were observed in class by an independent researcher to provide an overview of the level of engagement with the different aspects of learning.

Class format In the 2015/16 delivery, students received two hours of lectures and one of tutorial per subject in the module, which was adverse to creating a PBL environment, hence, in 2016/17 there was a move to online pre-lectures and one hour of synopsis, thereby addressing the issue of two hours tutorial time and the 2015/16 comment:

> *'Lecture seemingly unrelated to tutorial problems.'*

There were four tutors per class section, comprising the academic staff member and three postgraduate tutors, selected on a competitive basis for their prior knowledge and previous experience.

Tutors In the first evaluation, it was highlighted that tutors should adopt the role of mentors in future years and, related to this is, the need to establish a good working rapport with assigned teams, with tutors assisting only a subset of the cohort. This allows students to engage with their tutors by developing a positive interaction, while also allowing tutors to keep track of students' performance within the tutorial. 2016/17 students' views were generally very positive towards the tutors:

> *'They were helpful.'*
>
> *'They made sure that every group was attended to and had their questions answered.'*
>
> *'Helped when asked.'*

Group composition In 2015/16, students were randomly assigned to teams and both lecturers noted significant absences from class, despite over 60% of respondents stating that they valued the tutorial sessions, particularly for minority students (by gender, ethnicity etc.), with one 2015/16 student reporting:

> *'Few presences (almost alone) in my tutorial group.'*

Hence, the decision was made to allow students to choose their own group compositions in future years, thereby increasing ownership of the process and their learning. Significant improvements in engagement were observed with over 85% regular attendance at tutorials.

Worked solutions Each week two groups of students are selected to submit their materials as worked solutions for the rest of the group. These workings are annotated with comments from the lecturer and posted on the virtual learning environment for the benefit of all students. Previously, students were advised early in the session of who would be submitting their workings, however, this often resulted in the group dividing the work and tackling the questions independently, therefore, negating the team-working aspect of the session. In the 2016/17 session the students were advised of allocation towards the end of the session to avoid a similar situation, but at such a time as to allow them to ask for any further guidance before the end of the tutorial, thereby addressing the 2015/16 comment:

> *'Group work not satisfying (made me lazy).'*

Question layout and composition Finally, it was recognized in previous years that the layout of the tutorial sheet was integral to students' engagement, most notably that if the initial questions were particularly difficult, students' confidence was low and they often attempted very little of the tutorial. While reorganisation maintained the types of questions that resulted in good self-reflection from the 2016/17 cohort:

> *'It allows us to apply our knowledge to real-life problems.'*

In 2015/16 more than one student noted that:

> *'Tutorial questions often too difficult.'*

While another suggested:

> *'Provide some simple questions to build basic knowledge.'*

Thus, the question sheets were restructured for 2016/17, adding some additional, open-ended, questions to provide a structured exercise, which was seen to increase student engagement and confidence as students were able to believe in their growing abilities [87].

Iterative restructuring While the 2016/17 cohort has benefitted from these changes, there is always room for improvement, hence, class timetables will be altered next year as students highlighted problems with timings of tutorials and lectures due to reliance on the required self-study centred teaching style or PBL:

'More time between lectures and tutorials [they are on the] same day so no time to consolidate.'

'Sometimes the lectures move way too fast in the class, which makes it hard to understand and work effectively in tutorials.'

Some mitigation of this issue would have been possible had the students undertaken the self-study portion of the class more rigorously, however, it also highlights the need for reiteration of the newly encountered learning style arrangements and does identify the students' real need for consolidation time:

'Having lectures and tutorials right next to each other doesn't give time to read over [the] lecture and consolidate knowledge before [the] tutorial.'

'Not enough time between lectures and tutorials to fully absorb material for questions.'

This cohort also highlighted the positive impact that PBL can bring with increased satisfaction with the course, suggesting that students may well benefit from the use of similar teaching methods in other classes:

'Best format of any class I've had.'

'Feels more thought out and structured.'

and, despite contact times being similar for other modules:

'Get more help in tutorials – tutors encourage me to understand problems.'

This last comment touches upon the basis for PBL working and highlights that some students are benefitting from the changes. As stated above, tutorial attendance has increased, while observation from the classroom showed students were more engaged with their groups, were participating in active discussion and gave careful consideration to the questions posed to their tutors.

Discussion

As a means of supporting students' engagement with open-endedness in the design element in Y4 of the CPE degree, the introduction of PBL into earlier years has necessitated careful consideration and planning of suitable activities. The use of HPBL in Y2 has allowed staff to introduce Y2 students to open-endedness and PBL within a structured learning environment. The benefits of such working have been many: students have supported experiences of open-ended working earlier in their degree; tutors feel valued and not simply as gatekeepers of answers; staff have observed higher levels of engagement and a deeper level of understanding and criticality, as evinced from the quality of questions posed in class; and, finally, students engaging with HPBL performed better. The issue of open-ended working is crucial in chemical engineering and chartership requires that design must be completed by all students. Consequently, students invariably experience open-endedness and the liminality that coincides with it. In order to be successful in CPE, they must each address this threshold concept and develop the skills necessary to work in complex and challenging systems and environments. Chemical engineering students, therefore, have a need to engage positively with educational strategies aligned constructivism; in design, students are not only expected to tackle open-ended problems but also to actively construct and develop new concepts or ideas that build upon previously acquired knowledge or experiential learning, whilst undergoing social constructivism during mentoring by an academic supervisor who acts more as a facilitator of learning and group engagement. Consequently, introducing students to the nature of open-ended working in earlier years, allows them to accept such modes of working and deal with this threshold concept, such that when they do experience design, the negative impact of PBL is negated and students can embrace the educational constructs discussed above, which should additionally improve their engagement with troublesome knowledge by reducing the demands of the experiential activity.

Conclusion

There is evidence of improved student engagement and attainment in core classes by working in a PBL mode; by introducing more structured, PBL modules in year two and enhancing the open-ended aspects of design throughout year three, students can become more skilled in working on open-ended problems and dealing with the open-endedness of design. Positive outcomes resulting from the inclusion of problem-based elements include: increased engagement, mitigated stress, bolstered confidence reduced confusion, and improved student retention, while graduates of the programme also reported improved performance in recruitment processes and within the workplace.

Chapter 3: teaching alignment in chemical engineering

Proposed vertical integration of prior learning to support students undertaking Chemical Engineering Design

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Abstract

During academic session 2008-2009, the Department of Chemical Engineering, University of Strathclyde, changed Year 4 Chemical Engineering Design project teaching to include mixed groups from Bachelors and Masters programmes; team delivery and two separate components of design. This paper presents data for 408 students studying Chemical Engineering at the University of Strathclyde pre and post change; exploring the impact of these changes and highlighting potential for supported, vertically-integrated learning programmes, across the first four years of teaching, to provide a framework fostering student confidence and autonomy. The impact of course restructuring indicates that Bachelors students' aspirations are increased, with no detriment to Masters performance. Early years performance over this period is unchanged, allowing separate investigation of the changes made in 2008-2009. Gender basis analysis shows that male students' performance is little affected, although the whole cohort fit shows a marked change due to the improved performance of low attaining female students. Post 2009 final performance shows direct correlation with Chemical Engineering Design mark, suggesting the latter may indicate final expected grades for given students. The study reveals widely applicable benefits for increased student motivation, managing expectation, and facilitating students' utilization and integration of knowledge gained during their studies.

Introduction

Chemical Engineering (CE) is a sub-discipline of engineering that focuses on designing, constructing, implementing, operating and managing process plants and systems. As a result, the curriculum for CE degrees teaches students a wide range of knowledge and skills to be able to undertake this variety of tasks, including classes on core concepts and fundamentals, with incorporation of specialist material in the later years of the course. Students study core classes in heat transfer, fluid flow, thermodynamics, process analysis, reactors and process design, as well as department specific classes, such as statistics, particle technology, emerging technologies and communication. This means that the curriculum is broad yet intense and students' development is supported with myriad teaching and assessment modes, which supports the strategy of increasing student engagement [2] and enhancing subsequent performance [3] through diverse modes of assessment. The knowledge and learning gained in Years 1 to 4 is utilised in the capstone project of Chemical Engineering Design (CED), which is a requirement for accreditation of a CE degree course.

The focus of this paper is on exploring the impact of recent changes, made in 2009, to curriculum and course structure in relation to the CED class. These changes primarily targeted delivery and the student experience, seeking to engage, challenge, and educate students with a varied, research-informed curriculum structured so as to provide students with valuable, industry-relevant experience using a vertically integrated, problem-based course structure. The evaluative research undertaken reveals widely applicable benefits for increasing student motivation, managing expectation, and facilitating students' utilization and integration of knowledge gained over the full course of their study.

The paper also highlights the challenges encountered in trying to develop methods for enhancing the performance of lower achieving students, while meeting the expectations and maintaining standards for higher achievers. These challenges are far from unique and this paper seeks to further discuss and address issues in both pedagogy and effective student learning. The study presented here demonstrates the potential of supported, vertically integrated programmes to provide a framework for high quality, high impact learning experiences that better foster confidence and autonomy, help students to appreciate their own learning, and prepare them for real world situations.

Background

Chemical Engineering at the University of Strathclyde

Although only chartered since 1964, the University of Strathclyde (UoS), and Department of Chemical and Process Engineering (CPE), can trace its CE roots back to the Andersonian Institution and the introduction of a CE course in 1888 [14]. The CE course has increased its applications input by 70% in the past decade and admissions are up by 40% since 2005. The entry requirements have been increased in recent years, to AAAAB for Highers and AAA for 'A' levels, with mandatory qualifications in physics, chemistry and mathematics; there are few cases where exceptions are made to these requirements. As a consequence, the Department now admits cohorts of students with high attainment levels and aims to provide a challenging and varied educational experience for these candidates.

As a Scottish Institution, the University of Strathclyde generally offers degree programmes in line with other HE centres in Scotland, with 4 year Bachelor degrees and 5 year integrated Masters degrees. The majority of students enter University directly from Years 5 or 6 of High School in Scotland, hence, they are typically 17-18 years of age when beginning their degree programmes. Within CE at UoS, the student cohort is primarily composed of Scottish students, the greater proportion of which originate from the West Coast, and North East of Scotland. The Department offers a range of full-time degree courses, comprising the qualifications of BEng Chemical Engineering, MEng Chemical Engineering and MSci Applied Chemistry and Chemical Engineering, jointly run with, but administered by, Pure and Applied Chemistry. All three degrees are accredited by the Institution of Chemical Engineers (IChemE), and the MSci is jointly accredited by the Royal Society of Chemistry (RSC).

The CE degree at UoS was rated the best in Scotland and is a strong competitor within the UK; as a highly industry facing department, with a number of long-standing industrial contacts, there are myriad opportunities for students to engage with potential employers and gain valuable, relevant experience. Many companies specifically target CE graduates for job opportunities, placing some emphasis on preparation of students with key skills for improved sector employability. The average graduate starting salary is in the region of £28k [15] and many students aim to gain chartered status (CEng) as soon as possible after graduation, as this can have salary implications of up to £5k per annum. Thus, it is often these high salary levels and the opportunity to gain chartered status that appeal to prospective students when applying for their first degree, and these often remain the key drivers for employment upon graduation.

Since 2008 CPE, and UoS, have made significant strategic investment in staff, appointing seven new academic staff, with several other colleagues recruited in the five year period prior to that time; this has caused a substantial shift in department dynamics and teaching delivery, in conjunction with a burgeoning aim of the Department to become increasingly research oriented. As a result, teaching is increasingly research informed and some classes are delivered in teams to reduce individual burden.

Chemical engineering design

Course development

Following the inception of CE as a discipline in its own right, toward the end of the 19th Century, design has been an integral part of CE studies. The syllabus for Glasgow and the

West of Scotland Technical College, from 1888, describes a requirement for the construction and use of chemical plant in addition to core classes [14].

As part of all accredited CE degrees within the UK, students are expected to complete a CED project towards the culmination of their studies, as part of their professional training. Completion of the CED project allows students to apply for chartered status (CEng) from IChemE, upon graduation and attainment of a minimum period of professional experience. At UoS, failure to complete the CED project results in the non-award of honours status with the degree classification, and an extended period of proof, from relevant experience and additional study, to gain chartered status. Hence the CED project is viewed as highly desirable by students and industry alike.

CPE offers both a Bachelors of Engineering (BEng) degree programme over 4 years and a Masters of Engineering (MEng) CE degree programme, over 5 years; both programmes offer the same curricula in Years 1 through 4, with courses in CE core concepts and applied fields. The MEng degree is an integrated Masters, where students attaining a minimum level of achievement, currently 60%, can choose to study Masters level material in a fifth year of study and graduate with an MEng qualification. Students studying for the combined Masters of Science (MSci) degree in CE and applied chemistry are registered with the Department of Pure and Applied Chemistry but half of their annual curriculum is delivered by the CE Department. Consequently, all three cohorts are registered for class 18475: Chemical Engineering Design, as a core class in Year 4 of study. Within this class, students undertake two projects: detailed design and conceptual design, working in teams of six students, drawn from the amalgamated cohort. The design project is the capstone project within the first four years of all three degree courses and represents the application of knowledge acquired to that point.

The two Year 4 classes build upon a more structured 20 credit class in Year 3: Plant and Process Design (CP306), where students develop their thinking in relation to producing a design for a process; within this class the students receive significant tutoring and support, and it is a much less involved and less independent process than in Year 4. Many students experience theoretical difficulties with design, even in Year 3, which is partly attributable to the lack of engagement with key concepts in core classes and also related to the fact that there is often no one definitive right answer, and that the academics supervising them may not necessarily know what the best solution would be; this is especially true for the conceptual project in Year 4. It is possible that, for some students, this requires the revisiting of troublesome knowledge acquired as a result of not previously engaging with key concepts earlier in the course [56], it may also present a new threshold concept [56] for other students with the idea of design as a process in its own right, with many students unable to overcome their issues. However, it is not necessary to fully appreciate the concept of design rationale or for the students to 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 for each component then the team will benefit as a unit, and students may continue with the troublesome knowledge acquired, as part of core classes and design, even into their chosen profession. Key differences between the Year 3 and Year 4 design modules are delivery in Year 3 is by one staff member, assisted by a team of postgraduate tutors, who meet with their groups several times over the duration of the module; as the processes being designed are prescriptive and contained in Year 3, there is less emphasis on the group's ability to be creative or design a complete economically viable process.

As described above, the teaching regime within the Department has altered significantly since 2008 and it is now the case that where only four academic staff used to teach all 60 credits of design, it is now a departmental responsibility with every academic sharing in the teaching. This was introduced in the academic session 2008/2009. A few years prior to this change, the Department moved from a combination of 10 credits of process control, 20 credits of applied design and 30 credits of core design to the streamlined approach of 20 credits of conceptual design and 40 credits of detailed design. This reorganisation was partly the result of adopting the Bologna agreement [88], whilst also allowing the Department to reorganise and refocus design teaching within UoS. The portfolio of design experience offered to our students has always exceeded the national minimum requirement of IChemE, which is purely detailed design; the Department has been lauded in recent re-accreditation assessments for the new rationale of design and held up as a model to other CE departments. As a result of the two high credit bearing classes, design is considered a major contributor to Honours studies. The restructuring of the design project delivery introduced, not only a varied teaching team, but also the opportunity to embrace a new perspective on the creativity of design by altering the applied design project to conceptual design, allowing students the opportunity to develop research skills and present original ideas in a focussed manner.

Within the current class descriptor form for 18475, the class 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' [89]. Hence, the 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. Control is now taught as a core module in Year 4, with the two design components focussed on developing the students' critical thinking and problem solving skills alongside chemical engineering design strengths, via detailed design, and their creative abilities, through detailed design. Design tutors are aligned to the two disciplines via their previous training, providing greater support and guidance to the students within a more structured framework than was previously administered.

Course logistics

The entire Year 4 cohort is distributed into teams of six students; sometimes there are a limited number of teams with five members when the year group number is not a multiple of six, and each team is assigned an academic supervisor. The group size serves to assign a manageable number of groups per academic staff member, without making the groups too large to cause loss of individual student engagement. The group compositions are different for each class project, hence, each student works in two different teams concurrently, one for conceptual and one for detailed, and must learn to prioritise work and individual commitments for each group, in order to fulfil assigned tasks for both of the components of design. This approach simulates the time management issues that they will encounter in their Masters placement in Year 5 and/or once they are out in industry. Each group is composed of students with a range of previous academic abilities with no positive bias for gender, ethnic origin or age. The two project remits are similar in that the students must design specific processes; in detailed design they are tasked with sizing and designing unit operations, whereas conceptual design places greater emphasis on constructing a novel solution to a given problem. The two classes combined give students an excellent opportunity to experience common intellectual experiences, working in learning communities, collaborative project work and, importantly, '*Engineering as Engineering is done*' [16, 90]. As part of their project working students have to meet with each of their two academic project supervisors for one hour per week, over the 14 weeks of the project, to discuss progress to date and their targets for the coming week. Students must submit two separate project reports at the end of the semester, one for each project, which are marked and weighted accordingly (40 Credits of Detailed and 20 Credits of Conceptual). The only other required outputs are interim reports, which students must submit partway through the project, at a set date, to ensure the groups are progressing satisfactorily; this takes place at the end of week 4 for conceptual design and the end of week 5 for detailed design.

The project reports are submitted by each group as the combined work of the group, each contain authored sections from all team members, as well as combined sections, such as the executive summary, conclusions and recommendations. Sections are marked for each student but there is also an assessed component for report integration and the shared sections, as well as performance in the weekly meetings with supervisors. Teams are advised to produce a coherent overall process from their individual contributions and the learning outcomes place emphasis on gaining experience in the consideration of a process as a unified system rather than individual parts, undertaking creative development of a process design while considering economic viability, as well as 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*.'

Students gain credit for leadership and collaboration, completeness and integration, critical analysis, synthesis and understanding, design components, and innovation and creativity.

One of the most difficult aspects of the assessment process is the evaluation of creativity, especially in the conceptual design process. Students are advised to think about the novelty of their process but are not constrained by their supervisors as to what aspects are novel, hence, students may design a whole new process, combine aspects of different methods or demonstrate the added value of producing several products from one plant dependent on material supply or demand. The creative components are assessed continually as the ideas generated during the design process of 14 weeks, as well as the overall novelty of the end process. In order to ensure students are assessed evenly across the year group, conceptual design supervisors meet regularly to discuss the progress of their groups and the outputs delivered to date. A similar regular meeting is undertaken by detailed design supervisors to ensure groups are progressing at a similar rate and any recurrent issues can be addressed.

The IChemE offer guidance to HE institutions on the delivery of key teaching for the purpose of gaining accreditation for their course(s) [89]. Such directives have been instrumental in defining class descriptors, as above, for CE departments across the UK; although the document outlines the key skills that should be addressed by the design component, and there are significant guidelines for the achievement of expected learning outcomes (LO), there is little indication of how these might be achieved, for example team working is an expected LO but the only guidance offered is to undertake the project within a group or liaise with an existing unit, i.e. the actual mechanism of team working is not addressed and this may differ greatly across degree courses. As a result there are likely many institutions in the same position as UoS, where the importance of team interactions has been neglected until now.

The wider UK context

As indicated in the previous section, IChemE offer clear guidance on the requirements for design teaching, which are adopted at both the national and international level, but this is open to interpretation by individual departments. Interestingly, industry is not actively involved in design teaching in the UK [91], even though the project, and associated chartership, is often desired by employers.

As stated previously, within CPE at UoS, students undertake a design class in Year 3, which aims to prepare them for the project in Year 4. This class allows the students to develop some prior skills in design before undertaking Year 4 CED; and there are a few other examples of prior specific design training where a minor, well demarcated design project is, by contrast, undertaken in semester 1 before the major design component runs in semester 2 of the same year [91]. It is interesting to note that CPE appears isolated in offering both a detailed and conceptual design portfolio, with the general consensus in the UK being a single project, typically worth 30-40 credits, which appear to have developed greater conceptual components over the years [91]; these factors combined make CED delivery at UoS unique.

The design project runs over semester 2 only in Year 4 at UoS, however, in some UK institutions, the project runs for the full year [91]; the topics chosen at UoS are the same for all groups, in contrast some UK institutions allocate projects based on the academic supervisors' specific interests [91]. The latter seems open to variation and would be difficult to justify to students after there has previously been parity, especially if the groups were randomly allocated to an academic without any provision for project selection; the Department does form mixed groups of students, considering this assists in the simulation of a real life situation. As students progress through the degree course, staff often become aware of their traits and individual personalities, so caution should be taken with regard to the use of such prior information when composing groupings; as the composition of groups could come down to a single academic's whim and will probably not replicate the often random selection of working groups within industry and research communities; potentially providing the students with a biased view of real world group working. It is recommended that this aspect of the current system within UoS should be retained.

At present the Department awards individual marks to each student, which are comprised of contributions from individual, shared and group sections; each section is authored by one or more students and assessed separately for the quality of the work therein. Students are also assessed on group integration and performance in weekly meetings with their supervisor. This varies slightly from other universities [91] but the Department currently considers this a fair assessment method. In contrast, a number of UK departments have some form of peer assessment as part of design marking, whilst others use peer feedback; this involves each group providing written feedback on an interim report written by another team, the quality of the feedback influences the marks awarded [91]. The Department does not currently use such methods but the latter could provide a structured opportunity for students to reflect on the project and appreciate the relative merits of their own work; providing invaluable training for the workplace, where graduates will be asked to critically evaluate reports from colleagues and external parties. Using such peer interaction, akin to the high impact activities originally set out by the LEAP 2007 report: College Learning for a New Global Century [90], and built upon by Kuh,[16] could encourage independent thinking and ownership of learning.

Although not formally assessed, as in some other Universities, it is recognised within the Department that the weekly meetings with supervisors allow students to provide oral feedback to their colleagues, and the compilation of the final document requires critique and feedback on the work of other team members. The use of peer assessment has been identified by Kentish and Shallcross [92] as a key area for future development with emphasis on sustainability also a requirement. The department is teaching sustainability as a core class in Year 3 from 2011 and this is leading to an increased predominance of its effect on Year 4 design. Such integrated strategies are vital in producing graduates with the skill set for a developing industrial landscape.

Framework and methodology

Study objectives

This paper has four key objectives, to:

(i) determine the effect of recent changes in design delivery, most specifically the adjustments in design structure and academic management in 2008-2009, on student academic performance

(ii) evaluate the performance of students over the three degree cohorts (BEng Chemical Engineering, MEng Chemical Engineering and MSci Applied Chemistry and Chemical Engineering) in the design class and the correlation of this with pre- and post-design academic performance

(iii) rationalise the demands of current design curricula and provide a wider understanding of the issues within current design delivery and areas of success

(iv) propose changes for improved support of design teaching at UoS and integration with existing curricula across the first four years

In order to address these aims:

(i) it was necessary to analyse separate data sets for pre-2009 and post-2009 design teaching, to be used in conjunction with results from (ii)

(ii) data were separately analysed for all three cohorts, also subdivided by gender, to more fully understand the correlation between the mark awarded during design and pre- and post-design academic performance, and compared with (i)

(iii) discussions were held with design teaching staff to identify advantages and/or disadvantages of current delivery

(iv) design teaching across the UK, and models for best practice with UoS, were appraised to establish potential improvements to address issues identified in (ii)

Statistical analysis of the implemented changes made to design delivery in academic year 2008-2009, was performed on data obtained for students graduating in the previous seven years of the BEng degree programme, and the previous six years of both the MEng and MSci degree programmes. The three degree programme cohorts were grouped to address the effect of end qualification as a variable, and the effect of gender was also investigated. For each cohort, the grades obtained for design were correlated with the performance over Years 2 and 3 of the degree course, as these contribute to the weighted average of the final mark, relationships between early academic performance and final grade for each cohort were also probed; additionally the design mark achieved was correlated to the final degree mark awarded.

Methodology

The data used in this study relates to seven cohorts of students graduating from the Chemical Engineering (BEng) degree, and to six cohorts of graduates for both the MEng in Chemical Engineering and the MSci Applied Chemistry and Chemical Engineering degrees at UoS. This represents a sample of 408 students, broken down into the groups shown in Table 1:. These students registered in the period 2002-2008 for the four year BEng degree and between 2002-2007 for the five year MEng/MSci degree courses. These students entered the degree programme during a static period for entry requirements, hence, their baseline abilities can be taken as equal. Analysis was also performed to determine the effect of gender on design performance and the breakdown is also shown in Table 1:.

The BEng/MEng cohorts have 220 common core credits from Years 2 and 3, which were used to determine their average performance, the 20 credits taken as elective classes were excluded to eliminate any variance in class selection, providing consistency with student assessment at UoS as these classes do not contribute to the final degree mark. MSci students study 60 credits of common core classes in each of Years 2 and 3, i.e. 60% of Year 2, excluding electives, and 50% of Year 3.

As a consequence of the Department changing the delivery of design teaching in the academic year 2008-2009, the population described above was split into two groups pre-2009 and post-2009 design teaching. For the pre-2009 group, consisting of 134 students, this represents students graduating 2006-2008 and the cohort breakdown is shown in Table 1:; the very small sample of MSci students graduating before 2010 makes this group unsuitable for analysis. It should be noted that there were no female graduates from the BEng cohort for the pre-2009 period. For the post-2009 group, which covers the entire period for which there has been a 'departmental teaching team' employed for design, there is sample of 274 students, and the breakdown by degree programme and gender are shown in Table 1:.

Table 1: Breakdown of student numbers by degree programme and gender

	Total students:			Pre-2009 changes students:			Post-2009 changes students:		
Degree Programme	Graduated	Male	Female	Graduated	Male	Female	Graduated	Male	Female
BEng	144	123	21	31	31	0	113	92	21
MEng	236	193	43	103	80	23	133	113	20
MSci	28	16	12	N/A	N/A	N/A	28	16	12
Total	408	332	76	134	111	23	274	221	53

Results and Discussion

Impact of change of design teaching on student performance at UoS

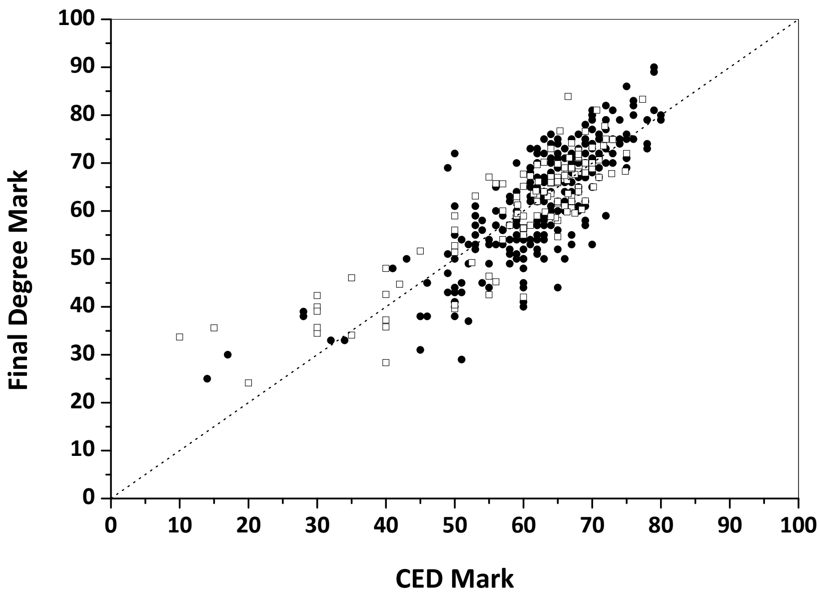


Figure 1: Correlation between design mark achieved and final degree mark for pre-2009 (open square) and post-2009 (filled circles) design teaching cohorts with unity correlation shown (dotted line)

Figure 1 shows the correlation of the mark achieved in the Year 4 CED class and the final mark attained by graduating students from all three degree programmes on the basis of those taking the design class before 2008-2009 and those receiving the revised mode of delivery in later years. The dotted line included in the plot shows a fit of unity, and it is evident that there is a good distribution of students around this correlation for both sets of data. There is a larger data set for post-2009 graduates but it is evident that the two groups of students show no marked change in the overall correlation trend, although the pre-2009 group show a greater proportion at the lower end of the trend; this is supported by the means of the final mark for these two sets of data (60.9 ± 11.8 for pre-2009 and 71.7 ± 9.7 for post-2009). Caution is required when considering this trend, as the past six years have seen a significant increase in the number of students progressing on to the MEng, which could be attributable to myriad factors other than a single CED class. As a consequence of the impact of MEng progression (a minimum performance of 60% in Year 4 and an average over 60%, applied at the end of Year 4) it is essential to consider the two sets of data separately in terms of cohort, particularly when the 5th Year class contains students from two different degree programmes.

Table 2: Contributions from year performances to final grade and relative contribution of CED mark (60 credit class) as a percentage of final mark

Degree Programme	Contribution from Year 2 / %	Contribution from Year 3 / %	Contribution from Year 4 / %	Contribution from Year 5 / %	CED mark as percentage of final mark
BEng	10	20	70	-	35
MEng	10	20	35	35	17.5
MSci	10	10	40	40	20

The separate data trends for the two samples shows a greater mixing of attained marks for the three post-2009 cohorts and an increase in the average design marks achieved by BEng students (Figure 2b) compared to the pre-2009 BEng cohort. In Figure 2 the fits shown are for the Masters cohorts only, indicating that the design mark for post-2009 is closer to unity correlation with final degree mark, and that BEng students are displaying a comparable trend, of design mark with final mark, to their MEng colleagues (as shown in Figure 2b). One of the major changes in the delivery of CED in 2008-2009 is that the BEng students have been integrated fully into the two CED teams now in operation, this may raise BEng students' aspirations by allowing them to work closely with students achieving MEng grades; additionally, the removal of process control to a dedicated class, makes CED a completely coursework driven process focussed on process design that may allow BEng students to demonstrate strengths in that mode of assessment; it also worthy of note that the contribution of the CED mark to the BEng final mark is twice that of the MEng contribution, making a good performance in CED even more worthwhile for the BEng students (Table 2).

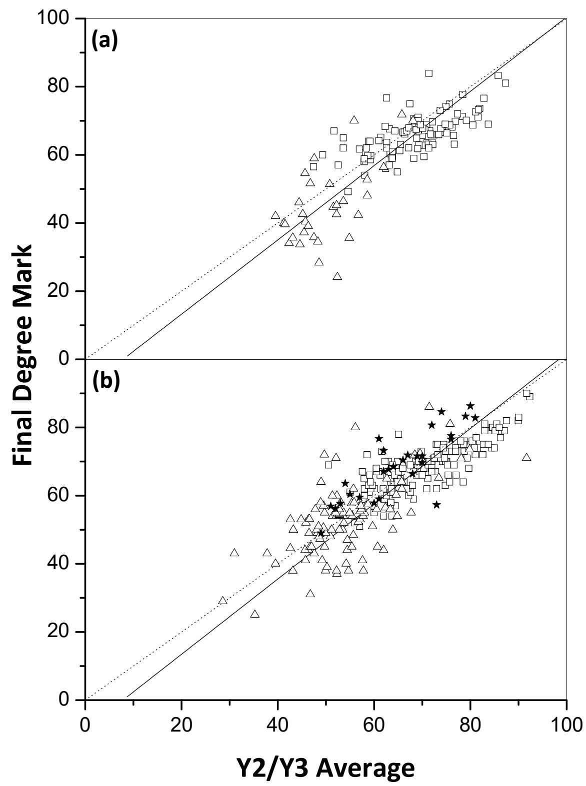


Figure 2: Correlation of design mark achieved and final degree mark for (a) pre-2009 and (b) post-2009 design teaching cohorts showing BEng (open triangles), MEng (open square) and MSci (filled star) cohorts with fits through (a) BEng and (b) MEng/MSci data (solid line) and with unity correlation shown (dotted line)

Correlation of prior student performance with CED mark

It is evident that there is a clear correlation between CED mark and overall performance, however, the trend of final degree mark with CED does not allow the full academic picture to be probed; hence, the data collected for CED mark was correlated with academic performance in the taught years preceding CED for both CED teaching groups (i.e. Year 2 and 3 for all cohorts, as this immediately precedes the design year, Year 4). This pre-academic performance, based on the average mark attained for Year 2 and Year 3 as Year 1 does not contribute to the final degree mark, was also correlated with final degree mark to determine the relationship between these variables.

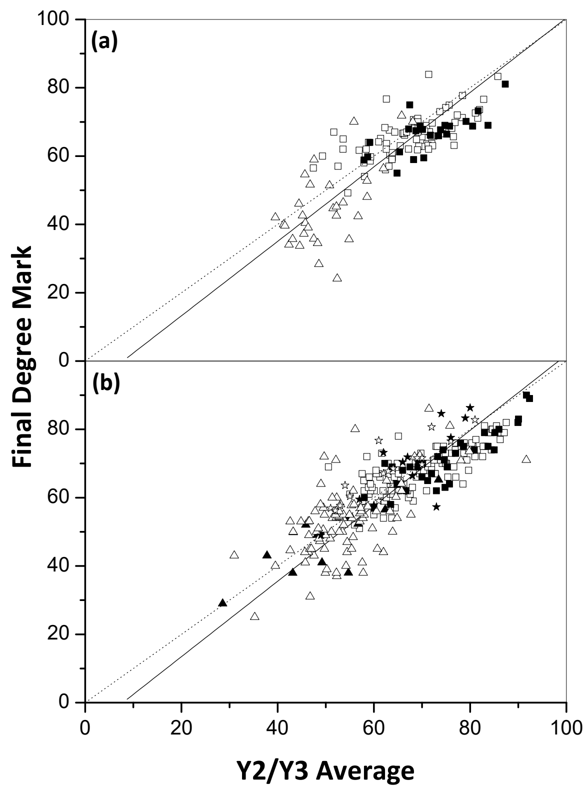


Figure 3: Variation in final degree mark with Year 2/Year 3 average for (a) pre-2009 and (b) post-2009 CED teaching cohorts showing BEng males (open triangle), BEng females (filled triangle), MEng males (open square), MEng females (filled square), MSci males (open star) and MSci females (filled star) cohorts with fits through MEng/MSci data only (solid line) and with unity correlation shown (dotted line)

Data obtained for Year 2/3 average and final grade for those students undertaking pre-2009 and post-2009 CED are shown in Figure 3a and Figure 3b, respectively. It can be seen that there is good correlation between early years performance and the final grade, close to unity for both groups (cohort average Year 2/Year 3 performance means of 63.7 ± 11.1 for pre-2009 and 62.9 ± 11.7 for post-2009). The negative intercepts obtained in both plots are expected as the level of difficulty increases from Years 2 and 3 into Year 4, suggesting students must improve their performance to achieve the same standard of marks. Interestingly, Figure 3b shows data obtained for all three degree cohorts: BEng, MEng and MSci and the trend is followed for all three sets of students; in contrast to the grades achieved by the BEng cohort pre-2009, as shown by triangular symbols in Figure 3a, who show a marked reduction in final grade attainment compared to the average performance in Years 2 and 3.

It may be that the change in delivery of CED teaching enhances the student experience for BEng students, raising their aspirations and, subsequently, their performance in the CED class, which contributes significantly to their final grade. However, this needs to be put in context with the performance of these students within CED compared to their average attainment in previous years.

Figure 4a shows the correlation between the mark achieved for average performance over Years 2 and 3 and CED mark, for students undertaking pre-2009 CED. It is evident from the overall fit shown for MEng students (solid black line), that the correlation between performance in Years 2 and 3 and the CED mark achieved is far from unity, suggesting a lower CED performance for those usually achieving high examination marks and, most notably, the very low levels of attainment achieved by those students with examination marks closer to 40%. The trend is affected slightly by gender, with female Masters students showing a correlation closer to, but still far from, unity (dotted black line). It is evident from the data shown that BEng students capable of 2(ii) performances in examinations (i.e. an academic performance not less than 50%) have significantly underperformed in the CED class in comparison. It is worth noting the difference in the relative contribution of the CED mark for BEng and MEng/ MSci students, where the class is more heavily weighted for the BEng students, at twice the value of the MEng course, increasing the relative effect on the final grade attained (Table 2).

Figure 4b shows the correlation between marks achieved for average performance over Years 2 and 3 and CED marks, for students undertaking post-2009 CED. The overall fit (solid black line) this time for MEng and MSci students, the whole Masters cohort, shows a correlation much closer to unity for the performance of students in CED with respect to previous academic merit. This trend is little altered when including the BEng student cohort, suggesting that the revised CED teaching allows all students to perform in line with their previous performances; again there are a few BEng students who underperform significantly but this is a much lower proportion than for the pre-2009 CED group. In both Figure 2 and Figure 4 it is possible to see a lower performance in CED than for either early years average or final mark at the high end of the marking scale but the opposite effect is observed for the low end, indicating that the marking in CED does not reflect that typically observed within exams, where outliers often occur, and appears constrained to a much narrower band. Such narrowing of mark bands in coursework has been noted previously [93], suggesting a smaller contribution is made to the final mark as a result [94], however, and the data in Figure 3 would tend to support this idea. Year 1 data is not included in previous performance marks as the marks do not contribute to the final grade (Table 2), hence, student performance is not always representative for this session.

It is interesting that data fits on a gender basis show the same trend in both pre-2009 and post-2009 groups, i.e. female students show less variance in CED performance with a narrower band of grades, whereas male students of the same academic standing after Years 2/3 have a greater distribution of CED marks. Figure 4b shows fits of the data on a gender basis for Masters only (dotted black line female/dashed black line male) and the whole cohort (dotted grey line female/dashed grey line male) and, interestingly, the grade band is always broader for the Masters students, symptomatic of greater variation in this cohort. Researchers have previously suggested that female students academically outperform their male counterparts, especially in examinations,[95] and conversely that male students are favoured by exams [96-101], but the data shown in Figure 3 show that both gender groups attain similar levels for both Y2/Y3 performance and final degree mark, in agreement with previous studies reporting gender equality [102] and parity of assessment mode for females [103], however, the issue is likely very subjective to differences in course subject, ratio of coursework and exams, and demographic drivers that alter students' perceptions of their own abilities. Thus, unsurprisingly, it has also been reported [102] that a perception exists that female students are advantaged by formally assessed coursework, such as CED, as a consequence of their personality traits [103-105], and a combination of their generic skill sets and examination anxieties [106, 107]. Reference to Figure 4 indicates that, at the low attainment level this perception may well be true and past work has suggested that coursework favours the less able [95, 102, 108], however, the narrow banding of CED marks disadvantages female high achievers, possibly indicating that the two opposing views of favour by examinations or coursework are both valid but for subsets of the CPE female population. Researchers have presented previous data that indicates female students studying law degrees perform to similar levels as their male counterparts when the female:male ratio is slightly enhanced [109]; while the 20%

female representation at CPE may seem a small female ratio, this represents a shift towards historical highs for UoS CPE, providing a positive skew and a supportive environment for the female cohort with a range of performances, in contrast to the diametrically opposed performances witnessed for lower female representation on law courses [109]. It should be appreciated that previous work suggests that both genders perform better at coursework than examinations,[103] however, this is contradicted by the data presented here. It must be noted, for the reader's benefit, that where CED is completely coursework assessed, most other classes have a maximum of 30% contribution from non-examination modes of assessment.

As discussed in the literature there has been a move towards new forms of assessment for degree courses, which has seen a growth in assessed coursework contributions,[110] which has been linked to uncertainty in the degree classifications awarded [111]. Analyses of the influence of assessment methods on overall marks attained have been performed and indicate that greater inclusion of coursework components tends to increase the average mark attained for those courses [112-114]. This trend supports the difference in marks observed at the lower end of the marking scale, as shown in Figure 2 and Figure 4, however, the trend for higher achieving students to attain lower marks is against these findings. It is possible that staff find it difficult to assign marks within the higher bands of the guidelines issued by the University for marking of undergraduate coursework,[115] which is also reflected in other classes throughout the BEng/MEng/MSci degrees, as the classification are currently Class 3 not less than 40%, Class 2(ii) not less than 50%, Class 2(i) not less than 60% and Class 1 not less than 70%, meaning there is a significant band of marks above Class 1 performance minima. The top band is guided as 80-100% and staff may find it difficult to apportion marks within this 20% range (all other bands above a pass cover only 10% ranges), hence they may tend to mark to the lower end of this band (i.e. 80%) as the higher end (i.e. 100%) would suggest near perfection, which is difficult to attribute in subjective marking.

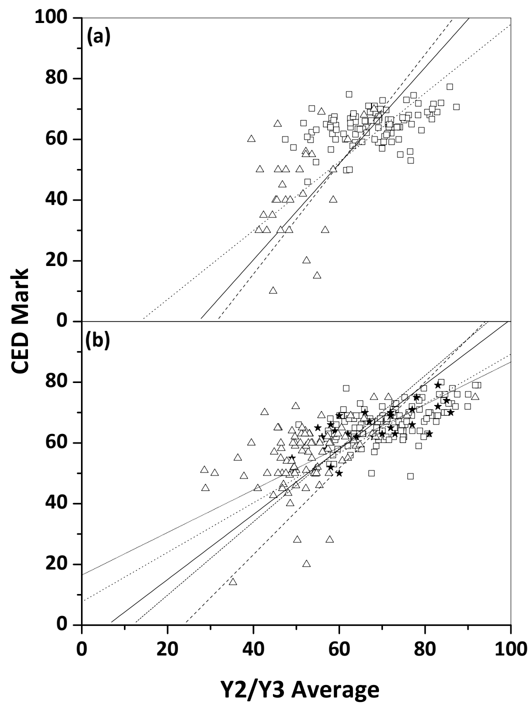


Figure 4: Variation in final degree mark with Year 2/Year 3 average mark for (a) pre-2009 and (b) post-2009 CED teaching cohorts showing BEng (open triangle), MEng (open square) and MSci (filled star) cohorts with fits through all MEng/MSci data (solid line), MEng/MSci females (dotted line), MEng/MSci males (dashed line), all females (short dotted line), all males (short dashed line)

Issues Identified in Teaching CED at UoS

Within this research, there were four main modes used to identify issues that arise during the delivery of the 18475 CED class; these were personal reflection, discussions with other staff members, student discussions at staff student liaison committee (SSLC) meetings and on a one-to-one basis with students. From these discussions and internal reflection, the main concerns can be summarised as:

1) The Department potentially expects too much from the Year 4 students and that they are not sufficiently skilled to meet the demands placed upon them.

2) There is a lack of group identity and no real understanding of individual roles within the team structure.

3) There is a distinct lack of project ownership by some students, which can manifest as a lack of cohesion and drive that affects other team members.

4) Some students display excessively high personal expectations, which have previously resulted in withdrawal of high calibre students from the course.

5) Students with poor performance in the first half of Year 4 can display a lack of engagement with the project and, once semester 1 exam results are actually known, this can result in non-submission of any assessable materials potentially with the implication of reducing the qualification awarded to an ordinary pass degree.

6) There appears to be a threshold concept [82] within conceptual CED that there has to be a correct answer and students, even those of high achievement, struggle to initially accept that even their supervisor may not know an absolute process to which they should be working.

Proposals for Improved Support of CED Teaching at UoS

Group Working Strategies Already Employed within UoS

The Business School (BS), at UoS, currently run a programme called the Management Development Programme (MDP) which was introduced in 2006-2007 to develop business, management and personal skills. The programme allows students the opportunity to understand what is required to be a business person, improves decisions development and provides a platform for the students to be heard. As a consequence of increasing their students' professional skill sets and making their graduates more industry facing, the School has since an increase in employability. Such achievements are integral to the drive to develop the delivery of CED focussed teaching within CPE. The motivations for the introduction of this course, which is vertically integrated with delivery over three years, are cited on the BS website as '*organisations are seeking flexible employees who can adapt to change, are effective in operating in interdisciplinary teams, have confidence in presenting and have well-developed interpersonal skills*' [116]. Such skills are required within the CE sector, and development of a similar strategy to align core skill training would enhance employability and allow full integration of the knowledge and understanding acquired during Years 1 to 4.

The course is structured to develop the students' capabilities including team working, communication, numeracy, IT expertise, interpersonal skills, while also addressing the issues of leadership, decision-making, entrepreneurship and negotiation. By Year 3, the students are expected to engage with ethics and research methodologies; many of these skills are also required of CE students and the Department appreciates that it will require a vertically aligned approach to realise this aim. However, it is not felt necessary to develop a separate programme to run concurrently with the existing curricula, but rather to embed the associated learning into existing classes, enhancing the learning experience form within the subject matter.

One of the main delivery modes within MDP is a series of recorded mini-lectures and seminars, which the students can use to support their learning and refer back to again and again. The Department has received several offers, in recent years, from companies who employ our graduates to become more involved in the delivery of their degrees and the use of video materials provided by such partners could offer an opportunity to provide greater industrial engagement for our students, while supporting their CED learning and professional development. By capturing the delivered teaching using audio or video recording, the Department will develop an increasing resource that can offered to subsequent cohorts, but which should be maintained to ensure the information is relevant and up-to-date.

Implications for future delivery of CED teaching

Educational theories to assist delivery of CED teaching

Teaching within CPE is already greatly focussed on team work, which simulates the real life expectations of a practising chemical engineer; such activities involve many of the actions suggested to promote participant engagement for improved performance [16]; including 1st Year experiences, collaborative assignments and common intellectual experiences [90].

At present CPE students are expected to work within teams from the very beginning of their studies with the composition of groups routinely changed to increase student interaction and enhance learning possibilities within diverse units. As detailed in the issues experienced, threshold concepts are often a problem for students in these activities, as they engage with and apply knowledge gained in core CE classes to assigned tasks, often revisiting, and maybe rationalising, troublesome knowledge as part of the process [56]. Additionally students may struggle with educational theories more aligned to constructivism, especially in later years, where the students undertake CED and are expected to actively construct or develop new concepts or ideas that build upon previously acquired knowledge or experiential learning [117]; there is also the added complication of social constructivism where the CED teams are mentored by an academic supervisor who acts more as a facilitator of learning and group engagement [118]. By reducing the influence of the latter educational constructs, it should be possible to improve the students' engagement with troublesome knowledge, which may be further mitigated by the use of Problem Based Learning (PBL) in early years.

Biggs [119]has previously emphasised the import of aligning assessment methods and the curriculum, and the literature has several examples indicating that the alignment of these two key aspects leads to deeper learning [2, 120], by providing students with an integrated learning framework [2] that demonstrates learning connectivity [120]. Both vertically and horizontally aligned education models exist [121] and have their own strengths, however, the latter is mainly concerned with standards and assessments but there are other factors that need to be considered such as curricula, reading materials, stakeholder concerns, delivered teaching, and academic achievement [121-123]. Much research has been dedicated to the successful integration of all these aspects of the educational system. Within the academic sector, vertical alignment has also become analogous to the threading of educational constructs and theories throughout the different years of a degree programme, much akin to the original strategy of aligning standards and assessments to reflect a logical and consistent order of delivery of course content over several years, but requiring the integration of material to the substructure of the course rather than sitting alongside existing methods and materials.

It has been suggested, through reviews of management practices within UK industry, that graduate recruitment and progression will be significantly linked to the possession of developed group working skills [124, 125]. Group dynamics have been the focus of extensive research for several decades and the role of individuals within the group have been identified as key. The Belbin team model [126] has identified nine team roles [127], which can be best allocated within a unit of six members [126], assigned a complex problem; this obviously requires some members to adopt more than one role, which has been discussed in the past and accepted as achievable [126], with some combinations more likely than others, influenced mainly by the confines of the task or relationship typing [128-131].

The use of Belbin team roles can be used to improve team effectiveness by either performance or team validity [132]. Teams with a single leader tend to outperform those with none or more than one [132], hence, one member either needs to adopt the two main leadership roles of chair and shaper, unlikely due to the personality traits of each role [126, 127], or the two roles have to coexist and work together for maximum effect. An understanding of role types and the strengths and weaknesses of each would lead to a greater possibility of the latter case occurring.

There are several stages of group development during a project timeline: forming, storming, norming and performing [133, 134], with studies indicating that groups have been observed to pass through these four temporal stages [135, 136] and an increasing maturity with the experience [137]. In addition to this progression, there is evidence that there must be task specific knowledge accrual, effective communication and the construction of problem solving strategies [138]. As a consequence, such skills must be addressed and embedded in earlier years to support development, which fits with the introduction of PBL across all years and increased team role awareness with improved dissemination requirements. An issue that was raised in the literature that could have significant impact in CE disciplines is the fact that there is a clear divide in team role with gender, with women gravitating towards team worker roles and men more likely to implement or co-ordinate [138]; as a result of relatively low levels of female participation in CE at UoS, typically less than 20%, this may affect the take up of team roles within a group and the impact on the gender based performances detailed earlier should be monitored.

Proposed learning strategies

One of the main aims to improve student performance and ownership within CED is to assist students in appreciating the key aspects of team working and their role(s) within the team(s), rather than only considering their own contribution(s). By using Belbin team roles [126, 127] it should be possible to develop students' skills at identifying the roles adopted by themselves and others, improving identification of omitted or duplicated roles and the demands placed upon individuals. This should be addressed by introducing the concept of team roles [126, 127] at the earliest stage (Year 1) and building on the understanding and reflection from that point forward. An increased awareness of the expectations placed on adopted role(s), and by understanding the relative strengths and weaknesses of their own and others' roles, the students will be empowered and their output quality should increase. The department will utilise Belbin-type tests to allow students a greater understanding of their current strengths, weaknesses and abilities within their present group. These results would not be used by staff to 'compose' groups for design as this would create a false representation of group dynamics in the workplace and may force some students to continually adopt a given role rather than developing new skills. By preparing all students for the demands of team working, this should no longer be such an influencing factor in project performance and students should be able to concentrate on the technical aspects of the problem set.

As students become more aware of the team members ability to affect the development of a team and the progress of their work, it would be possible for them to work together to ensure that any conflict or technical difficulties are resolved expediently and in such a way that the team dynamics are not adversely affected. This will prepare them for the difficulties expected in industry, and the introduction of lectures and seminars from industrial partners should increase the learning outcomes the real-life context by addressing process safety and design strategies using the information and/or guidance provided.

In addition to improving the understanding and use of team roles, it is also planned to increase the use of student focussed assessment methods within CED and other group projects, as this has been shown to impart greater reflection and deeper learning engagement for the student body [139]. Peer assessment [140] is viewed as a method of allowing students to learn from their own mistakes via the performance of others, imparting greater ownership of the learning process. Many students find the experience to be positive [141], often giving them an insight into the assessment methods used [142]. The process introduced within CE should be semi-structured to avoid issues that have arisen in the literature, which include students having difficulty in identifying mistakes in formative peer assessment [143] or struggling to judge appropriate grades in summative peer assessment [144]. Embedding the use of peer assessment from Year 1 will instil greater confidence in the students of their own abilities and provide them with an increasing framework in which to make comparative judgements on their peers. One method recommended for trial is to empower the students by allowing them to grade mainly technical material with increasing amounts of subjective material as the course progresses, as the latter aspect can be problematic for students [145]; this may need to be within the confines of a marking outline prepared by academics [139]. There have been suggestions that the inclusion of staff within group meetings to assist in assessing the validity of the peers assessments made [146] may inhibit the functioning of the group,[147] however, this inclusion is standard practice within the Department for CED teaching and many of the students have commented on the value of weekly discussion with their supervisors, whilst the group also meet outwith these times, improving integration. It may benefit students to actually perform the assessments anonymously, to prevent confrontation and tension within the group [148] and the Department would need to develop a suitable questionnaire for this process, like those previously shown to suitably reflect individual student contributions [148] with some aspects of the WebPA system developed by Willmot, which has shown promising results in engaging academics and students with a process that allows apportioning of weighted contributions for individual students [149] that could be ideal for the aspects of teamwork, integration, technical discussion and communication that are difficult to assess from the written submission.

The alignment and development of transferable skills will be undertaken in conjunction with a second aligned strategy to increase critical analysis skills though embedded PBL. Such methods used over all years of a CE degree, with increasing complexity, have been recently demonstrated to be successful for CE degree programmes in Singapore [150] and Australia [151], which placed emphasis on the consideration of when materials are encountered and developing design skills to suit [151].

The main concerns highlighted before will be addressed by:

1) Increasing the skill sets of our students, which should allow their performances to meet staff expectations, and the development of team working throughout the years will give all staff a greater insight into the difficulties faced within team working and the concerns of their students.

2) By providing the students with an understanding of team roles, this should improve their personal identity and allow them to relate to other team members more effectively.

3) Increasing student engagement with the project, through identifiable demands on each member, an improved view of group cohesion, and the use of peer assessment methods will improve the sense of ownership.

4) Allowing students the opportunity to understand their role in previous teams and identify their own strategies for dealing with assigned workloads and project demands will support student retention.

5) It is possible that increased engagement with the project from the beginning of the semester and a greater understanding of how they can positively affect the project outcome will help with those students achieving low grades in semester 1 exams of Year 4. The Department hopes that by increasing PBL in Years 1 through 3, the concepts met in Year 4 will be more readily understood as it is perceived that a lack of understanding threshold concepts and an absence of critical analysis skills that lead to poor performance in this set of exams.

6) By using PBL within earlier years, the students should become more comfortable with the idea of open ended problems and this should reduce the current stress experienced in Year 4, where students often meet such problems for the first time.

Additionally, determining students' team roles should allow the strengths and weaknesses of each role to be determined, allowing those students studying the MSci degree curricula, or who study abroad/Erasmus in Year 3, to contribute most effectively to the areas in which the skills specific to their alternative learning environments are required. This also more realistically simulates real life as often there will be a range of backgrounds and abilities within a group and more effective management of each student's contribution will improve the overall team performance.

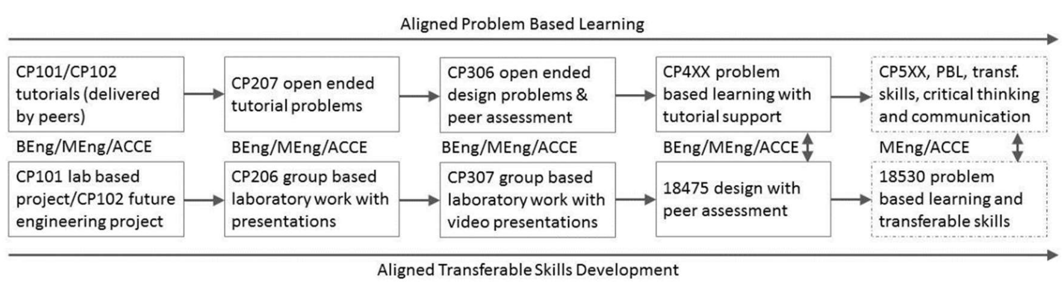
Proposed Integrated Vertical Learning Strategy for CED and Team Working Progression in CE at UoS

Over two decades ago, institutional reviews were suggesting that students should graduate with improved employability and personal 'soft' skills as a result of their studies [152]; team working was identified as a key driver for industry, and these skills must also be learned

[153]. It has been stated that CE students are expected to attain skills in design, project management, group work and dissemination, which are within the range of transferable skills considered important for graduates [154, 155]; some departments have developed strategies, including PBL [151], to address the provision of training, staggering the development over several years and classes. These methods have aimed to increase team project frequency as students felt they were unprepared for design [151], but this is already in place within CE at UoS, with several group projects per year, and there are a number of vehicles available, including report preparation, laboratory sessions and aforementioned Year 3 design projects, in which to embed the delivery of these key skills in earlier years.

At present there are several instances of group working within Years 1 to 4, as well as a number of classes that currently use tutorial based learning environments. Laboratory programmes have previously been identified, and successfully used, for such purposes [150]. It is proposed that the integration of PBL be aligned to those classes with tutorial support and the delivery of soft skills training aligned to the current group work structure. This means that there will be increased PBL in CP101 (Basic Principles in Chemical Engineering) and CP102 (Introduction to Chemical Engineering) in 1st Year, where peer tutoring occurs; this will be supported by introducing team work strategies into the CP101 laboratory class (semester one), which can be revisited and improved in semester 2 within the project in CP102. These classes use teams of six and three students, respectively, giving the students the opportunity to experience the effect of team size, as well as progressing from an experiential laboratory project (CP101) to a theoretical report (CP102).

In Years 2 and 3, the students undertake laboratory sessions in groups of three, and are expected to deliver an oral presentation in Year 2 (CP206). Until recently, the students also delivered a presentation in Year 3 (CP307), which was video recorded and played back to them, it would be useful to reintroduce this practice to increase the learning platform available. Group activities are also used in Year 3 CED (CP306) and within Safety and Project Management (CP205), which currently focuses on project not people management. CP207 in Year 2 unites Process Analysis and Statistics, which can both host a range of problem solving sessions that are more likely to open ended, adding to the experiences in Year 1 and underpinning the use of PBL in CP302 (Separation Processes) and CP306 (Chemical Engineering Design and Advanced IT). It was discussed previously that some students can fail to fully engage with CED in Year 3, yet pass as the result of other's work, hence, it will be necessary to develop both open ended PBL for this class and develop a new method of class assessment, including peer assessment methods, to allocate marks that more fully reflect student ability and contribution. The introduction of peer assessment in this mode should reduce staff workload for assessment, allowing greater time for supervision and guidance, while benefitting students as peers will be able to provide feedback more quickly [156].



Scheme 1: Vertically aligned strategies for the delivery of problem based learning and transferable skills to assist the delivery of CED, and subsequent Masters level classes

As can be seen from Scheme 1, this represents a wide range of subject areas, from core principles to more department specific classes, allowing the strategies to be adopted in a variety of subjects, increasing the students understanding of the applicability of the generic thought processes across all units. It is anticipated that the use of PBL will then succeed into Year 4 taught courses, across the whole curricula, culminating in Year 4 CED in semester 2. The Department is currently in the process of collating specimen examples for PBL and developing a list of key concepts that students should be engaged with at each milestone within the course. The learning experiences will be constructed with consideration of the Kolb cycle [157], and try to utilise data from real life process to facilitate experiential learning [157, 158]. These strategies should then underpin Masters level classes, and it is worth noting that for the final two years there is feedback between the two aligned strategies.

By having several instances of team working throughout all years, staff should be able to identify students failing to engage fully with group working and undertake measures to address each individual case. By improving student attitude and performance in Year 4, the Department should be able to encourage initial staff buy-in to the strategy and then maintain their commitment with improved interaction during the project duration.

Conclusions

The changes made to Year 4 CED teaching within CPE at UoS in 2008-2009, including the introduction of a team of academics to deliver CED teaching, the 20 + 40 credit bearing classes and the use of mixed groups, has enhanced the performance of lower achieving students, while maintaining standards for higher achievers, irrespective of degree course. Both modes of CED teaching, before and after the implemented change, saw a narrower band of marks awarded compared to examinations, which has been reported for other educational systems previously. Overall student performance for the degree courses offered shows no gender bias, however, this occurs despite variances in coursework/examination performance with gender.

Consideration of CED teaching delivery in other institutions and the requirements of the professional accrediting body have allowed an assessment of the strengths and weaknesses of current delivery methods, and indicates applicability of this work to these comparators. By addressing the issues identified with CED teaching in its present form, the Department has developed a strategy to enhance team role engagement and strengthen the prior skill set of students undertaking CED. Taking the fact that team structures are not set but fall within a range of constraints for different team requirements [159] with the conclusions presented here and that the combination of teamwork and examinations across the curricula and the use of a capstone project in final years is not unique to the course studied here; this study demonstrates the potential recurrence of issues associated with high value coursework classes and the proposed strategy of vertically integrated teaching support for capstone projects has wide applicability across the disciplines.

Chapter 4: tutors within group based learning activities

The role of tutors in peer led teaching

Jolan T. Nisbet, Mark D. Haw and Ashleigh J. Fletcher, "The role of tutors in peer led teaching," *Education for chemical engineers*, **2014**, 9(1), e15-e19.

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Abstract

Problem based learning can impact not only on students' academic performance but also their social interactions within their peer group, and many institutions have embedded such teaching within their core curriculum. This paper looks at the interactions within a first year undergraduate engineering cohort that uses peers to tutor small groups through problem based learning at a Scottish Higher Education Institution. Most significantly, this work focusses on the impact that these interactions have on the students engaged as tutors within the programme, bridging the gap left by previous studies and providing an insight into how tutors are affected by their experiences. It was found that the recruitment of tutors requires careful consideration of their social as well as academic qualities, and that they should receive training and guidance within their adopted roles that takes account of social factors, questioning the traditional practice of employing individuals purely on the basis that they have studied the class previously themselves. The dynamic of tutor position with regard to the presence of senior staff is also explored, and suggests mechanisms for further student development.

Introduction

The openness of problem based learning in tutorials is serving to shape students both socially and academically, as it provides a forum in which their contribution is not only valued, but essential to the overall process. According to Race the format of *'learning from other people is the most instinctive and natural of all the learning contexts that we experience'* [68]. Through the system of peer learning, educators are sending a powerful message to the learners, namely, that their input is valuable.

It is vital that these tutorials occur from the first year of study in order to assist students in the transition from school to university, which requires them to enter a new discursive community and adapt their expectations of thinking and learning [71]. Indeed, the process of peer tutoring appears a relatively new educational process in which knowledge is passed on from a peer or someone classified as within the same social standing, but may be likened to the monitorial system developed by Lancaster, and Bell, in the early 19^{th} Century [160]. There are a variety of ways in which the process of peer tutoring may occur, including the provision of help on a one to one basis, in a small group format or even on an informal basis away from the classroom. In this paper peer tutoring will be defined and focused as *advanced students helping others in a small group environment*.

Based on its positive impacts, peer tutoring is being employed more frequently in Higher Education as a teaching, learning, and even, at times, social support. There has been extensive research into the benefits of group work for students across the educational spectrum; however, more research is needed to examine how tutors are affected and shaped by the experience of tutoring a group. This paper will focus on the bridging role that tutors play. The research will build upon previous work, most notably from Colvin, contributing to filling the current gap in the literature by providing a narrative of the tutors' experiences whilst tutoring first year chemical engineering students at a British Institution [161]. This account will serve to illustrate the benefits to the student tutors, and challenge educators to ensure that all students are given the chance to adopt this role at some point during their academic development.

Methods

Research Methods

The study spanned a period of seven months and was undertaken in the Department of

Chemical and Process Engineering at the University of Strathclyde, Glasgow, where students are enrolled on either a 4 year BEng in Chemical Engineering, 5 year MEng in Chemical Engineering or 5 year MSci in Applied Chemistry and Chemical Engineering; all first year students take the same core classes irrespective of degree programme. Teaching and subsequent examination processes take place over two semesters, the first running from the end of September to mid-January, and the second from mid-January to the end of May, with exams at the end of each semester. Data were collected using two research methods: participant observation and focus groups; a qualitative approach fosters an understanding from the participants' perspective. The inclusion of problem based learning experiences, with tutor support, are key in ensuring that tutorials provide students with every opportunity to increase their academic performance. Participant observation focused upon tutor led tutorials of two separate compulsory first year classes: CP101 (Basic Principles of Chemical Engineering) and CP102 (Chemical Engineering: Fundamentals, Techniques and Tools). Tutors are used in each of these classes and candidates are selected from the current cohorts of Year 4 and Year 5 undergraduates, as well as selected postgraduate students. These tutors were carefully chosen by the lecturers based on their ability and willingness to act as tutors. The classes observed differed in the concepts covered, which resulted in a different atmosphere for each tutorial. In addition, at the start of the semester each lecturer divided the students into groups, which provided the students with an opportunity to interact with a higher number of individuals. The teaching requirements for CP101 included a tutorial in which students were split into groups of twelve. These groups continued throughout both ten week semester teaching periods. In the CP101 tutorial each group was assigned an individual tutor to their table; however, new tutors were assigned in the second semester in all cases expect two. This was a significant contrast as it allowed observations to be made of two groups in which the dynamic was continuous; whereas, the other eight groups experienced a shift. CP102 was observed only during the first semester. This class was split into groups of four or five students that attended tutorials every second week. The tutoring structure also differed as groups did not have an individual tutor assigned, rather two to three tutors who circulated around all of the groups. During both tutorials extensive field notes were taken that tended to note behavioural patterns of routine activities, rather than direct conversation, as the students and tutors were heavily engaged in the tutorial tasks.

Table 3: Distribution of invitations made to students and tutors over two academic semesters, and the completions/attendees received, for questionnaires and focus groups used to study the effect of peer led teaching on tutors engaged in the programme.

	Invited to a focus group	Number attended the focus group
Students (first semester)	120	108
Tutors (first semester)	15	13
Students (second semester)	120	114
Tutors (second semester)	10	9

As the research period developed it can be inferred that the researcher’s presence became more normalised for the students and tutors. This normalisation was a result of the researcher occupying a ‘middle ground’ between staff, tutors and students. As the interaction increased, particularly as a result of focus groups, the researcher became a type of confidant to each of these groups [162].

Focus groups were used as the second research tool. The first set of focus groups was held mid-way through the students’ first semester and continued over a two month period. Careful consideration was given when developing the focus group questions, in particular, ensuring that they were open ended and semi-structured. The first set of focus groups was voluntary and the second set was mandatory with students directly assigned to a focus group. One hundred and eight of the one hundred and twenty students attended which was a ninety per cent response rate. In addition to collecting students' opinions on issues related to the first year and their personal development, they were also asked about their experience with their tutors. The students also participated in focus groups in the second semester, which dealt with themes related to their first year experience and group work. The second round of focus groups brought a higher attendance rate, one hundred and fourteen of the one hundred and twenty students in attendance, which was a five per cent increase from the first semester. Tutors were also invited to attend their own focus group, where they were asked to reflect upon their experience as tutors, in terms of what their role meant to them as well as to the students. The focus groups for tutors were conducted at the end of each semester in order to collect their holistic experience. As Table 3 illustrates, almost all of the tutors attended a focus group.

Coding and Analysis

A significant amount of time was spent transcribing the focus groups and developing coding to assist in the analysis process. With the assistance of the software package NVivo (QSR International) the data were categorised into various categories and sub-categories using a line-by-line analysis. After completing the coding process, themes, and the links between these subjects, were identified. The results were continually compared and cross referenced to ensure their validity.

Ethical Considerations

Before the study began all students and tutors were given a description of the study and a Participant Information Sheet. They were then provided with an opportunity to have the researcher address any questions or potential concerns. During the coding and write-up of the information, all data were blind coded with generic labels of 'Tutor 1' or 'Tutor 2' in order to omit gender or any specific reference to an individual. In addition, all participants had the ability to remove themselves, and their data, from the study at any point.

Theory

How can this widely encompassing role of tutor be properly defined? A broad definition is an expert in the subject material, a resource guide and one who facilitates the process of learning in the group [163]. Process is stressed as an important component in tutoring, which, according to Donnelly and Fitzmaurice, *'requires many skills from the tutor, most of them in the field of social-pedagogy'* [163]. Certainly, this is quite a challenging role for a fellow student to play, which will be discussed in greater depth later in this paper. However, it must also be considered that it is not only the tutors that perform the role of tutoring as, in some cases, students will help or tutor other students through problems, albeit in a less formal process. One explanation for this development can be traced to the fact that problem based learning requires more students to play a greater role and take on more responsibility, thus an increase in peer tutoring is a natural consequence.

There are three positive theoretical linkages to tutoring. Firstly, prior research has indicated tutoring provides multiple benefits both to tutors and tutees including an increase in awareness and motivation [164-166]. In particular, Cohen, Kulik and Kulik argue that tutoring develops a more positive attitude towards the subject material for both parties involved [167]. It is the development of a positive attitude towards the subject matter which is seen as a catalyst for improved achievement of both the tutor and the student. Tutored students have been found to feel more assisted in transitioning to university [71]. Secondly, within this educational paradigm the traditional hierarchical relationship between the 'teacher' and 'learner' is reshaped as, without the emphasis on the inherent knowledge and power gaps, several students are able to interact with the material in nontraditional manners, which proves to be beneficial for many learners. Another significant element in this re-shaping is the power of peer influence; peers are often considered to be the most powerful influence in undergraduate education, notably more so than any advisor or instructor [168-170]. Finally in an age of increased fiscal accountability many lecturers have been stretched and strained. Tutors have been purported to bring economic benefits [161, 165, 171-173], including allowing the lecturer to be uninvolved or less involved in the tutorial and revision process. This is of particular importance as, in many cases, course enrolment numbers continue to climb, but new academic staff have not been hired to assist with the surplus of students. Indeed, a variety of factors are at play in explaining why tutorial led group work has become normalised and embedded within higher learning throughout the United Kingdom. The most notable drivers are the benefit to all involved parties, redefining the hierarchical relationship and economic benefits to institutions.

A contentious theoretical issue is how groups are actually selected before tutoring can begin. Mynard and Almarzouqi [174] argue that groups need to be carefully balanced, but this selection process was not used for two reasons. Firstly, it was not possible as all the students were new; therefore, it was impossible to balance them according to strengths and personality types. Instead, students were randomly placed into groups before the first session took place. And secondly the process of 'balancing' the groups was deemed undesirable, as engineers will be expected to work with a large range of diverse individuals, thus the random groups were anticipated to closely simulate real world interactions for the students.

The key aims of this work, therefore, were to evaluate the experience of tutors, including their methods of interaction, and the transitions of the tutees, with respect to the bridging afforded by peer tutoring; the effect of socialisation on both tutors and tutees; and consideration of the benefits to the tutors and tutees themselves from engaging in the process.

Results

Experience and methodology of tutor

One of the themes of the research was to ask the tutors how they would define their experience of tutoring. This question was intended to have the tutors self-reflect on their role. The answers varied; however, the majority indicated that their main responsibility was to, "*help out with any questions that they [students] may have*". The tutors were further prompted to explain the process of how this help was provided. This proved to be a difficult question for the majority, but those able to respond defined their role as, "*helping them with their ideas, not just giving them the solution*", which many confessed was not an easy feat to accomplish. This led to the question of how they prepared to be tutors:

> *Tutor 1: "Well we did the class in first year so I was just trying to remember what it was like when I took it and what the tutors were doing."*
>
> *Moderator: "Did anyone else go about it differently."*
>
> *Tutor 5: "There certainly isn't much training needed for basic principles, the solutions are given to you…so you are fine as long as you know what you are talking about."*

These comments emphasised that the trends in tutoring within this program tend to perpetuate themselves. There was no discussion into the methodology of tutoring that they had developed over the semester; rather, it was simply stressed that it was a repetition of previous experience. Access to the answers was of paramount importance to the tutors as many stressed that as long as they had this booklet that they would be 'fine'.

When asked about the most difficult element of the role, tutors reflected on the importance of methodology in chemical engineering and how tutorial students seemed unable or unwilling to grasp its importance:

Tutor 9: "The hardest part is when you are looking at their work and trying to figure out where they went wrong. They are always just asking for the answer but not about the method. Sometimes it is difficult because you are just confronted with too much information and I can't figure out where they went wrong."

Tutor 2:" I would agree with that. I think the struggle is within the methodology, they just want to get the final answer. I try to convey that the method is important. It has been a bit of a struggle, so far, but…"

Tutor 6: "Yeah, when the problem is quite complex it is quite hard to motivate them to actually keep going. Most of them are just like give me the answer…"

Tutors reflected upon the ways in which they interacted with students. In particular, they were asked how they coped with students who just wanted the answers and were not fully engaging with the material:

Tutor 1: "You kind of need to sit down and just coax it out of them. Put it to them in questions. Get them to try to answer the questions, rather than giving them, this is what you need to do…but even at that you need to nominate who you want to answer or what you want to be answered."

Other tutors mentioned the challenge of trying to pick up on which students were struggling with the tutorial problems:

Tutor 11: "I think it is hard for people in my group, they are equally as clever, just slower to catch on, so sometimes they are embarrassed to ask questions, they are quite embarrassed by the fact that they can't do it. It is a difficult situation for them *to ask questions, because they don't want to. They don't want to appear stupid, and they aren't stupid, it is just the way that some things are covered in the lecture, if they don't click on to it in the way that it has been taught. They can feel quite bad about that."*

Tutor 15: "With that you really have to identify the people that are struggling and you have to get involved."

Moderator: "And is that difficult? You have 12 students… I mean that is quite a few students to be evaluating who really understands? Who is engaged, who isn't?"

Tutor 12: "Yeah, that is the challenge, but it gets easier to spot as time goes on."

Socialisation of students and tutors

Colvin's research was confirmed through the focus groups. She argues that the, *'peer tutor - role could not be used as a resource until some sort of academic socialisation took place'* [161]. This was most obvious in the initial interactions between the students and tutors, as students were striving to better understand who their tutor was and the extent of their role. Students explained there was an initial struggle to understand the role of the tutors:

Student 1: "When I came in there was some group work and discussion happening around the table. I didn't even realise that he was my tutor until he stood up and started to take control. And then I was like, oh yeah, that must be the tutor."

Moderator: "Did you interact with your tutor that day?"

Student 1: "No. I didn't really know what I could ask them….or how. I felt a bit embarrassed, you know; when you start Uni you don't really know the rules."

Moderator: "And how long did it take for you to feel comfortable with your tutor?"

Student 1: "I am not really sure, a wee while I suppose. I noticed that other students *were asking questions…I just waited until I was stuck.”*

Moderator: “Did anyone else have a similar experience?”

Students: (variations of positive responses and nods).

After the process of socialisation many students had no qualms about addressing the tutors in a colloquial fashion and the majority of tutors understood this as a positive development, due to the fact that students were comfortable approaching them as peers and less of an authority figure. Some tutors struggled with this redefinition of power, while others embraced it:

Moderator: “How do you feel about the shift [from one of respect to a peer]?”

Tutor 1:” I think it is important for the relationship….we are not as clever in their eyes as academics.”

Moderator: “So they see you as more of a peer, even though you are almost done your PhD?”

Tutor 1: “Yeah, but they don’t u*nderstand that.”*

Although none of the tutors alluded to being concerned with the management of their image this was clear during the participant observation. Colvin’s research initially alerted the ethnographer to this behavioural pattern, which can be confirmed by the research. Many tutors went to great lengths in order to assert their image and show that they were in charge. This power dynamic greatly ranged from the way in which they approached students to their wardrobe choices. Image management increased when tutors were predominately male. This behaviour was also presented more clearly when the lecturer was not present, as perhaps the tutors sensed that this powerful position was unoccupied and it provided them with the opportunity to further assert a level of control or in some cases the image of control.

Benefits to Tutors

In terms of the benefits they perceived, many mentioned the financial return to their tutoring. When probed a bit further the majority responded that they felt this experience had a positive impact, which they concurred would be mostly in the area of CV development and during job interviews, although a few deemed the experience to be less meaningful:

Moderator: What have you personally gained from tutoring?

Tutor 1: "Yeah it could be very useful in industry because we have to explain something really simply."

Tutor 2: "My friend did an interview just last Thursday and he had to answer how to explain the most difficult part of your course to a 5 year old…. So it is a valuable skill."

Moderator: "Will you use this experience of tutoring in an interview?"

Tutors: Yeah (coupled with positive acknowledgements).

Moderator: "And would you say that it is more important or less important than any other experience?"

Tutor 3: "For me, the experience has been less important… I think it is good because you can talk to them on a more one to one basis, but I don't find it will help when going for jobs or transferable skills. I found it to be better when I demonstrated in the labs. It was more applied. And they will usually talk to you more. There is more of an overall purpose to what you are doing. Whereas during the tutorials, I think they just have the questions and if they can do them then…they don't really need *me."*

Discussion

The increase in use of peer tutors across higher educational institutions has changed the dynamics within traditional educational spheres. One of the potential issues that emerged from the experience of advanced students tutoring first year Chemical Engineering undergraduates at University of Strathclyde was that the tutoring style within this institution tends to perpetuate itself. This continuation of tutoring styles is not necessarily a problematic issue, as it is possible that future tutors benefit greatly from the evolution of past tutors. However, there was little awareness among the current tutors that their own style would very likely be repeated by the tutees who decide to move to the tutor's role in the future. This could be corrected by offering training advice or workshops to help tutors fully understand and develop their pedagogic role. Indeed, it cannot be automatically assumed that tutors will be, 'utilised' or become *'an asset to the classroom'* [161]. Thus in order for tutors to reach their full potential and offer students the best service possible training sessions should be arranged. It is possible that not all tutors will require the sessions, as mentioned above, some come armed with a natural disposition or prior experience to successfully approaching the students and educational methodology; however, it is not always the case.

The notion of socialisation is of particular importance as tutors gain confidence through the interaction with students, which is anticipated to have positive results in their transition from university to the workforce. This is due to the role forcing tutors to improve time management and communication skills. Interestingly, many of the tutors felt that their skills in these areas were above average; however, the role forced them to hone these skills even further. Another element of the socialisation process, that is anticipated to have educational benefits for the tutors themselves, is seeing and interacting with the educational paradigm from a different perspective. The role of tutoring has led many students to have a fuller understanding of the lecturer and pedagogical processes.

Payment is a significant factor and arguably some system of formal remuneration is needed. Many tutors mentioned pay at some point during the focus groups and it can be inferred from the discussion that it was significant in building their confidence, both academically and personally. It built their confidence in knowing that the role they personally played was worth a financial remuneration. However, payment is not the only method that can serve to instil this confidence, as some tutoring programs offer credit towards the tutors' degrees, which is also a beneficial form of compensation.

Conclusion

It is important to consider that each group will have a unique and diverse approach when interacting with their tutor, as the tutor has the ability to shift the group dynamic to a certain extent, but some groups may respond more positively. This research shows that there are benefits to tutors and tangible effects on tutees engaged in peer tutored teaching within Chemical Engineering at University of Strathclyde. It has also investigated the tutor as an individual occupying the realm between peer and lecturer, encompassing certain aspects of each role, but who are also distinctly diverse. Tutoring plays a significant role in self-development, but this role is also significant and influential for learners, in particular students within the first year of university. Selection of tutors should include consideration of students' existing abilities but not exclude those with less experience, allowing all students to gain skills from their involvement in peer tutoring schemes. Departments should provide training for tutors, focussed on modes of engagement and methods of evaluating and modifying their teaching style by assessing tutees' responses and in response to other informal feedback from their tutees. It is also advised that departments facilitate not only the academic preparedness of tutors but also the assimilation of tutors within their tutor groups, to ensure coherent socialisation. This is essential to group development, allowing maximum benefits to both tutors and tutees and contributing to the normalisation process that students encounter when entering university. The results suggest further study of such interactions over an extended period of time using a longitudinal study, which would also allow the impact of peer tutoring on students who go on to be tutors in their years to be evaluated.

Chapter 5: inclusivity in group based learning activities

Group work experiences of women students in a Scottish chemical engineering programme

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Abstract

Chemical Engineering, similar to other Engineering courses, has seen an undergraduate gender shift in recent years towards greater women student representation. This raises the issue of the inclusion, in terms of equality of participation and opportunities, of these women students in learning activities and also the role that they can play in encouraging inclusion and development of others, which can have implications, not only for their current studies, but their future careers. This paper provides both statistical evaluation of students' attainment from group working activities, and a narrative account of the students' experiences along with the resulting impact on their inclusion, engagement and group interactions. We highlight the changing role filled by women students and their awareness of these changes and impacts. Notably, the work identifies a change in attitude with regards to roles for women in facilitating group work with many women students purposefully avoiding the additional work-load that past studies have identified.

Introduction

Similar to other engineering courses, Chemical and Process Engineering at the University of Strathclyde has seen an environmental shift in recent years towards a balance in gender population. While a completely balanced population does not exist at present, there has been a significant move toward more equal balance from the heavily men-dominated composition at the start of the millennium. There is a growing interest in diversity, both as a result of the growing number of minority personnel (including women) within the workplace [175] and the move for organisations to utilise the varied skill sets and backgrounds offered by their workforce [19]. Researchers have previously found gender diversity to produce a variety of effects of on group performance, including reduced cognitive task performance as a result of gender heterogeniety [28, 29], improved same-gender support [20] and impaired men-women support [21]. Conversely other researchers have reported no such effects [22]. As a result of the gender shift in the Department, this paper aims to fill a gap in the literature, by providing an account of the experience of women students within group activities, in an environment that was previously almost exclusively men. These activities are designed to develop group working skills and to foster inclusion of all students, which is important for women engineers due to demands that industry has set for its graduate level employees [5].

The role of women in team activities has been evaluated as cooperative, as opposed to the competitive nature associated with men students: this has, in turn, suggested that women students are more suited to collaborative working than their male colleagues [23, 24]. Despite their natural cooperation in group situations, it has also been reported that women students often face negative attitudes from their men peers [25, 30], and may be allocated group roles, such as secretarial tasks, based on gender related assumptions. It is notable and encouraging, however, that University teaching staff offer fair treatment to all students regardless of gender [25] [30]. The assignment of office based tasks may result from women students' inherent feelings towards contributing to the nurturing and people oriented areas of group dynamics [25]. It has also been postulated that such submissive behaviour may be related to the established but, more importantly, latent male dominance evoked by the cultural system of reproduction [176] or instilled definition of role via gender associated parental bonding [177]. Studies have suggested a move towards androgynous group working, allowing some socialised reversal of established roles, whereby men students may, for example, demonstrate a more nurturing character [178]; supported to some degree by a proposal for the wider acceptance of men to adopt more woman-like characteristics, again to develop their nurturing side [177]. One criticism of such changes in stereotypical behaviour is that ‘female’ characteristics may cause, as well as resolve, conflict in a team, by making individuals less assertive, easily dominated by 'male' colleagues or against female authority as a result of interpersonal conflict with women leaders [25].

A question that has been extensively investigated in the literature is the issue of proportional representation in group activities: while some have argued that increased gender representation should not only increase interactions between men and women [179], but also reduce stereotypical role assignment [180], and the overlap of sexual and workplace roles [181], hence removing barriers to inclusion [182], others have argued that increasing the minority threatens status of the majority [183]. In addition, there are conflicting reports of negative [109, 184] and positive [21, 185] outcomes for numerical minorities within group work, and gender-heterogeneous groups have been shown to perform both better [26, 27] and worse [28, 29] than gender-homogenous groups, suggesting that the issue is heavily subjective. Hence, the study undertaken here does not seek to balance gender within groupings, which would not be possible for all groups due to the under-representation of women students in the total cohort. Rather, the Department adopts a random allocation of students to groups, to more accurately simulate the potential working environments faced by students whilst also offering insight into the effects of women representation on academic attainment.

It is important, in light of the collaborative working environment expected, not only in chemical engineering, but also the wider industrial sector, that students are able to integrate into teams and work collaboratively with colleagues, as and when required. Hence, the principal aim, over all degree streams and years of study, is to foster inclusion of all students to achieve their maximum potential, which can be an issue for the integration of minority groups, such as women students. It is worth considering inclusion within education as a broad and complex issue, impacting more than a single group of learners, providing *'equal opportunities for all pupils, whatever their age, gender, ethnicity, attainment and background'* [31].

Previous studies into the development of science and engineering first year women undergraduates have focussed on the social aspects of their inclusion and experience, including socialisation practices based on gender [186-188], the impact of negative interactions with peers and University staff [189-191], and dissuasion of continuation by stereotyping [192, 193]. Chemical engineering teaching often uses group work to simulate the real-life working environment that students will encounter upon graduation, and previous research indicates that such practices can enhance student learning [194, 195] by providing students with exposure to the same methods that they will employ in the workplace [196, 197]. However, studies on team diversity have generally focussed on functional and educational diversity [198-201] rather than specifically on gender. Knowing that an isolated individual's behaviour is very different to their behaviour in a group situation [202], and that women students, especially those from minority backgrounds, have been previously cited as preferring to work in teams [203], the programme studied at Strathclyde promotes group work and integration as a means to enhance both learning and employability.

This paper aims to build on a solid foundation of earlier research, most notably the contributions of Walker, who argued that, ‘women’s and men’s experiences are bound into the construction of their engineering identities through relations with others and under particular social and individual conditions of (gendered) possibility’ [204]. Students continue to be bound in the construction of these identities, but the social and individual conditions have changed. This paper explores the impact of group activities on student attainment and reports students’ experiences (both men and women) of diverse group working. It highlights a shift in the role many women engineering students occupy within this educational domain.

Research methods

Table 4: Total students enrolled on MEng/BEng degrees and the number of women students with calculated percentage.

Year of entry to degree programme	MEng and BEng (total)	MEng and BEng (No. women)	MEng and BEng (% women)
2015-2016	113	38	34
2014-2015	105	31	30
2013-2014	108	27	25
2012-2013[1]	88	19	22
2011-2012	85	23	27
2010-2011	83	15	18
2009-2010	106	28	26
2008-2009	106	17	16
2007-2008	88	11	13
2006-2007	88	12	14
2005-2006	67	14	21
2004-2005	54	11	20
2003-2004	64	11	17

Ethical considerations

Before the study began all students were given a description of the study and a Participant Information Sheet. Students were provided with a consent form and the opportunity to address any questions about the study. Following completion of the consent form, a questionnaire was used to gather basic socio-demographic information. Students had the

[1] Cohort of study

ability to remove themselves and their data from the study at any point. In the discursive sections below, pseudonyms have been used.

Composition of the study

The student population sampled was composed of 120 first year students aged 16 to 18 years old and enrolled on either a 4 year BEng in Chemical Engineering, 5 year MEng in Chemical Engineering, or 5 year MSci in Applied Chemistry and Chemical Engineering. These students all entered their degree programmes at the University of Strathclyde in the autumn of 2012, and the population of 120 represents the full cohort for intake to the three degree streams for the academic session 2012 – 2013

Gender balance

Table 4 illustrates admissions trends to the chemical engineering BEng/MEng programmes at the University of Strathclyde for the period 2003-2015. As these statistics illustrate there has been an increase in the number and ratio of women students. Representation of women in the cohort was 21.6%, which is in line with previously reported demographics [30], and a slight increase on the historical average up to that time (19.4%).

Cultural/social

As mentioned above, on the first day of lectures students were asked to complete a questionnaire, which aimed to capture various pieces of socio-demographic information. One of the questions asked the students if they have ever been involved in any form of extracurricular activities, without placing significance on the type of activity. Out of the 120 students surveyed only 12 students had never taken part in any activity additional to their studies. The remaining 90% responded that they were involved in an extracurricular activity, with the vast majority of respondents listing multiple activities, many of them with differing natures, such as a sport coupled with playing an instrument, and the majority group based activities. This reveals that most students within the study took advantage of opportunities to develop themselves beyond or outside of academia, and such prior experience is not atypical of applicants to the Chemical Engineering courses at Strathclyde. A variety of implications that can be drawn from this, however, in terms of inclusion, it illustrates that the majority of students have been afforded the opportunity to engage with a social group outside of their family unit. Arguably, they have been exposed to a variety of situations that, tethered together, have developed an element of social capital. Indeed, this exposure to various forms of socio-cultural integration can also be linked to finance, as these students had the financial means to participate.

Economics

The effects of economic factors were somewhat limited in this study as the students taking part attend a Scottish University and the vast majority (> 98%) meet the Government's requirements to guarantee a free five years' of education, with fees paid directly by the Student Awards Agency For Scotland. However, this is not to devalue the importance of economic drivers as it is appreciated that these factors had a great influence on how the places were filled. As Connell comments, '*Education is not…a mirror of social or cultural inequalities. That is all too still an image. Education systems are busy institutions. They are vibrantly involved in the production of social hierarchies. They select and exclude their own clients; they expand credentialed labour markets; they produce and disseminate particular kinds of knowledge to particular kinds of users'* [205]. Hence students participating in this study are, by their nature, participating at University, having successfully gained a place of study, hence, their economic backgrounds were not examined in detail, although the authors do acknowledge the demands of external commitments, such as part-time work, and that financial matters can deduct from a student's time. However, all students are reminded during their time at University of the need for a work-life balance and the maximum hours that should be undertaken in external activities, whilst there is also significant student support for those suffering economic hardship so as to reduce the burden on student time.

Formation of groups

In order to understand student interaction within groups, students from two classes were (1) assessed in terms of attainment and (2) asked to participate in focus groups to discuss their experiences from their group based activities and pre-University activities and learning. Students recounted experiences related to their weekly tutorial/workshop sessions (over ten weeks for each class), and also within their Chemical Engineering laboratory sessions that took place in the first semester. The tutorial/workshop sessions were guided by fourth/fifth year undergraduate student tutors, supported by lecturers, who were also present to help with questions. It should be appreciated that the main interaction in these sessions was peer-to-peer and student to student tutor. The tutorials provided a time for small groups to work through various practical problems that, in many cases, forced students to use the knowledge from lectures, and in other cases to expand their reasoning skills beyond the course material. Students also undertook a group-based project in semester two that required little formal contact with teaching staff but, nevertheless, provides an additional comparison on the basis of group composition and attainment.

The first year students in Chemical Engineering, and Applied Chemistry and Chemical Engineering discussed their experiences from their core classes: ‘Basic Principles of Chemical Engineering’ and ‘Chemical Engineering: Fundamentals, Techniques and Tools’. The groupings for the tutorials were different for each module, however, it should be noted that in all instances the Department strived to ensure integration of students on the basis of degree stream and no other factors; the Department teaches two pure chemical engineering degree courses, but also co-teaches on the MSci in Applied Chemistry and Chemical Engineering, which has a much smaller intake (~25 versus ~100 for the chemical engineering degrees), hence, it is seen as an important factor to encourage integration of the two streams.

Groups consisted of exactly twelve students in ten groups for tutorial sessions in 'Basic Principles of Chemical Engineering', where gender composition was randomised, simulating the unknown group composition found in employment, as discussed above. Despite the random allocation, it is notable that all groups contained between two and four women students. The 'Basic Principles of Chemical Engineering' class also required students to work within a group environment in their 'Renewable Energies' laboratory project, this time in groups of five (thereby giving 24 groups), of which eight were composed purely of men students while the others contained between one and three women students. Although this did create six groups with only one woman student, attempts to prevent minority groups sets a false perception of future working environments, which the Department feels should, in itself, be avoided. Workshop teams in 'Chemical Engineering: Fundamentals, Techniques and Tools', analogous to the tutorial groups of the Basic Principles in Chemical Engineering' class, consisted of five students per team for 24 teams, the random allocation giving rise to seven teams with men students only, all other teams again containing between one and three women students. Finally, students undertook a paper-based 'Frontiers in Chemical Engineering' research project in 'Chemical Engineering: Fundamentals, Techniques and Tools', working in 30 groups of four, creating nine groups of only men students, all other groups containing between 1 and 3 women students. These multiple groupings created a platform for discussion across a range of situations and environments.

Each class employed student tutors of both genders, the principal lecturer for 'Basic Principles of Chemical Engineering' was a woman while a man principally lectured 'Chemical Engineering: Fundamentals, Techniques and Tools'.

Focus groups

Focus groups were selected, over interviews, as a method to allow students to voice their opinions as: 1) there was a specific theme emphasised, which could be explored more deeply; 2) there was more than one session, to probe inclusion in group dynamics; 3) emphasis was placed on *'the ways in which certain individuals discuss a certain issue as members of a group, rather than simply as individuals'* [206].

Table 5: Distribution of invitations and completions/attendees for questionnaires and focus groups used in this study.

	Questionnaires (given)	Questionnaires (completed)	Invited to a focus group	Number attended the focus group
Students (first semester)	120	120	120	108
Students (second semester)	-	-	120	114

Mid-way through both semesters, focus groups were held to provide students with opportunities to reflect and comment upon their trajectory of study and development. In the first semester, students were provided with the option to attend a focus group of their choice. In the second semester the focus group was integrated into the students' coursework and built into summative assessment, which required students to attend the discussion within their defined workshop groups. It is also notable that these project groups, used in the second semester, were encouraged to meet outside of the timetabled sessions to undertake their project work. While this differs to the tutorial activities in semester one, a parallel group work activity (‘Frontiers in Chemical Engineering’ project) did allow for such socialisation aspects in semester one providing a basis for comparison. There was a difference in the number of responses collected according to the grouping (Table 5).

The focus groups proved to be a beneficial method of enquiry, as students were able to deconstruct their experiences, while either challenging or agreeing with other students’ perceptions. This generated data that, in some cases, was unexpected about the first year experience and their perceived meaning of it. As students explained their experiences, this led many to qualify or, in certain cases, modify some of their classmates’ responses. This element of challenge was highly important as it arguably offers a more realistic and unbiased account. Overall it is also anticipated that this method has allowed students to reflect on their experiences and develop a deeper awareness of their role within group interactions.

Statistical evaluation of attainment

The marks awarded for group project activities (‘Renewable Energies’ and ‘Frontiers in Chemical Engineering’) and final examination marks for both modules were treated as discrete variables and were analysed by determining the arithmetic mean or average, $\bar{x}$, 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:

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

Focus group outcomes

Belonging is a basic human need [207, 208]; the desire to belong is encapsulated as a significant element of the first year university experience. For many students their relational paradigm may have shifted significantly due to relocating for their studies, moving away from family, friends, and/or traditional roles in established peer and family groups. As a result, an increased importance is placed upon new relationships that mainly evolve around aspects of the educational institution. This transitional phase is also true for students not required to relocate, as their paradigm is still likely to have undergone a transformation to accommodate the demands of their course. In either scenario, students are likely to experience some element of struggle as they assume their new role.

During the focus groups with the students, many students of both genders clearly expressed that the level of group interaction directly from the start of the semester was unexpected, but a pleasant surprise:

Focus group moderator: Have you been surprised at the amount of group work required?

Matthew: Yeah you think that I am at Uni and I am going to have to work by myself…

Rachel: Especially at the start!

Matthew: Yeah, it helped get you into it.

Other groups of students, especially women students, were equally positive about the introduction of group work early on:

Becky: It is a good way to meet people.

Maria: Yeah we have different people in every group.

Becky and Maria expressed sentiments similar to many of their fellow students in that the variety of group work forced social interaction that may not have occurred otherwise. This also relates to the re-definition of students' social dimensions and stresses the importance that they place upon meeting and interacting with others in the early stages of their degree.

A few of the students also reflected on how group work served to help with their personal development and overall sense of worth, specifically with regard to the work undertaken outside of timetabled classes.

> *Simon: You feel more responsible because you are not being told when or how often to meet your groups.*

Students also expressed that the novelty of the experience has not been without challenges.

> *Focus group moderator: How is your group work going so far?*
>
> *Raj: It has been rather good.*
>
> *Freddie: Yeah….challenging, but good.*
>
> *Focus group moderator: And what has been challenging?*
>
> *Freddie: I guess thinking and behaving in different ways than in school.*
>
> *All: Yeah (nods of agreement)*

Interestingly, even though the emphasis on group work in the syllabus may be rooted in the need for students to develop transferable skills, such as responsibility, time management and communications, for their future professional careers, the work also serves to develop many important elements of each student's sense of belonging and identity. This sense of identity within a group is distinct as it can break down barriers; as Forsyth states '*[g]roups* *blur the boundary between self and others, for members retain their personal qualities, their motives, emotions and outlooks, but add to them a sense of self that incorporates their collective rather than their individual characteristics'* [209].

Despite the positive reactions from students, some groups' work continued to be more productive than others' and, similarly, certain groups claimed that the experience was more rewarding than others. Common issues for differences in group integration and progression are discussed below.

Disengagement

Engagement in the chemical engineering degrees occurs in two ways: (1) as an individual with the course itself and (2) in myriad group activities with the assembled team. Defined as the 'process by which individuals in an interaction start, maintain and end their perceived connection to one another' [210], engagement requires interaction from all team members for the second case considered here, hence, disengagement by even one group member can affect the whole group.

Disengagement can manifest in a range of forms, e.g. individual disengagement, the domination of a group by one or more members, or complete group breakdown as in a collection of individuals who do not integrate or collaborate as team workers. Disengagement from groups by members presents a major challenge and an on-going obstacle to groups reaching their full potential. During the study, two principal explanations for disengagement from group work manifested in the majority of cases. Firstly, the amount of previous experience that students had working with others was evident. The focus groups served as an outlet to confirm these observations. This disengagement is not deemed as a severe concern as it is a skill that is more innate for some and, ultimately, can be developed by anyone. Students who experienced previous group work through school, sports, work or clubs generally took more naturally to the task; although it is important to emphasise that simply having a job, playing a sport or being a member of a club did not serve to automatically enhance one's ability to function in a group.

Secondly, disengagement may also be related to the fact that some students struggled with the concept of the ownership for learning through a group structure, which includes the domination of the group to the potential exclusion of others, thereby enforcing disengagement.

> *Phillip: I know that I am a bit of a control freak, but I need to be. (Laughter) I just don't trust the other members of my group to upload the work on time. I don't like to be this way, but I feel I must be this way…*

A related theme of interest that appeared from the focus groups was how the structure of the work given to the students could either foster or diminish the incentive to work as a group. For example, if the work could be easily sub-divided into equal or almost equal parts then students admitted to splitting the work and working independently until it was necessary to submit the work as a unit, circumventing the group process and the potential learning and skills development opportunities that it affords.

> *Lucca: I don't really see what we did as group work. Is that bad to say…? Each person took their part then when that was complete we spent a little bit of time putting all of our individual parts together. I still don't think that it read as one report….*

There have been three previous conclusions offered from research into disengagement, however we found these to be unfounded in our study. Firstly, according to Healey, some students find the 'active' role to be quite difficult to fulfil and preferred to be passive learners [211]. It is possible that some first year students might wish that they could go back to their 'passive' selves, as at school, and not be responsible for their own learning. However, none of the students in the focus groups verbalised any evidence of this. Secondly, diversity within group work may also be another factor in disengagement; although, as in the case above, there is no direct evidence from our study to link to previous studies that confirm this. As Harrison *et al.* argue, there are two types of diversity, 'surface level diversity', which can include overt factors such as a person's age, gender, and ethnicity, and 'deep-level diversity', which refers to differences in values, beliefs or attitudes [212]. During the focus groups, students made no reference to gender or ethnicity. Age was referenced, although not in a negative manner: while it showed that students were aware of the difference, they did not find that it deterred from group work in any way. Finally, the inherent difference in status may *'impede communication between high status and low status members'* [212]. It is quite significant that this theme did not emerge. In fact from the study there is evidence that students felt equality among their peers.

> *Claire: I enjoy all the teamwork, really because everyone is in the same kind of position, like you don't really know many people, if anyone, at University, so working in a team helps that. It also shows that everyone is interested.*

> *Paul: Everyone is putting in the same effort as everyone else, because it's not like schoolwork where somebody gets it and somebody doesn't.*

The evidence from the focus groups suggests that the incoming first year students were at the top of their year at school; however, after they entered University they felt no real advantage over other students, which is reflected in the statements expressed by the students above. The equality, perceived by students, at least before the first university marks were assigned, was something of a struggle for those who linked their identity to their performance in school. Thus it was quite difficult as they jockeyed for position among their new peers.

Jackie: Yeah, the days of being the best in each area are over. It is kinda strange to consider being weak…or less knowledgeable in an area….

Andrew: …the days of being top student are over! (Laughter and the consensus of other students)

Gender differences

Peer interaction and socialisation are fundamental elements of any educational setting. Much of the previous research in this area has been dedicated to studying the formation of masculine identities and the pressure to adapt to specific gendered norms [213-215]. According to Swain, *'the boys' position in the peer group is determined by an array of social, cultural, physical, intellectual and economic resources that they are able to draw on'* [216].

The introduction of a higher number of women into this environment has consequences for all participants. This was expressed during the focus groups by a number of men students as they vocalised surprise at the number of women in the program. Some of the men students expressed that there was equality within the groups with no gendered differences clearly apparent. Others expressed that there were differences, but indicated that the differences were positive.

Jacob: I am really happy to have girls in my group. They are much better than me at organising and keeping the group on task.

During many of the group discussions the theme of leadership within the group was addressed.

Focus Group Moderator: Does group work improve if you have males and females working together?

8 of 10 students: Yes

Focus Group Moderator: And why?

Hugh: I guess you can chat more

(Laughter)

Focus Group Moderator: And who would you say is usually the leader, a female or a male?

Paul: A female

Lily: Yeah

Chen: Always a female

Robbie: I don't have any females in one of my groups

Focus Group Moderator: So, is there a leader to keep you on task?

Robbie: No

Focus Group Moderator: Do you stay on task?

Robbie: No

In another focus group similar sentiments arose.

Focus Group Moderator: Does a mix of guys and girls work well?

Pete: All my groups are all male, apart from my elective

Sam: Mine is all male, except for one group there is a girl and she is very good at keeping us on task

Barry: Yeah, I would say the same thing

Thomas: Yeah me too

Sam: It is good to have somebody like that

Igor: All my groups have girls in them and it works well

Pete: Yeah in my elective I am in a group with four girls and it seems like I do less work

It is notable that this final statement (from Pete) takes a bit of a negative turn from the 'positive difference' outlined above, this was repeated in other groups.

Henry: Having the girls in the group is great...

Focus group moderator: And why is that?

Henry: Well I have less work to do. I can turn on the charm and the girls don't mind doing a bit extra. They want it done a really certain way....

Across all of the focus groups there were women who voiced concern with the problem of students not engaging within group work.

Focus group moderator: Would you be more concerned with people not engaging?

Multiple students: Yeah

Holly: Quite a lot of people in my renewable energies group were slow to start and engage, but me and another girl were like 'we need to start!'

This final statement is quite revealing as in-class observations by staff confirm that, in many cases, women students were responsible for encouraging the group to engage as a unit.

In the second semester, students attended the focus groups within their project group. This yielded differing results to the first wave of focus groups. In total the students were split into 30 groups and only one of these groups mentioned that there was a difference in gendered inclusion within the group dynamic. From this we can infer that there has been a shift from first semester to second: women were less willing to take on more of the work.

Jill: I told the rest of them no, that we could all plan the meetings

Focus group moderator: And was that difficult for you?

Jill: Well kind of, but I had enough after the first term [semester]

Many women did not mention any type of struggle in ensuring that the work was split equally. Instead groups spoke of 'democratic processes' and everyone rotating through the various roles. Both men and women students commented on this being the best way forward with their collaborative work. Such views were more prevalent in the second semester and this suggests some development of the understanding of group processes and dynamics, as well as maturation within their study methods.

Attainment

Analysis of the academic performance of the four group working activities in the two classes observed showed that for 'Chemical Engineering: Fundamentals, Techniques and Tools' there was no statistical difference in student final examination performance with respect to workshop group allocation: final examination average 81(2) with averages for the workshop groups in the range 80 - 82 (n = 24). The group based 'Frontiers in Chemical Engineering' project saw a comparable trend of minimal variance between groups: averages were in the range 63 - 68 (n = 30), with a global average of 65(6), suggesting that the groups perform to a similar level irrespective of gender composition. In the class 'Basic Principles in Chemical Engineering', there was, again, no clear difference in student attainment as a result of group composition: exam average was 65(9) with values in the range 60 - 67 (n = 12). These results cover a range of working compositions and group sizes (four to twelve team members), suggesting that group size and number of women participants had little impact on overall group member performance in these specific instances.

It is notable, however, that, by contrast to the results discussed above, the 'Renewable Energies' group project for 'Basic Principles in Chemical Engineering' saw an increase in student attainment with representation of women within the group, while the global average was 67(8) in the range 65 - 73 (n = 24), those groups with no women members saw the lowest final grades with an average of 65(6), while those with three women students, thereby creating a minority of men students, achieved an average of 73(2).

This raises the question of: what are the differences about the group based project of 'Basic Principles in Chemical Engineering' compared to the other forms of group working in the first year of Chemical Engineering? Firstly, one stark difference is that this is the only laboratory based component of those assessed, with all others based on purely theoretical and paper-based research methods. The difference in performance agrees well with the trend observed for gender averaged marks achieved in the first year chemistry practical laboratory class, which is the only other hands-on activity undertaken by the cohort (average for men students 80(6) (n = 91); average for women students 86(5) (n = 86(5)). Secondly, the assessment of the 'Renewable Energies' project happens at the end of the first semester, while all other assessments are undertaken in semester two. As indicated by the previous discussion, and supported by the open literature [25], there is a tendency for women students to rebel against their assumed roles but only once they have identified that 'pigeon-holing' has occurred. It could, therefore, be that women students' awareness of being assigned specific tasks happens during semester one, during which time they have assumed greater responsibility for these tasks, such as the report presentation and group organisation required in the 'Renewable Energies' project, correlated to an increase in marks for women-dominated groups. By semester two, women want to be treated equally and no longer adopt these roles so easily, as discussed above, hence there is greater homogenisation of attainment, as evinced by the grades achieved in the 'Frontiers in Chemical Engineering' project. It is interesting that this dismissal of assumed roles appears, in turn, to negatively impact on the attainment of the women students themselves, leading to homogenisation of attainment as well as group contribution.

Conclusion

This paper presents a short-term longitudinal study across two semesters and the results, in the first semester, point to the same direction as Harrison *et al.* who argued that diverse groups were more effective in identifying problems and generating solutions than their homogenous counterparts [212]. Indeed, diversity at all levels is needed within students' group work as it is increasingly reflective of the professional environment that students will find themselves in after graduation. While it is clear that women students play an early vital role in facilitating group work, the progression of students' mentality, even within the year-long timeframe of this study, is evident: during semester two, long-embedded roles adopted by women students are rescinded as many women students purposefully avoid taking on the extra work-load that past studies have identified. This is a positive step in the transition towards gender equality, as it is only when students conform to these expectations that inequality is perpetuated [217]. However, this response may also be detrimental to women students' attainment. The progressive nature of student perceptions and action would benefit from a longer term longitudinal study, especially in view of the continually increasing proportion of women students within the cohort.

Chapter 6: upskilling chemical engineering graduates

Using the Perceptions of Chemical Engineering Students and Graduates to Develop Employability Skills

Ashleigh J. Fletcher, Abdul W. Sharif and Mark D. Haw, "Using the perceptions of chemical engineering students and graduates to develop employability skills," *Education for Chemical Engineers*, **2017**, 18, 11-25.

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Abstract

Recent years have seen increased global industry sector demand for chemical engineers, subsequent growth of Chemical Engineering (CE) degrees, producing additional qualified graduates. The Confederation of Business Industry have regularly indicated that employers are dissatisfied with skills sets offered by graduates; a 2004 World Chemical Engineering Council (WCEC) survey of experienced and newly employed chemical engineers' perceptions of their own work skills indicated highest importance for general transferrable skills, with technical knowledge ranked considerably lower. A decade later, we investigate whether chemical engineers, both employed and in education, have similar skills perceptions, by surveying CE undergraduates in penultimate and final years of study, and CE alumni employed in CE roles; all from the University of Strathclyde. Again, transferrable skills were perceived as most important to respondents; as undergraduates gained industrial experience, a shift in perceived relative importance of technical knowledge occurred, again similar to the WCEC survey, otherwise, alumni and students had similar opinions regarding perceived degree of learning of various skills. Alumni were more critical of the quality of education with regards to management and transferrable skills, while female participants perceived business skills as undertaught, feeling considerably overexposed to the potential of research compared to male colleagues. Focus groups showed that male undergraduates valued '*technical knowledge*' and '*communicating*

professionally'; by contrast, female graduates highlighted '*initiative*' and '*business skills*'. Consequently, training sessions were developed, focussing on transferable skills identified as important by all groups, to be delivered during academic year inductions, aligning skills to year curricula.

Introduction

Chemical Engineering (CE) is a versatile discipline, both in education and employment. The taught curriculum is varied, offering problem solving, design, control, management, materials science, safety, economics and environmental impact, in tandem with CE fundamentals, which all prepare students for a range of roles within industry and research. This accrual of knowledge, in itself, is only part of the educational process, which ideally also sees students develop key transferable skills required within chemical and engineering industries. Often, such 'soft' skills are latent within the curriculum with the consequence that participants may not immediately perceive the degree of learning or of opportunity to learn. Hence, students are encouraged to engage with professional development activities to reflect on their own progress. However, it is also essential for staff, as educators, to similarly understand when and how such transferable skills are being developed.

In the UK alone, there has been an overwhelming increase in interest in CE degrees. Successively from 2000 to 2014, CE degree intake has seen growth. In 2013, there was a record 2,790 enrolments on CE courses across the UK compared to 1,820 enrolments in 2010 [13]. With this growth in student recruitment, it is vital that the CE student cohort is provided with a high quality education, fit for industrial standards. As with many other disciplines, a professional body will often accredit university courses for quality assurance but such accreditation alone may not perfectly capture the success or otherwise of 'latent' skills development. This paper focusses on understanding the perceived skills development and shortages within the recent CE degree programme delivery at the University of

Strathclyde (UoS). By canvassing recent undergraduates and Strathclyde alumni, the aim is to understand those skills perceived to be under taught within the current programme and how these may be further developed within the current curriculum.

Background

Institute of Chemical Engineers (IChemE) Course accreditation

Table 6: Comparison of similar LOs found in accreditation documentation of various accrediting bodies [218-220]

IChemE Course Accreditation Guide	**ABET** Engineering Criteria 2000	**EA** Policy on Accreditation of Professional Engineering Programs
• *Knowledge and understanding*: essential facts, concept, theories and principles of chemical engineering and its underpinning mathematics and sciences. • *Intellectual abilities:* application of appropriate quantitative science and engineering tools to the analysis of problems. • *Practical skills*: acquired through laboratory, individual and group project work. • *General transferable skills*: communication, time management, team working, inter-personal skills, effective use of IT.	• Ability to apply knowledge of mathematics, science, and engineering • Ability to use the techniques, skills and modern engineering tools necessary for engineering practice. Ability to identify, formulate, and solve engineering problems • Ability to design and conduct experiments, as well as to analyze and interpret data • Ability to communicate effectively. Ability to function on multi-disciplinary teams. An understanding of professional and ethical responsibility.	• Ability to apply knowledge of basic science and engineering fundamentals • Ability to undertake problem identification, formulation and solution. • In-depth technical competence in at least one engineering discipline • Ability to communicate effectively; creativity and innovation; function effectively as individual, team leader and member in multi-disciplinary teams, understanding of professional and ethical responsibilities.

The global professional body of membership for chemical engineers is the Institution of Chemical Engineers (IChemE), who provide accreditation of university degree courses and company training schemes, and award qualifying members with chartered status (Figure 5) [218]. Other engineering accrediting bodies take a similar role to the IChemE such as the Accreditation Board for Engineering and Technology (ABET) and Engineers Australia (EA) for chemical engineering programs within their respective countries and internationally too. The IChemE aim to ensure that the CE workforce remains skilled and, as an accrediting body, bring their experience of best global practice when assessing institutions and awarding chartership to members [218]. Accreditation has the benefit of worldwide recognition for CE courses and provides a comprehensive benchmark with which CE departments and courses are evaluated. Accreditation also benefits students, with a structured route to chartered status once employed and satisfying the experiential requirements for chartership. Consequently, documentation is available from IChemE [218] that provides a thorough framework to which all participating institutions must adhere to if they wish to seek accreditation, wherein IChemE adopt an approach based on learning outcomes (LOs) as opposed to being content-driven, which has been the general paradigm shift across engineering education [221-223]. LOs focus on the student; highlighting the expected skill or capability, but not necessarily the method or content with which it must be achieved. As a result, this gives academia greater flexibility in teaching, however, it can be hard to explain the exact subset of skills developed in cohorts and assessing some outcomes can prove difficult. Furthermore without explicit knowledge of LOs, learners may not be aware of the aims of, or meet the requirements to achieve, these LOs [221].

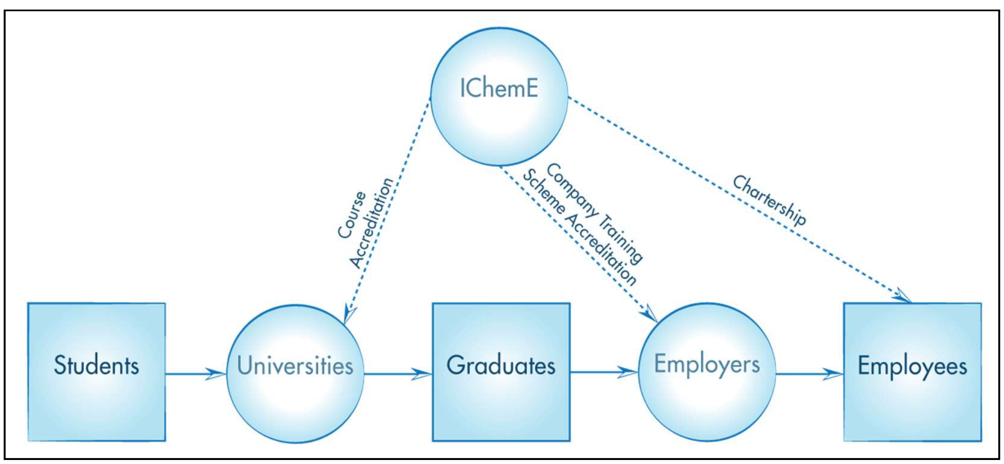

Figure 5: The route from CE student to employee and the various agencies involved.

Nevertheless, accrediting bodies such as the IChemE, ABET and EA, have adopted and outlined outcomes in their respective guidelines. Some of the similar outcomes found in available documentation [218-220] have been highlighted in Table 6.

University of Strathclyde Chemical Engineering Department

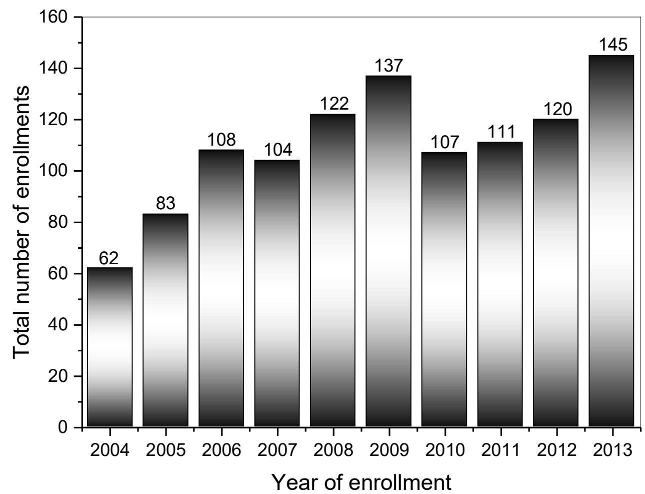

Figure 5: Enrolments to Year 1 degree programmes offered by the Department of Chemical and Process Engineering, University of Strathclyde, from 2004 to 2013

In line with the global trend, the University of Strathclyde (UoS) has seen significantly increased student enrolments in their undergraduate CE degrees, with a doubling of student intake over the past ten years (Figure 6). Strathclyde's CE degrees have long been accredited and the department has adopted a LO approach to teaching, with key LOs split into three broad areas of university education, technical knowledge and understanding, practical experience and transferable skills. As expected for an accredited programme there is coherency between IChemE's LOs and those set by UoS Chemical and process engineering (CPE) department. Technical knowledge and understanding are fundamental to the discipline of CE, summarised in the current UoS degree programme as '*a good* *understanding of chemical engineering principles*', '*an awareness of the responsibilities of professional engineers for safety and the environment*' and '*a good understanding of the technologies and methods which underpin the design, operation and management of processes which are safe and have minimum impact on the environment.* Practical experiences are provided by '*laboratory and practical work and a knowledge of best practice in the collection, analysis and presentation of experimental data*' and '*generic IT skills such as word processing, spread-sheeting and subject-specific IT skills such as computational, design and simulation packages*'. Transferable skills are those required in all professions and roles, such as '*written and oral communication, project work and team work*' and '*experience in a range of analytical and problem solving skills*'. The curriculum is structured so as to provide good skills development for future employment, in alignment with the policies of IChemE and, ideally, congruent with prospective employers' expectations

Employers' and Employees' perceptions

The Confederation of British Industry (CBI) conducts an annual education and skills survey. The 2011, 2012 and 2013 surveys collated the views of 566, 542 and 294 employers, respectively, consisting of either the managing director, chief executive, chairman or human resource director and representing combined workforces of ~2.2m, ~1.6m and ~1.24m employees, respectively [4-6]. Approximately 30% of respondents represent the engineering, manufacturing, energy and water sectors. 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; the awarded ranks of dissatisfaction amongst employers are shown in Table 7. 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, with varying employment spells, to investigate '*how does chemical engineering education meet the requirements of employment?*'[32], 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. Table 7 shows the average response of the various skills in order of perceived importance to work and their rank with respect to the perceived deficit in skill acquisition.

Table 7: Confederation British Industry (CBI) employability skills definitions and employer dissatisfaction percentage by year (data compiled from [4-6])

Employability skill	Definition	% Dissatisfied		
		2011	2012	2013
Business and customer awareness	Basic understanding of the key drivers for businesses success and the need to provide customer satisfaction	44	47	48
Self-management	Readiness to accept responsibility, flexibility, time management, readiness to improve own performance	25	31	32
Team working	Respecting others, co-operating, negotiating/persuading, contributing to discussions	20	25	19
Problem solving	Analysing facts and circumstances and applying creative thinking to develop appropriate solutions	19	23	27
Communication and literacy	Application of literacy, ability to produce clear written work and oral literacy, including listening and questioning	17	15	20
Application of numeracy	Manipulation of numbers, general mathematical awareness and its application in practical contexts	9	10	15
Application of IT	Basic IT skills including familiarity with word processing, spreadsheets, file management and use of internet search engines	5	6	3

One critique of using the average 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 average deviation rank assigned to '*apply knowledge and basic CE fundamentals*' is 25th out of 26, compared to the work 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 LO for students 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 average deviation), which indicates that educational institutions are not yet addressing the need to develop these skills in their graduates to an appropriate level.

More recently, studies have shown that the WCEC survey results can be confirmed at national levels. An Australian study, conducted by Male *et al.* [33], found that communication, teamwork, self-management and creativity/problem-solving competencies were amongst the most important competencies amongst practicing engineers, whereas "applying technical theory" was rated lowest. Similarly, Passow's longitudinal study of engineering graduates from an American Midwestern University [34] highlighted a comparable top tier of important competencies which were consistent across seven administrations of an annual survey.

Table 8: World Chemical Engineering Council generic skills results ranked in order of importance to work (data compiled from [32])

Rank wrt work	Generic skill/ability	Average response		Deviation ($\overline{\Delta_s}$) $[(\overline{x_e}) - (\overline{x_w})]$	Rank wrt deviation
		Work ($\overline{x_w}$)	Education ($\overline{x_e}$)		
1	Ability to work effectively as a member of a team	4.364	3.850	-0.514	13 (↓12)
2	Ability to analyse information	4.323	4.053	-0.270	20 (↓18)
3	Ability to communicate effectively	4.279	3.482	-0.797	5 (↓2)
4	Ability to gather information	4.232	3.966	-0.266	21 (↓17)
5	Self-learning ability	4.232	3.937	-0.295	19 (↓14)
6	Ability to solve problems	4.222	3.884	-0.338	18 (↓12)
7	Appreciation of an interdisciplinary approach	4.028	3.524	-0.504	14 (↓7)
8	Critical thinking	3.978	3.578	-0.400	16 (↓8)
9	Ability to identify and formulate problems	3.972	3.564	-0.408	15 (↓6)
10	Importance of a broad and general education	3.958	3.803	-0.155	24 (↓14)
11	Expectation of the need for life-long learning	3.950	3.433	-0.517	12 (↓1)
12	Understanding of ethical and professional responsibilities	3.924	3.208	-0.716	7 (↑5)
13	Ability to be a leader	3.834	3.155	-0.679	8 (↑5)
14	Ability to apply knowledge of basic science and chemical engineering fundamentals	3.754	4.063	+0.309	25 (↓11)
15	Management skills	3.696	2.726	-0.970	2 (↑13)
16	Ability to use a systematic approach to process and product design	3.614	3.367	-0.247	23 (↓7)
17	Competence in information technology	3.596	3.339	-0.257	22 (↓5)
18	Knowledge of methods for project management	3.365	2.401	-0.964	3 (↑15)
19	Understanding of cultural diversity	3.332	2.812	-0.520	11 (↑8)
20	Business orientated thinking/business approach	3.332	2.275	-1.057	1 (↑19)
21	Appreciation of the potential of research	3.242	3.576	+0.334	26 (↓5)
22	Understanding of principles of sustainable development	3.196	2.671	-0.525	10 (↑12)
23	Understanding of fundamental principles of financial analysis	3.141	2.604	-0.537	9 (↑14)
24	Knowledge of methods for total quality management	3.063	2.186	-0.877	4 (↑20)
25	Foreign languages	2.887	2.488	-0.399	17 (↑8)
26	Knowledge of marketing principles	2.730	1.998	-0.732	6 (↑20)

Grant and Dickson [224] have also reviewed the 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:

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

which align with the 6 skills identified as most important in employment by the WCEC [32], and in line with IChemE's LOs 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* [218]. Agreement also exists between the WCEC survey results [32] and the CBI reports [4-6], with skills perceived as under taught in universities by current employees similar to those towards which employers have expressed dissatisfaction, most notably business and management skills with significant differences in expected level and resultant deficiencies 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 transferable, and significant deficiencies exist for some skills, which are recognised by both employers and employees.

Framework and methodology

Study objectives

This study aims to assess the views of chemical engineers, who study or have studied at the University of Strathclyde, using an online questionnaire to gain insight into individuals' views on personal employability both pre-and post-graduation.

Methodology

Evaluation of skills and abilities by questionnaire

A questionnaire on personal employability was developed 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. The questionnaire was distributed online to increase accessibility for participants, providing a spreadsheet of data and responses on completion. To eliminate bias in the collected results data was obtained from all available demographics, including penultimate and final year students, recent graduates or alumni (i.e. within 2 years of graduation), and part-time distance learning students; this crucially provides a representation of the changing attitudes that experience brings to a chemical engineer's views about their work and education. The questionnaire requested:

- ***demographic information***: current educational/employment status, method of course delivery (FT/PT), gender, age, year of study (if applicable) and degree classification,
- ***career experience and/or interests***: type of experience (summer placement, current employment etc.), area of experience, area of interests and offer for graduate employment
- ***comparison of perceived skills in employment with quality of education and teaching methods***: utilising the generic skills/abilities identified by the WCEC (Table 8) [32], excepting '*knowledge of methods for total quality management*' and '*knowledge of marketing principles'*, which were deemed less relevant to chemical engineers.

For the skills comparison, participants rated each skill on a 5-point Likert scale, firstly with respect to how well their education enabled development of the skills and, secondly, with respect to how important the skills were in their current or future employment. It is important to note that all ratings are based on individual perceptions; in the case of those with no work experience, they reflected on what they expected work life would entail. Conversely, it was assumed that graduates had an accurate memory of their education and that the general syllabus was mostly unchanged. Participants were also asked to rate themselves or their perceptions of future requirements, in the 5 key areas identified by Grant and Dickson [224], on the same 5-point Likert scale. Finally, participants were asked to rate various modes of teaching, and to identify modules that were particularly beneficial in developing the skills mentioned in the questionnaire. An open response textbox allowed participants to comment on how prepared they were/are for employment and how their preparedness could have been/can be improved by the CE department.

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

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

Likert scale questions are a form of ordinal measurement, i.e. there is no assurance that a linear relationship exists between ‘Agree Strongly (5)’ to ‘Agree (4)’, hence, an average of 4.6 does not necessarily indicate that the result is closer to ‘Agree Strongly (5)’. The misuse of Likert scale averages have been reported in the literature [225], where it has instead been recommended to use the most frequent response i.e. the mode; however, using the average in this study is justified as it is only used as a means of comparison to similar data, not as a discrete result. This technique was also adopted in the WCEC analysis [32].

Average skills deviation, $\overline{\Delta_s}$, was calculated as the difference between $\overline{x_e}$, the average education response, and $\overline{x_w}$, the average work response:

$$\overline{\Delta_s} = \overline{x_e} - \overline{x_w}$$

Hence, a negative skills deviation indicates an under-taught skill, whereas a positive skill deviation suggests it is over-taught. This deviation can also be thought of as a quantitative representation of the perceived degree of learning.

Quantitative results and discussion

Demographic analysis

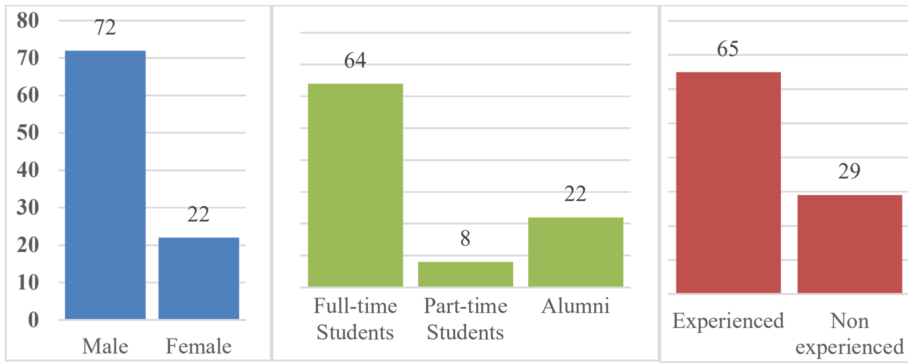

Figure 7: Demographic breakdown of participants canvassed for their perceptions of employability in chemical engineering sectors. Experience refers to either graduate chemical engineering employment or an internship during studies.

The demographic composition of the total of 94 participants is shown in Figure 7. There is a clear gender imbalance; however, the numbers are a fair representation of the general global situation for higher educational engineering courses [226]. The majority of respondents were full-time students. There was insufficient data to provide statistical evidence for the population of part-time students but the group was incorporated to provide breadth to the study [227] and include general comments made by this group. The majority of the participants had industrial experience, validating the data with regards to the aims of this study, and providing a comparison between the expectations of chemical engineers pre- and post-industrial experience, and within graduate employment. ‘Experienced’ participants comprised those in chemical engineering employment, as well as students who had undertaken internships or summer vacation placements in an *industrial* *setting*. Out of the 22 Alumni who responded, all were in employment bar one who had no experience. The participating students and alumni represented 79% and 12% of their respective target populations. The number of alumni who participated was the most significant limitation, however, the responses gathered were in agreement with other global and national studies discussed below [32-34]. The age distribution (Figure 8) was centred around 22 years of age, indicative of those approaching graduation and recent graduates; respondents above the age of 30 represented the majority of part-time students.

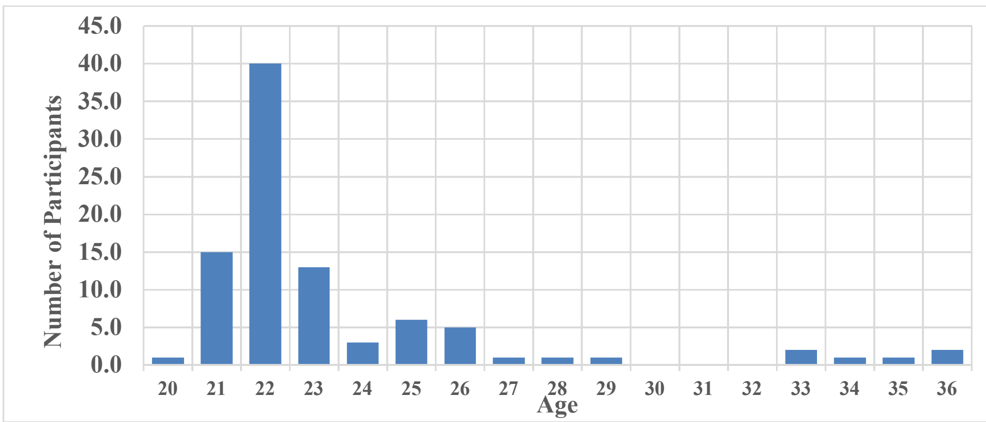

Figure 8: Age distribution of participants canvassed for their perceptions of employability in chemical engineering sectors.

The majority of the participants' experience lay in the oil and gas, chemical process, pharmaceutical and petrochemical sectors (Figure 9); therefore, the results from experienced participants are particularly relevant to these industrial fields.

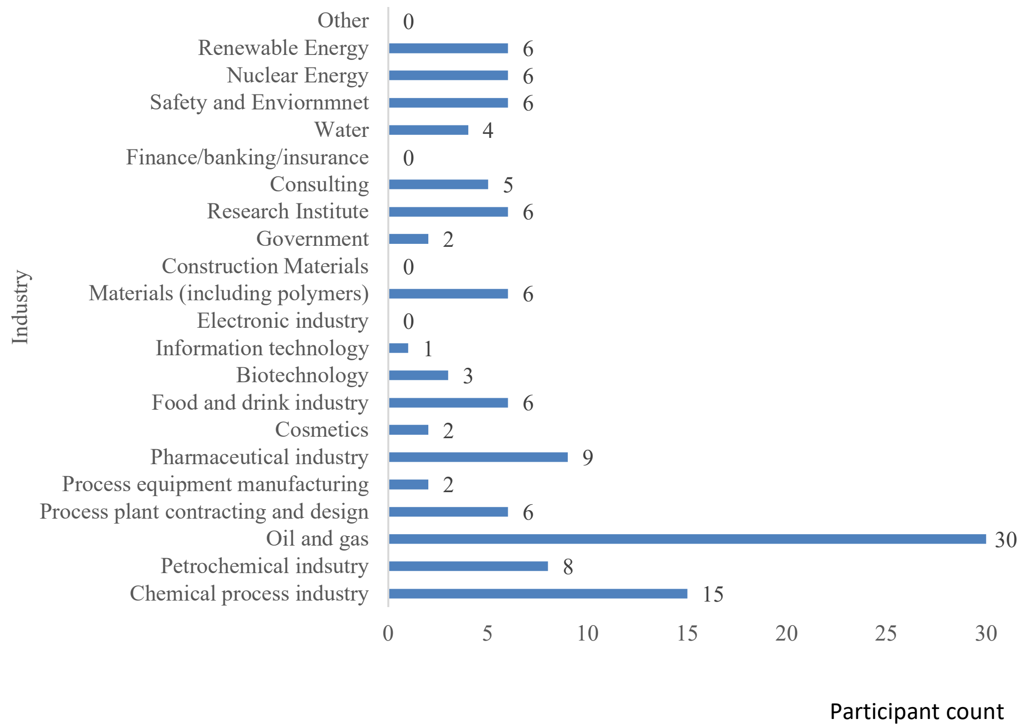

Figure 9: Experience in various Industries for participants canvassed for their perceptions of employability in chemical engineering sectors (includes multiple experiences for single participants).

Full-time students' skills analysis

The results obtained from the questionnaire showed full-time students rated an *appreciation of the potential of research* most highly in terms of perceived degree of learning, which was also the most recurring skill to be perceived as over-taught (i.e. the perceived ability level provided by education was greater than the perceived need in working practice), see Figure 10. This may possibly be an indication of over-exposure to the potential of research, as a result of the background of the teaching staff involved (many lecturers are also researchers), it is also possible that opportunities for students to experience research via summer vacation research placements and final-year research placements increases students' awareness of research. Contrastingly, part-time students were the only demographic to evaluate the skill as under-taught, which may be a consequence of the distance learning nature of these degrees where students, often in full-time employment, do not have the option to undertake research placements or be aware of lecturers' roles as researchers. Other skills considered well taught by full-time students included *gathering and analysing information*, *systematic approach to design* and *self-learning abilities*, agreeing with several identified skills from the previous review by Grant and Dickson [224]. The high evaluation rate of such skills may be explained by considering the demographic itself: full-time students are comprised of penultimate and final year students, at the time of delivery of the questionnaire, penultimate year students were progressing through the group design project and final year students were undertaking either research projects or industrial placements. Furthermore, many classes throughout the CE degree require independent research and learning on certain subjects, culminating in semester-long projects.

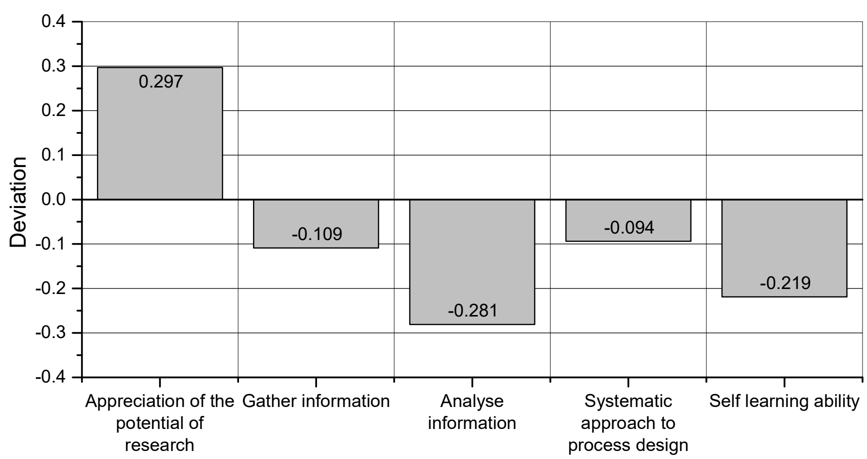

Figure 10: Full-time students' highest rated skills in terms of perceived degree of learning ($\overline{\boldsymbol{\Delta}_s}$).

The relatively poorest taught skill for full-times students was *foreign language knowledge*, as seen in Figure 11. As part of the degree programme, participants were offered an elective in language classes in the first year, although the results indicate that this is not considered adequate by the majority of students. The more experienced alumni, however, still rate the foreign languages as under-taught but evaluate it less critically than full-time students (see below). A third of the final year cohort participated in a university exchange program at the time of the survey, which may have influenced the strong importance of foreign language skills. Other perceived poorly taught skills include *interdisciplinary approach*, *understanding cultural diversity* and *ethical responsibilities*, even though the latter is taught together with sustainability and economics in the third year of the undergraduate course. This highlights the abstract and situational importance of ethical issues which can prove challenging to teach. Amongst all demographics, the most widespread under-taught skill is business-orientated thinking. Not only is this rated poorly amongst future and current employees but it is the area that employers identify as the most unsatisfactory in graduates [6].

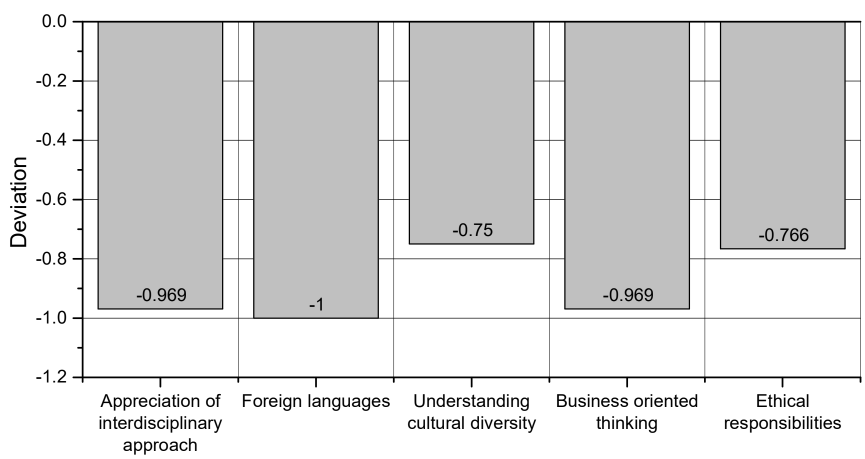

Figure 11: Full-time students' lowest rated skills in terms of perceived degree of learning ($\overline{\boldsymbol{\Delta}_s}$).

Part-time students' skills analysis

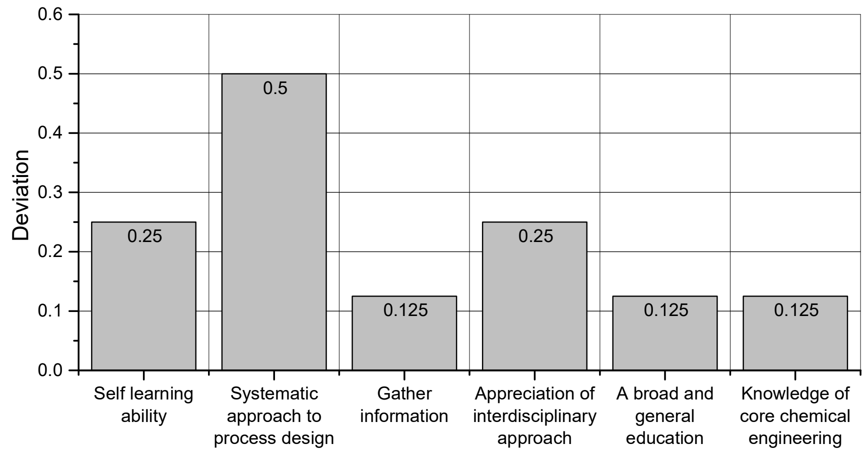

Figure 12: Part-time students' highest perceived chemical engineering skills deviation ($\overline{\boldsymbol{\Delta}_s}$).

The least statistically accurate demographic, part-time students, had the most contrasting view with their full-time counterparts and alumni, returning the most favourable views regarding the course, with 6 skills over-taught and 1 ideally taught (*project management methods*). Unsurprisingly, the over taught skills included *self-learning ability;* due to the nature of distance learning, part-time students are required to take a more proactive approach to their learning. Other well-taught skills were similar to the alumni: *technical knowledge* and *research appreciation* were over-taught, the former being the focus of distance learning (Figure 8).

The poorest taught subjects according to part-time students (Figure 13) included *working effectively as a team member*, *being a leader* and *communicating effectively*; these are the most difficult skills to develop via distance learning as participants are often in different time-zones, there are limited face-to-face meetings and most conversations are conducted using Virtual Learning Environment (VLE) forums. Furthermore, this cohort represents the distance-learning community, composed of a range of international and home students; communication can be difficult with students from different cultures and countries, or individuals whose first language may not be English.

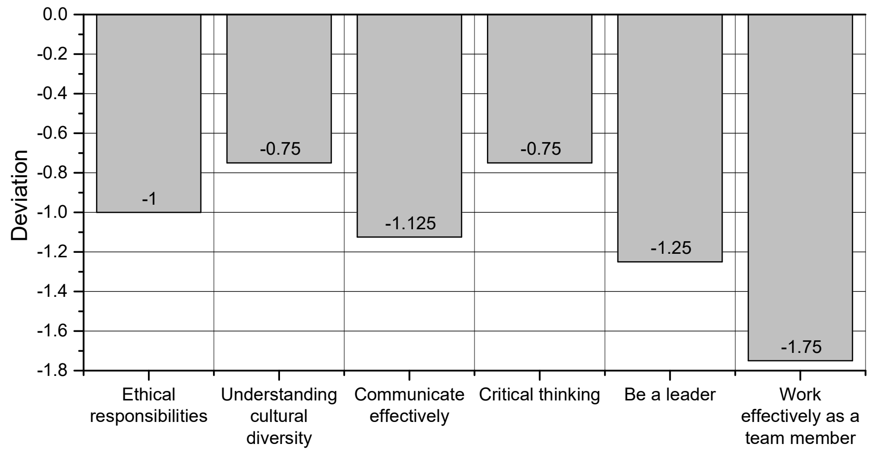

Figure 13: Part-time students' lowest perceived chemical engineering skills deviation ($\overline{\boldsymbol{\Delta}_s}$).

Alumni's skills analysis

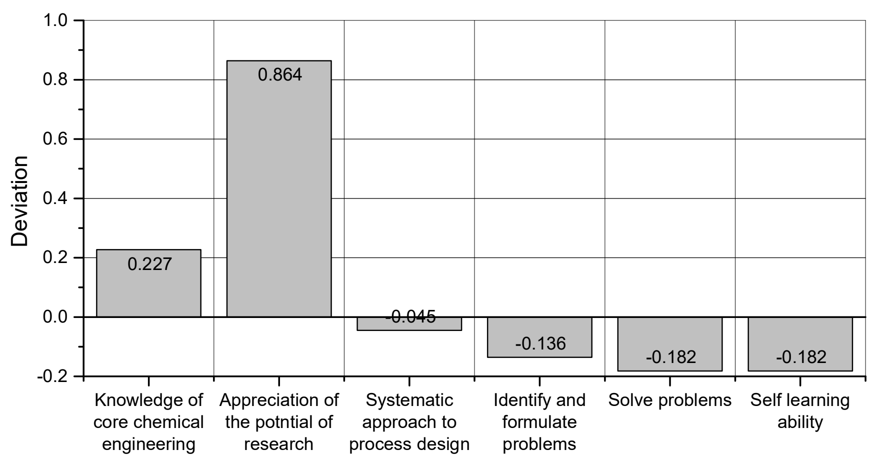

Figure 14: Alumni highest rated skills in terms of perceived degree of learning ($\overline{\boldsymbol{\Delta}_s}$).

Alumni indicated that *knowledge of core CE* is over-taught, an expected result as the majority of the degree focusses on fundamentals of CE such as basic principles, thermodynamics, fluid flow, heat transfer, reactors, process analysis and separations. Interestingly, full-time students rated this ability poorly with a deviation of -0.469, indicating a perception of insufficient CE knowledge expected for professional work. There is a clear and distinct change in attitude as graduates gain more experience indicating that the CE knowledge is more than sufficient for graduates to develop in their future roles. Similarly, *systematic approach to process design* is near the perceived ideal for employment, along with *self-learning abilities*. *Identification, formulation and solving of problems* are rated highly as key skills for employment, as mentioned previously [224], and this is an area that employers have recognised as weak amongst graduates [6]; CE alumni rate this with a small deviation of -0.182 (Figure 14), demonstrating a potential closure of this gap.

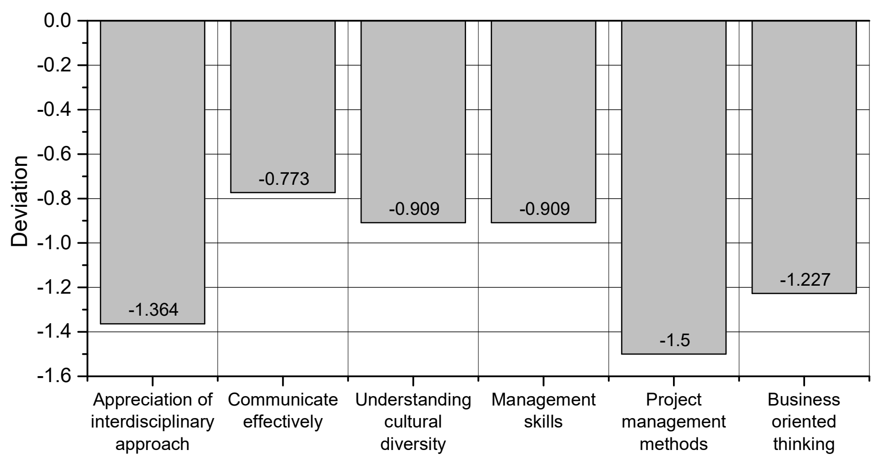

Figure 15: Alumni lowest rated skills in terms of perceived degree of learning ($\overline{\boldsymbol{\Delta}_s}$).

Generally, alumni were concerned (Figure 15) with business related skills such as *project management methods*, *management skills* and *business-orientated thinking*. Although project management is a taught class, at the time of the study it is delivered in the second year of the degree course and is not explicitly revisited in later years. The CE department have recognised this and plan to move the module to run alongside the penultimate year CE design project in the form of e-learning; otherwise, there are no business or management classes offered in the undergraduate course. The UoS does offer many free, bookable classes on self-management, effective time management and leadership; but these are not well publicised and often conflict with scheduled class times.

Full-time students and alumni comparison

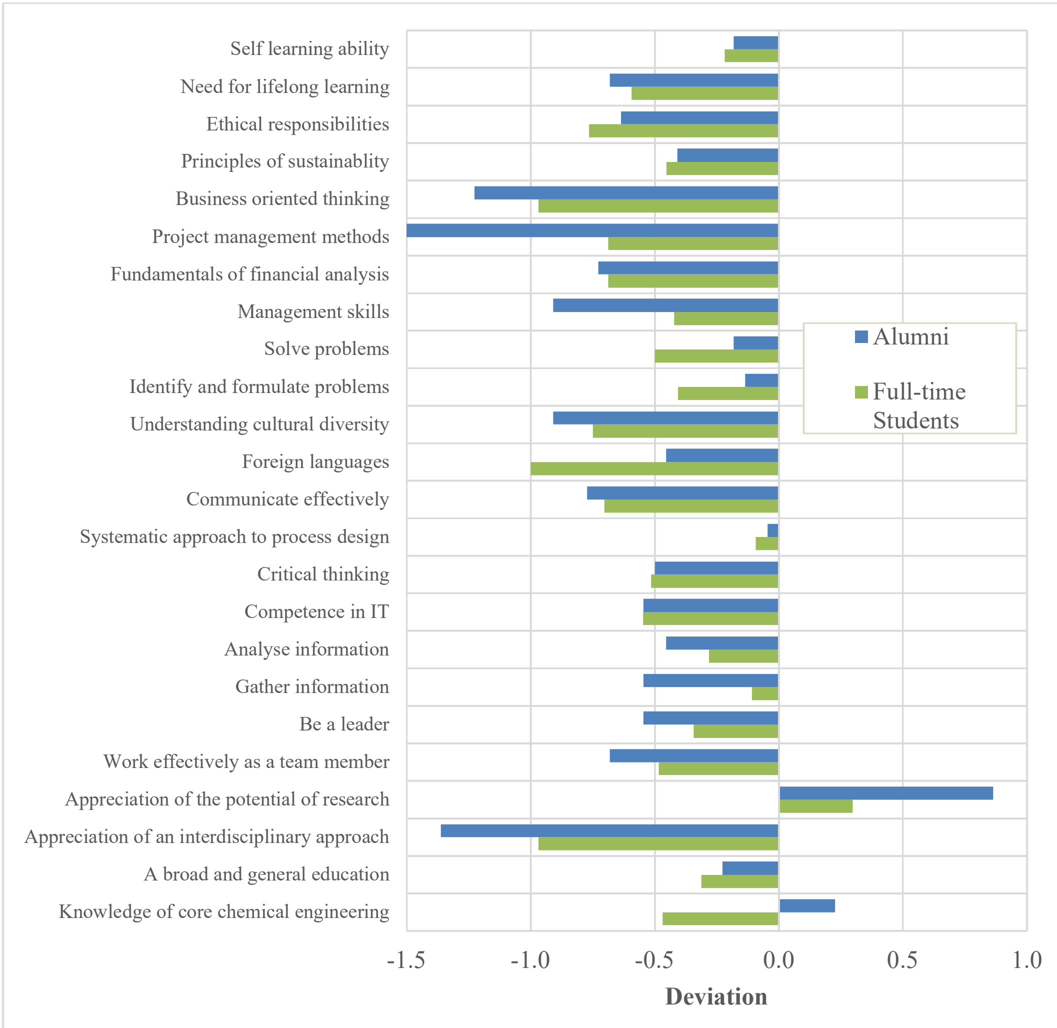

Figure 16: Chemical engineering skills' deviation ($\overline{\Delta_s}$) comparison of full-time students and alumni

Generally, students and alumni have similar views on the perceived degree of learning for all skills, except *knowledge of core CE*, where students perceive it as more relevant for employment than it actually is, as observed by the alumni's positive degree of learning result (Figure 15). As mentioned earlier, it is necessary to be aware that there is a significant bias exhibited by both groups. The full-time students have an 'accurate' perception of education as they were undertaking their degree at the time of canvassing; hence, full-time students are required to project forward their views and anticipate what skills employment will necessitate. On the other hand, alumni have an 'accurate' view of the skills required for their employment, yet some time has passed since graduating from their respective degrees, and employment experience will most likely have altered their views of education. It is also important to note that the content of the degree programme has changed over the years and alumni will have a different perception of what is taught. Although both groups carry a bias, there are some coherent views, such as *competence in IT* and *critical thinking* (Figure 16).

The comparison between alumni and full-time students' responses to rating skills, in terms of importance to employment, is shown in Figure 17. Those skills considerably exceeding the average difference between the two groups are highlighted with an 'X'. Students underestimate skills such as *appreciation of an interdisciplinary approach*, *project management methods* and *business-orientated thinking* whilst overestimating the importance of certain skills: *knowledge of core CE* and *ethical responsibilities*. This indicates a general change in graduate perspective once they have gained experience of work life: from one concerned with technical CE knowledge to one focussed on business methods and success. Furthermore, the ranking of the skills importance by alumni reflect studies conducted by others globally and nationally. Passow's longitudinal study on ABET competencies found a statistically-significant top tier of competencies comprised of *teamwork, communication, data analysis and problem solving* [34]. Male's Australian study similarly highlighted communication related skills; working in team; managing self; solving problems amongst the top ranked skills [33]. Both these studies provide support for the rating of these skills given by alumni.

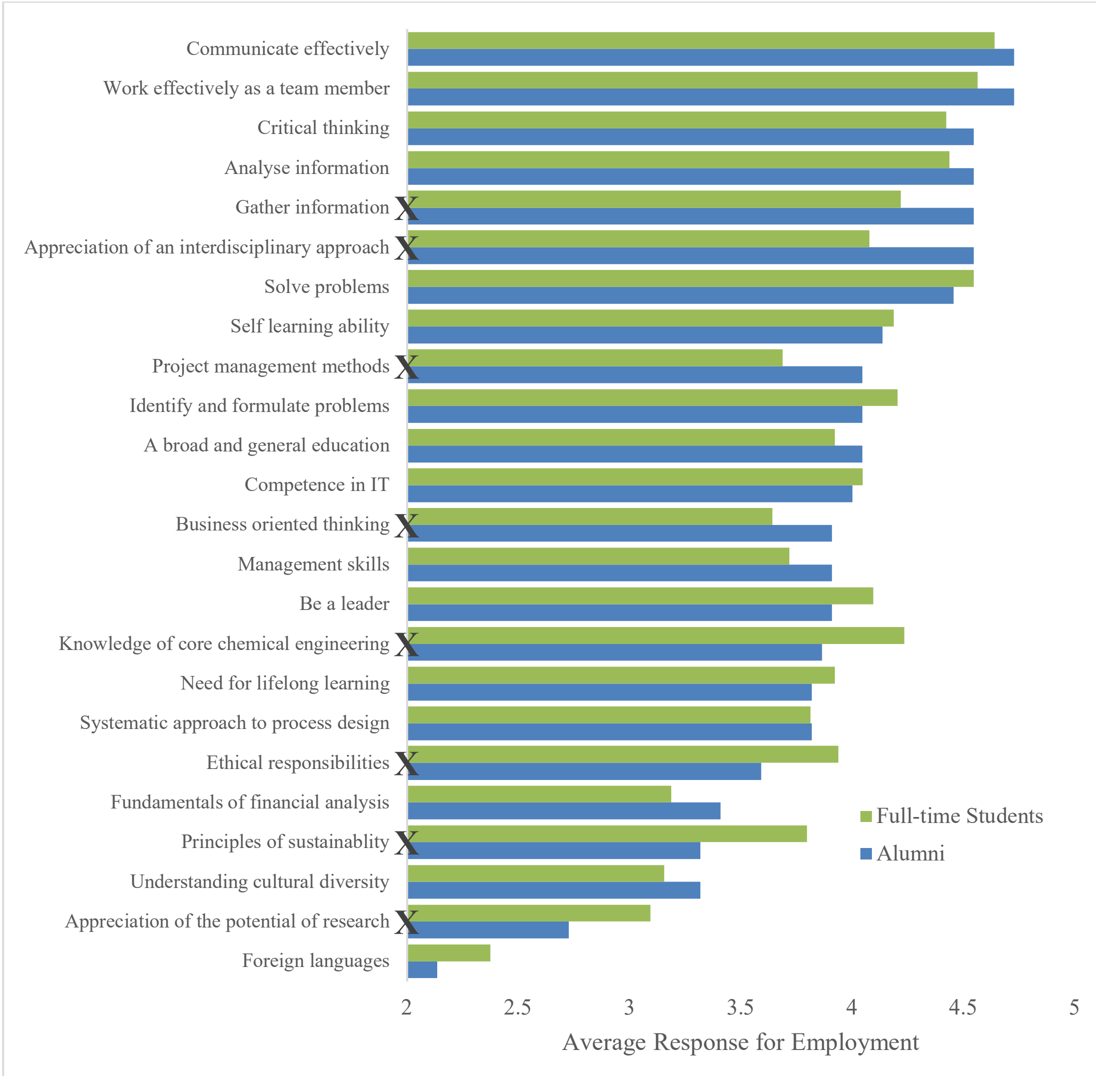

Figure 17: Average response for employment importance - full-time students and alumni (ranked for alumni); skills considerably exceeding the average difference between the full-time students and alumni groups are highlighted with an 'X'.

Both demographics do, however, agree upon the significance of the five most important skills for employment mentioned previously. Of particular interest is that both groups identified the two most important skills for employment to be the same: effective communication and effective teamwork, indicating that these skills are of high value, yet these skills are perceived as under-taught by both groups. This should be considered carefully as lack of confidence in a skill may manifest as perceived under-teaching, which may contribute to employer views expressed in studies such as those conducted by the CBI.

Experienced and non-experienced comparison

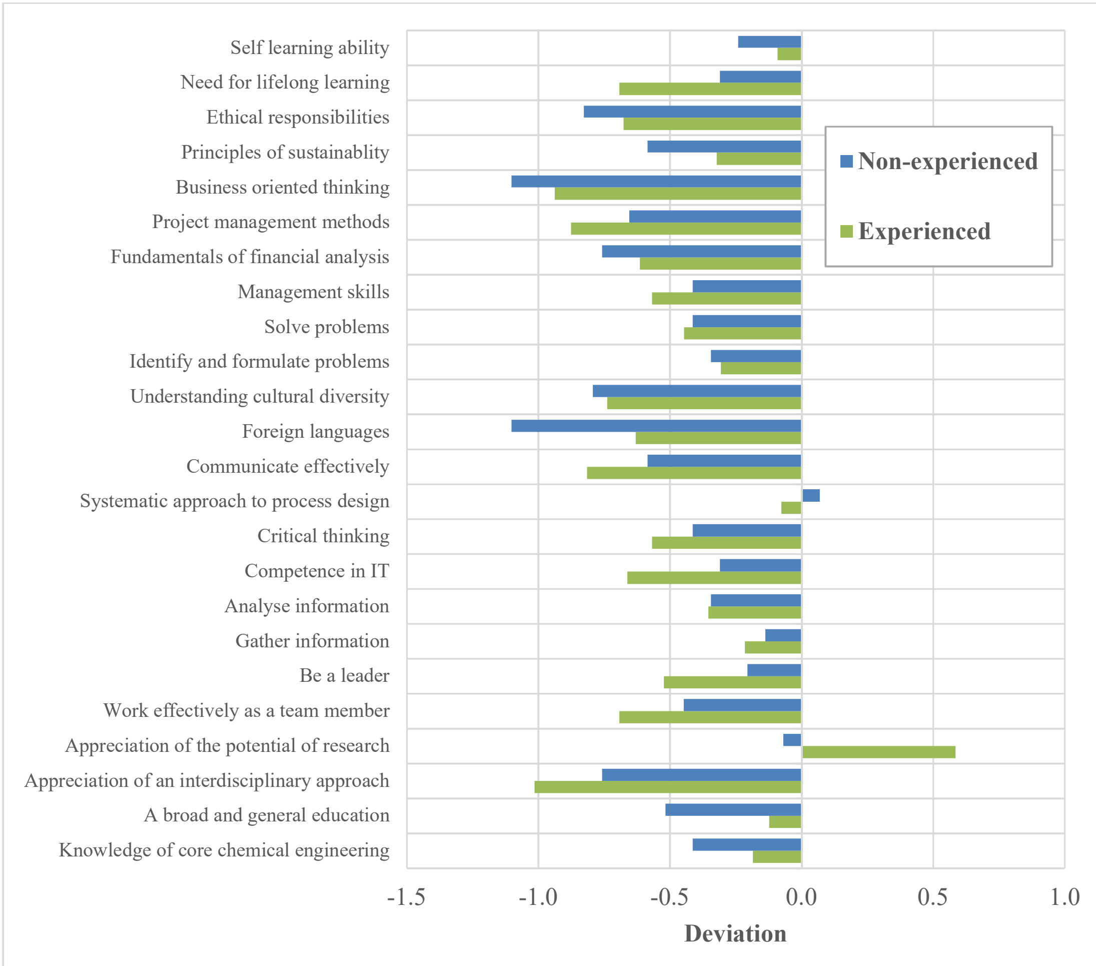

Figure 18: Skills' Deviation Comparison ($\overline{\Delta_s}$) of Experienced and Non-experienced Participants

Industrially experienced and non-experienced participants had similar views on most skills assessed in the questionnaire but there were some significant differences. *Appreciation of the potential of research* was perceived to be considerably over-taught by those with experience, whereas non-experienced participants considered it a skill slightly under-taught; this may be a consequence of non-experienced individuals who do have research experience but lack exposure to industrial experience (Figure 18). Despite their comparable curricula while at University, non-experienced participants also rated foreign languages as considerably more under-taught (deviation -1.103) than experienced participants (deviation -0.631), perhaps indicating greater importance of foreign languages in non-industry related careers, such as academic research. However, it is possible that some non-experienced participants who wish to pursue an industrial career may overestimate the importance of foreign languages. Both groups recognise the importance of *foreign language knowledge*, as both research and industry are international career options.

Competence in IT is an area that industrially experienced participants recognise as considerably under-taught (deviation -0.662) in comparison to those with no experience (deviation -0.310); this is more of a complaint regarding employer specific software that graduates encounter, as reflected in the individual comments. This is a difficult issue for educators to address as there are many different software used by employers. It perhaps indicates the need for specific IT training led by employers that builds on core IT competence gained at University.

Gender analysis

Female and male participants had substantially different views regarding many skills; most notably *business orientated thinking* and *appreciation of the potential of research* (Figure 19). Females evaluate *business orientated thinking* more critically than males and identify the *potential of research* as more over-taught than males. It is interesting to consider this result in the context of female career preferences, with studies indicating that the majority of women studying engineering go on to non-engineering employment upon graduation [226, 228] and that female students are significantly less likely to believe that they will remain in engineering-related fields than their male counterparts [229].

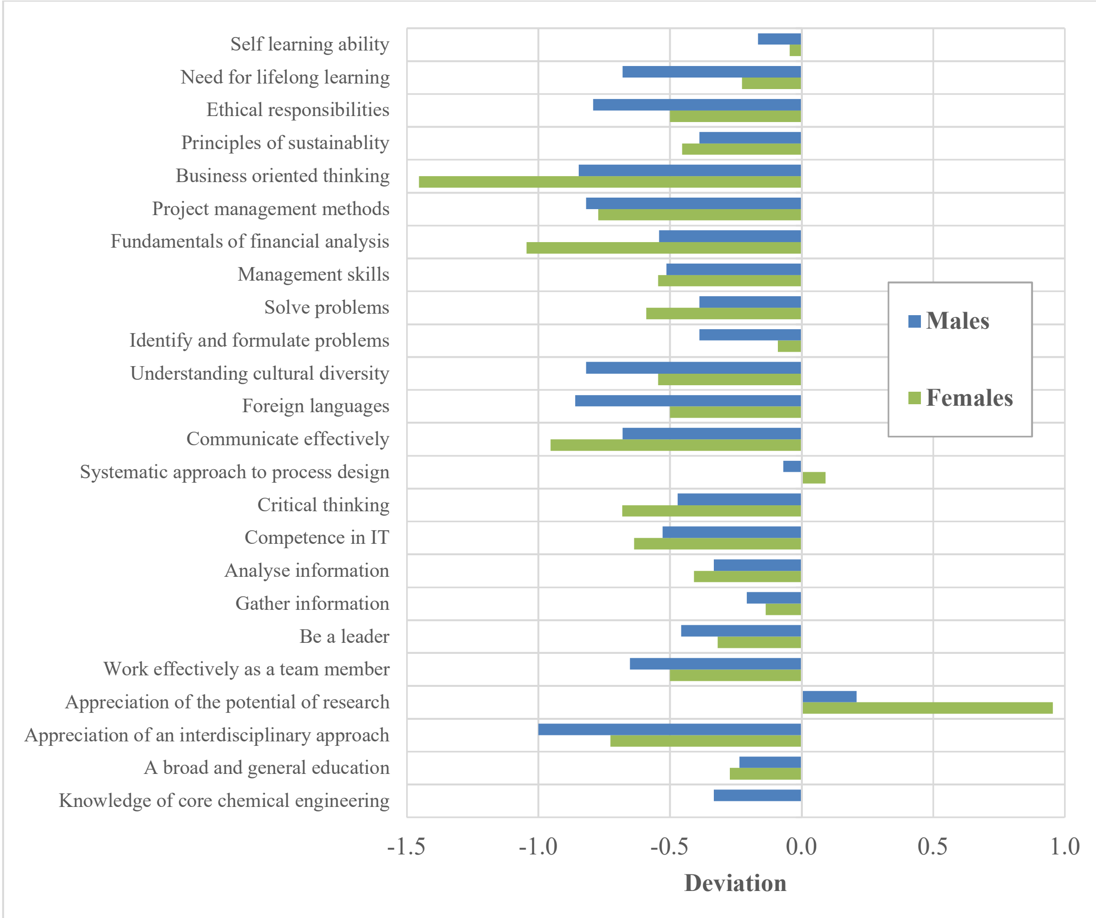

Figure 19: Skills' Deviation Comparison ($\overline{\boldsymbol{\Delta}_s}$) of Male and Female Participants for all cohorts (full-time, part-time and alumni).

The result of our survey may be evidence of a greater interest in female respondents of pursuing business as opposed to technical careers, whether within or outside the sector. Women evaluated *self-learning ability*, *need for lifelong learning* and *gathering information* closer to the ideal teaching for employment but felt slightly less confident with regards to *competence in IT* than males, and much less confident in *effective communication*. This may be due to the gender imbalance in engineering sectors, which may result in lower confidence for females when communicating with peers [230].

Teaching methods analysis

Full-time students and alumni recommended lectures with tutorial support as a teaching method, closely followed by group-orientated projects, the importance of which is emphasised in the CE design project, which allows student to develop a number of skills and provide experience of independent research (Figure 20). Conversely, part-time students preferred video lectures with tutorial support, as this is the most accessible method distance learners, who criticised group-orientated projects, probably due to the difficult nature of remotely managing a group.

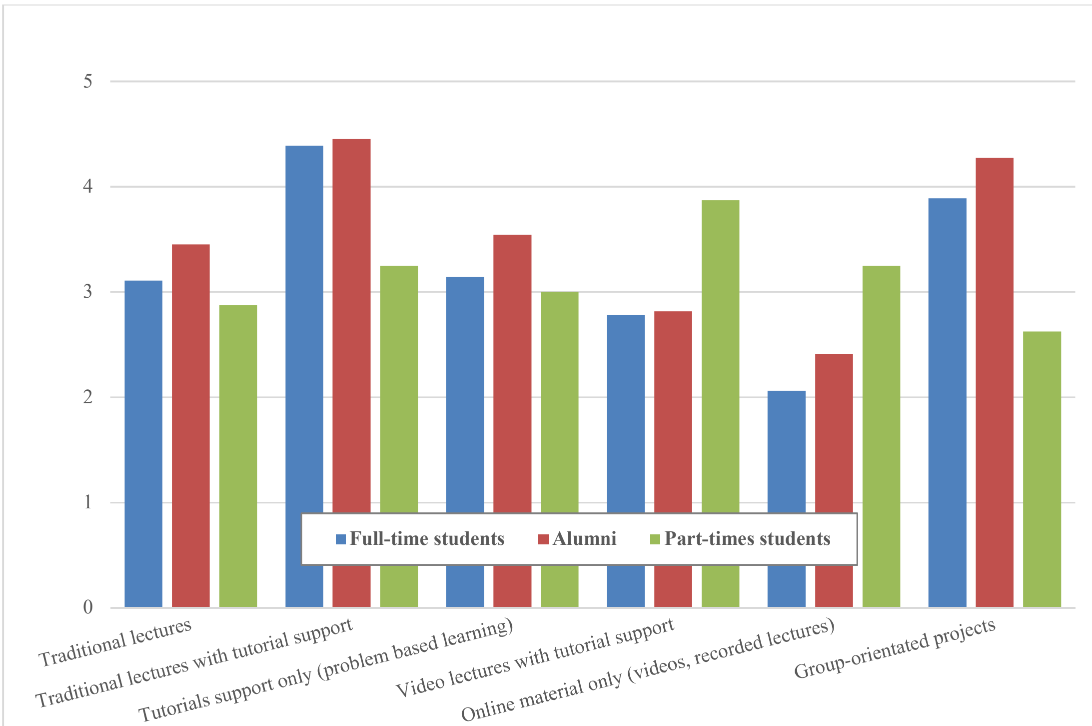

Figure 20: Teaching Method Preferences of Full-time Students, Part-time Students and Alumni

Experience and employment analysis

At the time of delivery of the questionnaire, 18 student participants (51%) with prior experience had received graduate job offers, compared with only 2 non-experienced respondents (7%). This key finding indicates the value that employers place on previous experience; indeed the CBI have consistently reported the high dissatisfaction of employers with regards to this attribute [6].

Addressing the issues

The survey results suggest that, on average, those with experience felt that their technical knowledge surpassed the requirement for employment, while transferable skills and management-related subjects were generally lacking. Although learning outcomes are beneficial to learning and teaching, students may not be completely aware of which skills they have developed during their time at university, if not explicitly stated. This is of particular concern with embedded learning outcomes for transferable skills, which are often additional to the main content of the course but allow students to develop certain skills or awareness. These embedded learning outcomes are utilized in the course as is documented in the UoS CE undergraduate handbook. Fitzpatrick *et al.* [221] found that students taught using explicit reference to the class LOs expressed confidence in understanding the LOs based on students' prior and post teaching perceptions. More importantly, almost all students found the session, which communicated the LOs, to be useful. Similarly, Felder's work on the explication of learning outcomes highlights the importance for academic staff to have established clear and specific LOs [222, 223]. For these reasons, it was recommended that academic staff should incorporate a proactive approach and introduce classes with a verbal or written explanation of the various learning outcomes associated with the module; upon closing a class the learning outcomes should be restated, to allow students to reflect on the material covered. Due to the low evaluation of most transferable skills, it was recommended that classes should be introduced to cover various skills that are relevant and useful to students, both during their time at university and once they enter their chosen career: industrial, academic or otherwise.

Potential delivery constraints for delivering transferable skills

Degree flexibility - Currently, the degree offers very little flexibility for additional modules to be introduced on top of the 120 credits per year workload, which corresponds to 1200 hours of student learning, including lectures, assessment work and exams. As mentioned previously the department is required to meet certain learning outcomes for accreditation purposes and many core classes are integral to this. One solution might be to replace an already existing Integrated Masters 5th year module with content pertaining to professional skills development. Such modules focus on specific subjects and are required to be of sufficient depth for accreditation; however, students have freedom of choice in class selection and there is some scope for variety within accreditation expectations from advanced level classes. Unfortunately, to address the concerns raised by questionnaire participants, an introductory class timed at the start of semester was more preferable, which would not be favourable for accreditation. An alternative was to deliver an extra-curricular lecture series, however, this required additional teaching time for staff and would potentially result in poor student participation.

Teaching Staff - Staff availability is key to delivery of any module; however, lecturers often have many roles (as researchers, supervisors and academic advisors etc.). Another valuable resource for teaching is postgraduate researchers, and following publication of the Roberts' Review in 2002 there has been increased focus over the well-rounded capabilities of researchers [231]. As a result the University of Strathclyde have adopted a Researcher Development Programme (RDP), which requires PhD students to accrue 60 credits during their research degree towards a Postgraduate Certificate (PGCert). Students are required to submit evidence of the development of a range of skills, e.g. supervising and teaching junior students. Involving PhD students in the teaching of this module both provides credit-bearing experience for PhD students while removing some demand on otherwise preoccupied lecturers. However, lecturers still need to design classes and assessments for delivery by PhD students and it is important to recognise that not all PhD students and lecturers will have industrial 'work' experience.

Assessment - Evaluation can provide documented evidence that a student has demonstrated attainment of specified learning outcomes and can take a variety of forms; formal examination, assessments, class tests and group projects. Assessment has been shown to increase class attendance [232]. Continuous assessment is beneficial to both student and teacher as it provides valuable feedback to both, allowing the former to improve upon weaker areas and the latter to focus on identified failings. On the other hand, assessment can be time-intensive, hence, the proposed class should require no formal assessment, which is not an issue if the class is not tied to a core module. Instead it is suggested that students who attend will be awarded a 'skills award' that will be presented on their academic transcript, thus ensuring attendance. Additional to this an alternative option, allowing immediate feedback and assessment of the general topics of the classes, would be personal response systems (PRS); If coupled with meaningful questions and preparation these could provide significant feedback for class improvement.

Class Sizes - Over the last few decades, universities have undergone a process of 'massification' whereby student enrolment and class sizes have increased dramatically [233]. CE continues to attract increasing numbers of students and class sizes have increased rapidly, which presents a potential issue with regards to student performance. On average, "larger classes reduce students' achievement as measured by test scores" [233, 234] albeit the magnitude of the inverse relationship between large class size and student final mark in a higher education setting is significantly smaller than other tiers of education [233]. Nevertheless, it is beneficial to consider online virtual learning environments (VLE) to deliver the material, increasing accessibility for all students, including distance learning cohorts. Due to the ever increasing CE cohorts, it is wise to consider sustainable changes when implementing classes.

Delivery Proposal - To minimise impact on staff workload, it was recommended that PhD students deliver the material, allowing credit accrual for the RDP; such sessions would be run as part of the yearly induction program for all student year groups. The proposal would not add significantly to teaching hours and, at the time of writing, was a scheduled part of students' timetables. As the yearly inductions incorporate the full cohort, the class sizes are already accommodated for the complete year group. There is a relatively high attendance at early years' induction events, with lower attendance in later years, most likely due to the brief and repetitive nature of previous yearly inductions; students are informed of the classes they will undertake and given a general welcome followed by a careers talk. Introducing lectures on practical skills may improve attendance, and by delivering skills development at the start of the semester, the skills covered can be matched to the demands of the upcoming academic year and advertised as such e.g. the 4th years induction covers running effective meetings in preparation for the group design projects. Meaningful feedback and assessment of the session could be obtained by paper surveys, show of hands or even web-based feedback applications that can be run on smart phones such as Socrative [235], however, the latter would require good Wi-Fi availability/assurance that students were in possession of smart devices.

Practical Suggestions for delivering transferable skills

Induction skills classes - Transferable skills were selected for their relevance and practicality to the degree course and a variety of job roles. These are outlined below with justification of relevance, cohort delivery recommendations and resources used to develop materials.

Steve Jobs or Bill Gates? How to Develop and Deliver Excellent Presentations serves to improve student perception of the degree of learning of effective communication, rated both an important and poorly skill by most demographics. The importance and lack of exposure to presentations were mentioned specifically by some participants of the questionnaire, with several noting their preference to 'give students a chance to practice presentations' and others, the belief that they 'lack presentation skills in comparison to others from different universities'. Furthermore, this is an important skill for students who go on to pursue post-doctoral degrees, with group presentations a regular occurrence. Reviewing the curriculum, it was found that presentations are required from students in 1st, 2nd and 5th year, hence it was decided that delivering presentation skills material prior to 1st year presentations would be of greatest benefit to students, allowing students to apply the teachings in later years as well. Topics covered include planning, design and delivery, and resources used were Weissman's *Presentations in Action* [236] and Reynolds' *Presentation Zen series* [237, 238].

Cramming or Prepared? How to Organise and Manage Your Time was developed to reduce the students' negative perceptions with regards to management skills and self-learning ability, introducing concepts for project management methods. Management is involved in decision making with regards to available resources and time is a resource that every student and employee possesses and uses to achieve a goal - an invaluable skill for students to learn. In 2nd year, students have a significant number of assignments with staggered hand-in dates; importantly, in this year the module Chemical Engineering Practice 1 is introduced, which requires students to participate in several laboratory sessions and submit a detailed report fortnightly over the course of the year. This continues in the following year with the delivery of Chemical Engineering Practice 2. Both modules run over two semesters, requiring individual effort and resolution of conflicting deadlines requiring good organisational skills. This skill is also valuable in later years, particularly 4th and 5th years, as students are required to participate in group and individual projects, respectively - the importance of a proactive approach and good self-management is key for succeeding in complex projects. Areas covered include Eisenhower's time matrix, scheduling, combating procrastination and technological assistance using the Sunday Times' publications: *Successful Time Management* [239] and *Organise Yourself* [240] as resources.

Group or Team? How to Work Effectively as a Team - The importance of teamwork for chemical engineers was recognised by both alumni and students who participated in the questionnaire. The CBI has also noted this as a key employability skill, with a fifth of employers unsatisfied with team working abilities in graduates. Chemical engineers have particular interest in effective teamwork as they often work as part of interdisciplinary teams made up of engineers from various disciplines. It is vital for academic success that students are able to perform well in teams and, likewise, for graduates to do so to achieve business success. Students are exposed to elements of team work in all years, and the most important year for students to be able to perform well in teams is 4th year as part of the 60-credit design module, a hallmark feature of all accredited CE degrees. During this module students are expected to work together, assign roles, delegate and collectively come to decisions to achieve common goals, which is the essence of team work. Although it was initially considered to deliver the material in the 4th year it was instead considered more beneficial to run the material in 3rd year prior to the introductory course for the 4th year design project; Chemical Engineering Design and Advanced IT. This module gives students a simpler and more constrained primer to 4th year design but with the same element of team work. For this reason students can apply the material initially in the 3rd year, working to improve their performance in the capstone 4th year group projects. Areas covered include stages of team development, team styles, team roles and methods for team problem solving and decision making, using De Bono's *Six Thinking Hats* [241], Belbin's Team Roles [242], *Effective Teamwork: Practical Lessons from Organisational Research* [243] and *Team Players and Team Work* [244] as resources.

Organised or Time-Wasted? How to Plan and Run Effective Meetings - An important aspect of effective teamwork, communication and management is being able to organise and execute meetings that are time-efficient and address the need for the meeting. Meetings are required for many reasons as part of the undergraduate degree: to update team members on progress, to inform supervisors of progress, to discuss issues, to plan coming events and to make decisions. Similarly, meetings have a vital role to play in employment, however, meetings can often be counter-productive if not planned properly and result in wasted time. Meetings often go hand-in-hand with teamwork, although not exclusively, and require a tailored approach depending on the purpose of the meeting. As a result, meetings are present in every year of the undergraduate degree course and the proposed material may have been delivered in any year but, as undergraduates are presented with the most number of meetings in their 4th year, as part of design, it was recommended that the material on meetings be run in 4th year. Students meet with design supervisors on a weekly basis but are also expected to meet regularly outside these meetings to make decisions, update team members and work together, providing significant practice, while the 5th year research project provides an additional opportunity for improvement. Meeting preparation, types of meetings, key roles in meetings and post-meeting considerations are covered using Barker's *How to Manage Meetings* [245] and Delehant's *Making Meetings Work* [246] as resources.

Project management methods and business-orientated thinking accrued high average skills deviations amongst alumni; however, the significant body of published literature associated with these skills indicates that they are unsuitable for short induction classes. Instead, it was recommended that implementation of both be embedded within the curriculum. An example of this implementation for business-orientated thinking skills was the explicit and graded division of group design projects to include a conceptual phase which required students to provide a feasibility study and business justification for the proposed design.

Conclusions

Employers have recognised various shortcomings in graduates, as observed by the Confederation of British Industry. In this study, the views of chemical engineers with regards to employability skills were obtained by means of a survey; transferable skills were deemed most important for employment. In addition to this, management and transferable skills were perceived to be under taught by the participants, hence, the development of these skills was addressed by the introduction of induction skills classes. Taught by PhD students, with instant feedback received via a smart device-based personal response system, the classes focus on presentations, time management, effective teamwork and meetings in alignment with student needs throughout the current degree programme.

Questions raised/further study

The results also indicate directions worthy of future, more detailed, study. The contrast between male and female perceptions and confidence is clear, and it would be informative to further explore this, especially given current concerns over gender equality of opportunity in engineering and science. The transition of perceptions from students at university to alumni is clear in some cases, such as the perceived importance of, and competence in, core chemical engineering knowledge, and it would be interesting to study, in more detail, how perceptions of confidence in skills develops throughout the university career as well as the impact of skills development on the early years of industrial experience. Graduates do not stop learning once they leave university, and with such a diverse range of activities in the CE sector, further development of skills is of core importance to the industry. Further, work to understand what definitions are associated with various skills such as *effective communication* and *teamwork* would prove to be helpful for educators.

Chapter 7: graduate employability

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.

Introduction

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 [13]. 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 [247]. 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 [247].

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 [221]. 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.

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’ [16]. 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 [56], namely Design as a process in its own right, with many students unable to overcome their issues.

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 [7]. 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?' [32], 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 [247] 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 [224] 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 [32], 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' [89]. Agreement also exists between the WCEC survey results [32] and CBI findings [7]. 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.

Skills development

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 [248] 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 [43].

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 [249] 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 [44]. Students can sometimes fail to appreciate the applicability of taught content to transferable skills development [43].

(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 [46]. 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 [48], as the importance of the skills themselves is often diminished [43].

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.

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 [76]. 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 [76]. 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.

Methodology

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:

What skills do staff and undergraduate students think are developed during Design?

Is there agreement between the expectations of staff, regarding project learning outcomes, and undergraduate students undertaking design?

How do students' perceptions of their abilities in selected skills change during design?

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.

Composition of the study

16 CPE staff were sampled in the design scoping survey (see Appendix), 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 [30]) 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.

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.

Evaluation of skills and abilities by questionnaire

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.

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 [225], 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.

Results and Discussion

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 Appendix), 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, oral 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.

Student data

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 9, 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).

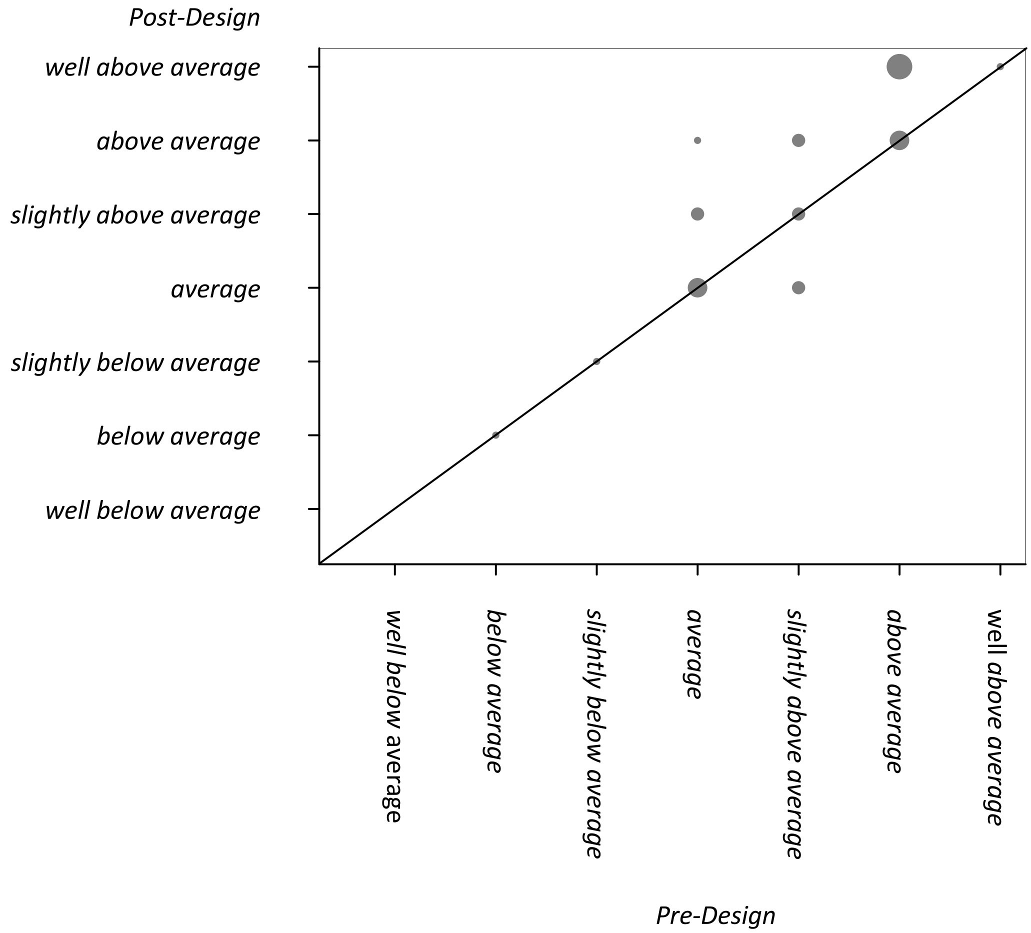

Figure 21: Bubble plot collating Likert responses of the 22 students that answered both pre- design (x-axis) and post-design (y-axis) surveys for verbal communication ability.

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 21 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 pre- and 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 [250] 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 8); 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.

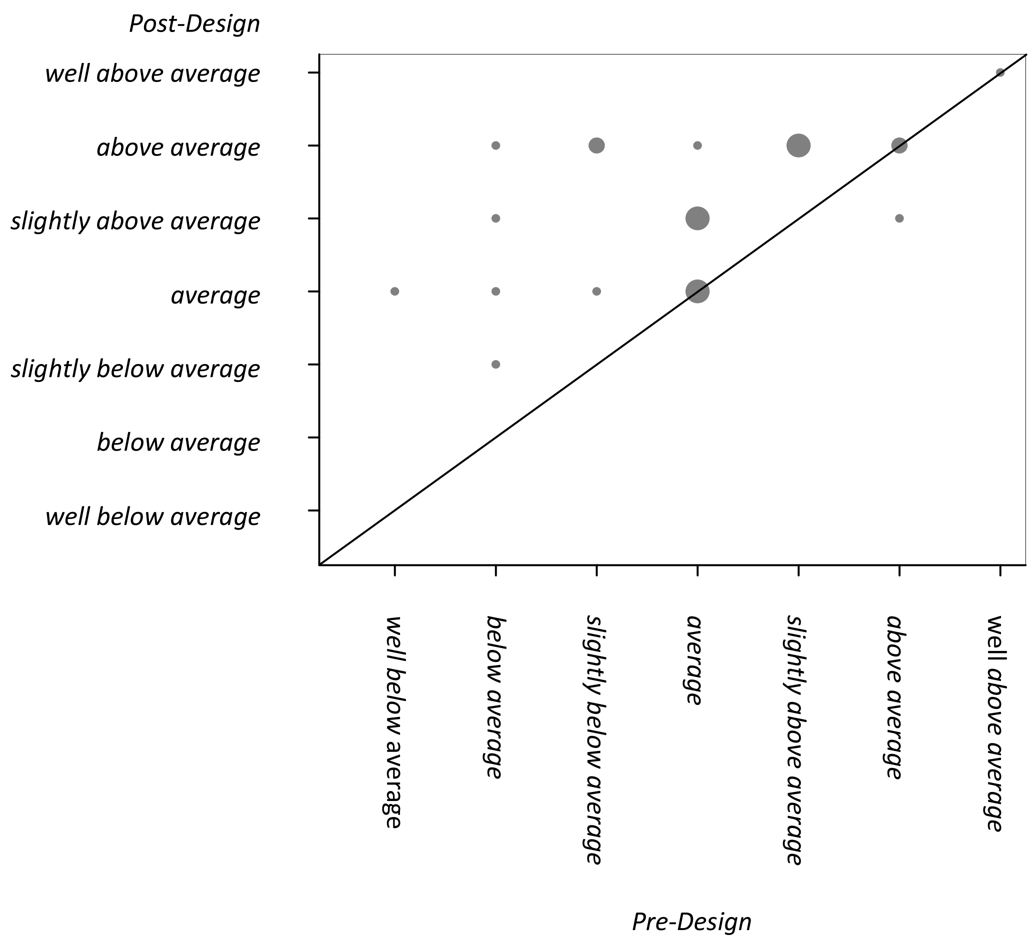

Figure 22: Bubble plot collating Likert responses of the 22 students that answered both pre- design (x-axis) and post-design (y-axis) surveys for oral presentations ability.

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 9) 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 9) 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 22. 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.

Table 9: Percentage respondents in each Likert category when asked about their relative ability in communication skills both pre- and post-design.

Skill	Verbal communication		Listening		Oral presenting		Written communication		Minute taking	
Pre or Post-design	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post
Well below average	0	0	0	0	2	0	0	0	2	0
Below average	4	4	0	0	18	0	0	0	4	4
Slightly below average	5	8	5	0	20	4	9	16	14	12
Average	27	20	23	24	29	28	34	12	50	44
Slightly above average	29	16	25	24	18	20	29	20	23	12
Above average	30	32	41	40	9	44	25	48	5	28
Well above average	5	20	5	12	5	4	4	4	2	0

Table 10: Percentage respondents in each Likert category when asked about their relative personal effectiveness both pre- and post-design.

Skill	Time management		Project management		Lead		Working with others		Decision making	
Pre or Post-design	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post
Well below average	0	0	0	0	0	4	0	0	2	4
Below average	0	8	4	8	5	0	0	0	2	0
Slightly below average	9	0	9	0	7	4	2	4	5	12
Average	34	12	32	12	30	16	16	4	30	8
Slightly above average	27	16	36	28	27	32	25	20	38	20
Above average	25	48	16	52	29	40	52	52	21	56
Well above average	5	16	4	0	2	4	5	20	2	0

Table 11: Percentage respondents in each Likert category when asked about their relative ability in research skills both pre- and post-design.

Skill	Word processing		IT		Data analysis		Literature research	
Pre or Post-design	Pre	Post	Pre	Post	Pre	Post	Pre	Post
Well below average	0	0	0	0	0	0	0	0
Below average	4	0	7	0	2	0	5	0
Slightly below average	4	0	9	4	7	0	11	8
Average	38	36	52	40	50	36	43	20
Slightly above average	18	16	13	8	18	28	25	32
Above average	36	40	16	36	21	28	16	32
Well above average	2	8	4	12	2	8	0	8

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.

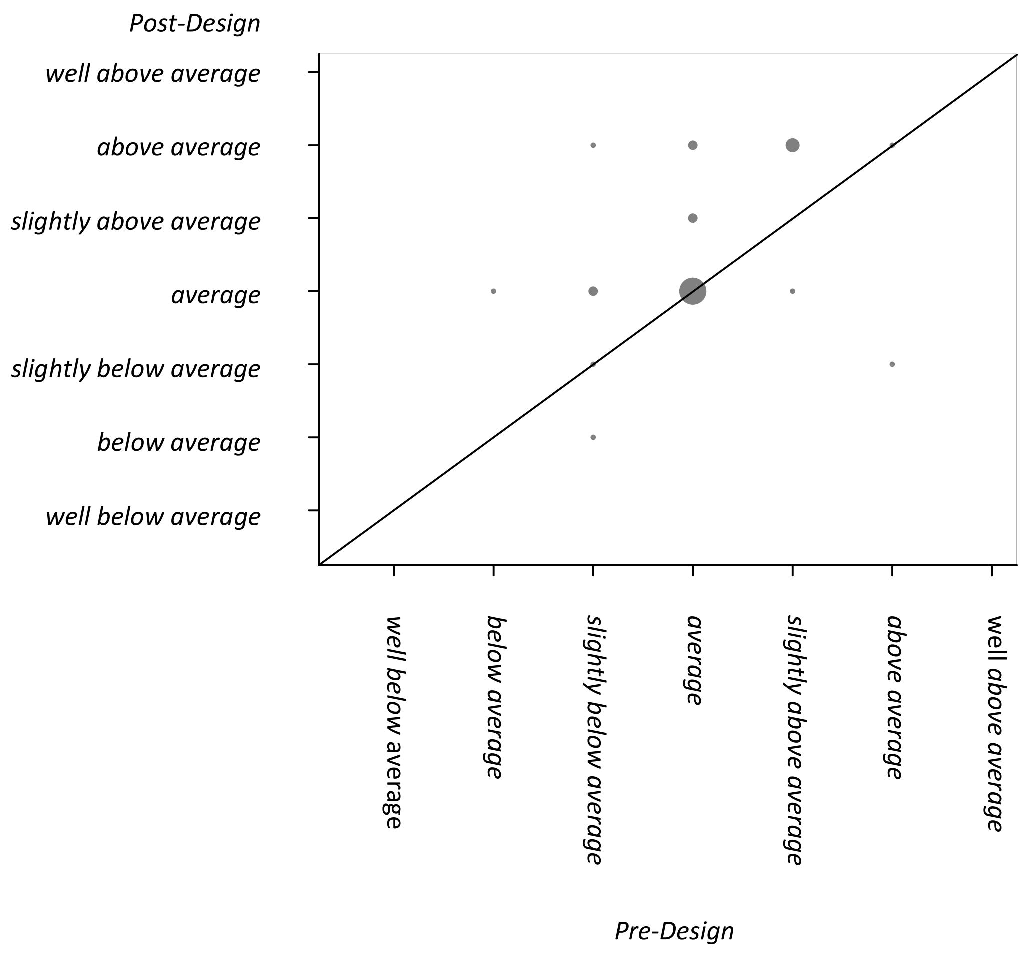

Figure 23: Bubble plot collating Likert responses of the 22 students that answered both pre- design (x-axis) and post-design (y-axis) surveys for minutes taking ability.

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 9).

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 9). 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 23), hence, there is little difference in the global distribution excepting the response rate for above average (Table 9).

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 [251], there remains an underlying trend that most educators do not appreciate that a 'hidden' curriculum exists and need to acknowledge the fact [252] 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.

Personal effectiveness skills

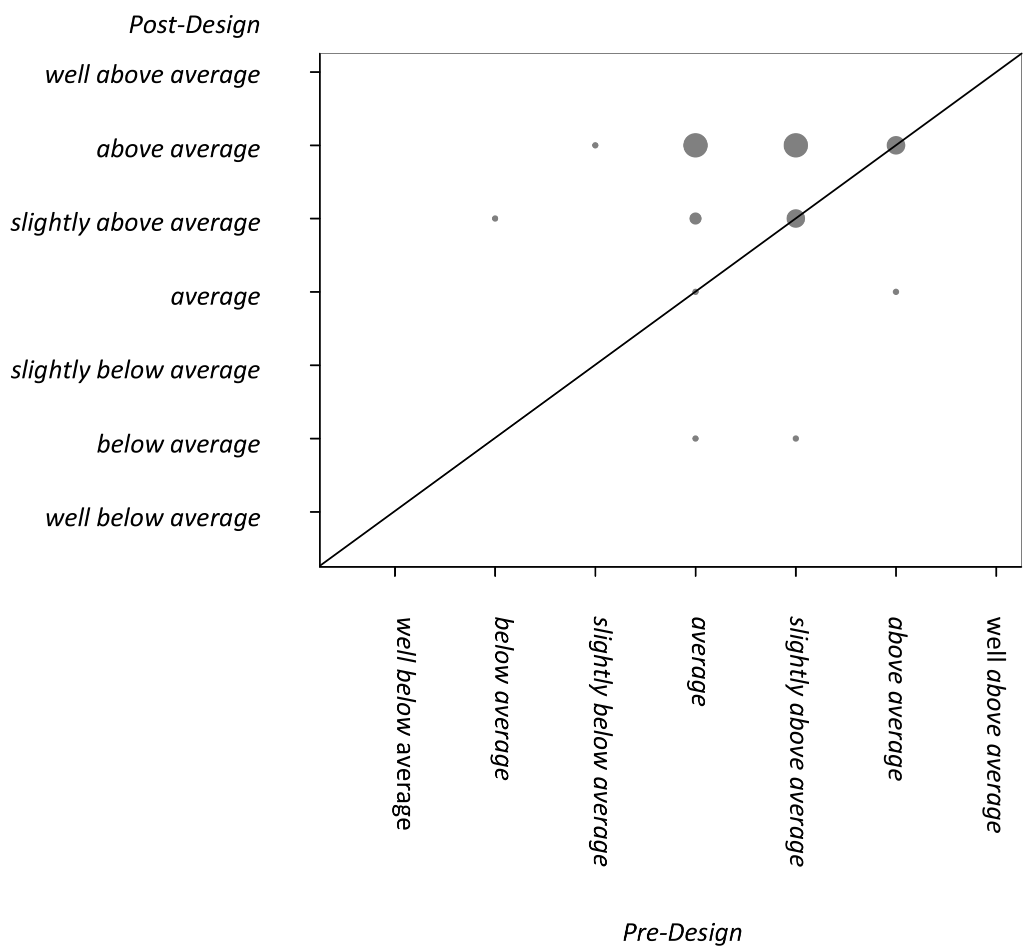

Figure 24: Bubble plot collating Likert responses of the 22 students that answered both pre- design (x-axis) and post-design (y-axis) surveys for project management ability.

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 10). 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 10 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 24 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 10). 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 10).

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 [56] 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 10) 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.

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 [25, 30]. Hence, it is interesting to consider their development in word processing during Design.

The survey results for perception of word processing ability (Table 11) demonstrate the limitations of considering the mode as an isolated variable [225], 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' [25]. They are consequently more likely to work in a cooperative manner [23-25], however, previous work has shown that women students can face negativity from their men peers [30], 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 [253] 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 11 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 11 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.

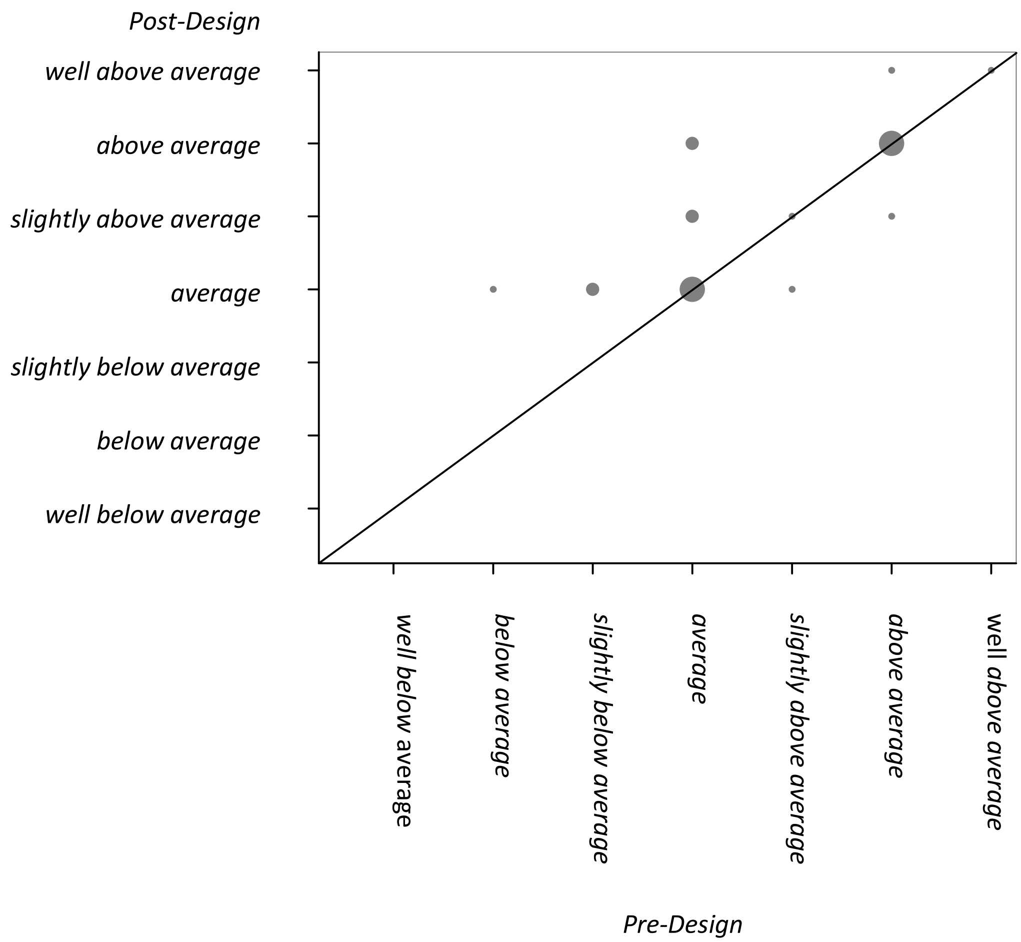

Figure 25: Bubble plot collating Likert responses of the 22 students that answered both pre- design (x-axis) and post-design (y-axis) surveys for data analysis ability.

Despite the significant number of responses in the greater than average categories, the mode is average (Figure 25), 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 11, 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.

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 [254]. 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.

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 Appendix).

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.

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.

Chapter 8: conclusions

Overarching discussion and conclusions

As shown in Chapter 2, which deals with the wider concept of threshold concepts in Chemical Engineering, structured problem-based learning can result in enhanced student engagement and achievement, as well as the development of transferable skills and increased confidence, both in working practices and application of knowledge. The use of problem-based learning in this context is used to underpin and support later design components, but these, in themselves, offer additional opportunities to undertake problem-based learning while benefiting from experience of the approach in earlier classes. This means that the role of problem-based learning evolves within the students' learning portfolios and can be used to challenge students, but also as a supportive mechanism. The learning gained here is not only applicable for Chemical Engineering disciplines, but the wider field of Engineering and beyond.

Active learning, such as open-ended problem solving, projects and teamwork are a continuing focus in chemical engineering [255], and while problem-based learning continues to be used within the discipline and the findings of previous works are summarised and collated for the benefit of academic practitioners [256], a distinct lack of evaluative studies beyond those dealing with teamwork roles and conflict resolution [257-259] still exists.

As discussed in chapter 3, teaching alignment, focussed on the operational delivery of design as a capstone project, showed that, irrespective of mode of delivery, there appears to be clear opportunities for students to demonstrate their abilities in the discipline; generally an increase in performance is observed for most students but a particular improvement for weaker students, possibly by engagement with more able students or by allowing the work to be spread over the semester and removing the time focussed element of examinations, which can often undervalue students' performance or fail to fully evaluate their understanding [260, 261]. It is of value to note that the roles of women students, as discussed in Chapter 5, appear to be more equally distributed within this later project, and it is likely that the opportunities to undertake group work, and to find their place within these teams, may be crucial in this repositioning of women students by this point, who capitalise on the fluidity of group work identities dependent on team and project requirements[159].

Student identity is also a powerful message from Chapter 4, where the roles of tutors within group tasks is studied; the groups themselves have individual modes of engaging with assigned tutors and the tutor may even become a 'member' of the group, thereby affecting the dynamics of the unit. This working relationship is symbiotic in nature, providing development opportunities for all parties, and this is especially powerful for new entrants, while capitalising on the unique position that later year students can occupy in contrast to staff in their engagement with undergraduates [262, 263]. As a consequence of the position in which they sit, these facilitators should possess a skill set that allows them to engage their tutees, reflect on the in-session feedback that they observe and receive, as well as an ability to reflect on their practice to ensure that they can further develop their teaching. Successive cohorts may well benefit further from tutors' experiences of being peer tutored themselves in earlier years. It is important in these tutoring roles that the students delivering tuition are assimilated into the groups that they teach. However there have been previous observations by Harrison *et al.* who posited that diverse groups were more effective in identifying problems and generating solutions than their homogenous counterparts [212], and the individualism and advanced educational level of tutors may make them sufficiently different to actually help the groups become more effective learning communities. As discussed in Chapter 5, these heterogeneous environments and group structures are critical for tutors and tutees alike to ensure that they can integrate easily once in the work place, and have some understanding of group dynamics and conflict resolution.

Peer tuition has seen increased deployment in recent years [264], resulting in further evaluation of the process. As anecdotally observed in this study, Roberts [265] found that students not only sought academic assistance in these small tutor groups but they also acted as sources of non-academic information, reinforcing the observation made here that peers are more influential in a student's education than academic staff. Abedini *et al.* noted that the tutors in these 'mid-way' positions provide a conduit for informal discussions that may be prohibited by the usual formal teaching environments[266]. This is supported by reports from students involved in peer-tutoring in other institutions who cited positive benefits such as increased social network, and the development of learner communities [267]. It should be noted, however, that some members of the same cohort reported that they had negative experiences, due to unpreparedness or a lack of knowledge from their tutors [267], as also observed in other studies [268, 269]. This ties with the observations discussed in this theses, where tutors who were less adept at the role often elicited negative feedback.

As discussed above, women students play vital roles in early group activities by facilitating the process of working as a unit, however, as detailed in Chapter 2, their attitudes change and they work towards parity in group roles and, more importantly, towards equity of effort in the assigned tasks. This transition is a move towards gender equality, by ensuring that the seemingly socially expected conformity of roles, and the associated disparity of workload does not continue [217]. The findings from Chapter 5 must be contrasted with those discussed in Chapter 7, where men strived to adopt leadership roles, possibly devaluing women colleagues, however, women were able to capitalise on their previously acquired skill sets in organisation focussed areas. Ideally, working towards parity within group roles would be without detrimental impact on women students' performance but this requires further study.

Engaging students in early years' problem-based learning is aimed at addressing the perceived shortfall in transferable skills, as observed by the Confederation of British Industry, as mentioned in Chapter 6 [4-7], and in subsequent surveys [8-10]. Students taking part in the study into skills perceptions, agreed with staff that *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) constituted the core skills to ensure job market preparedness.

As discussed in Chapter 7, students value and learn well from experiential activities, as seen previously [270], and their engagement with external activities may well provide additional skills development, often as a result of undertaking a hobby for enjoyment, a part-time role for remuneration or by perceptively understanding that academic merit alone is no longer a guarantee of gaining employment. San-Valero *et al.* have since found that both staff and students perceive an increase in communication skills after participating in a series of innovation workshops [61]. This simulated professional setting is akin to the design project studied here, in that it gives value to skills development through experiential learning. Similarly, the outcomes of implementing a gamestorming approach in engineering conceptual design saw improved decision-making through engagement with teamwork oriented tasks [271]. This appears to have fostered students' creativity, which may be more confidently manifested in a known and supportive group environment.

Since the work within this study was conducted, some researchers have suggested the implementation of team-based learning, where, in contrast to the one-to-one facilitation offered by problem-based learning, one tutor facilitates several small permanent teams of approximately six members working through individual pre-sessional materials and completing individual and group based tests on the concepts covered [272-275]. Students engaging in team-based learning reported high levels of engagement, improved team work, common respect, equity in contribution and increased attentiveness [276]. It is evident that several courses within the chemical engineering programme studied in detail here are already utilising team-based learning to some degree and this may present a further avenue for improved student support across the curriculum.

It still remains an issue that graduates are generally perceived to lack 'business-ready' skills [8-10], and UK Higher Education has some work to do in ensuring that future graduating cohorts have advanced skill sets that match the expectations of employers. It is crucial that any changes are informed by industry to ensure that the definitions of key skills are universally understood. For example 'communication' is a broad and all-encompassing term that could hold myriad interpretations depending on stakeholder perspective. These defined 'required skills' must also be balanced with student expectations and perspectives, as well as academic requirements, as discussed in Chapter 7.

As discussed in the opening chapter of this thesis, open-ended working can prove problematic for some chemical engineering students, hence, the use of problem-based learning in earlier years to support students in overcoming this threshold concept. This mode of working should limit the number of students who continue with the troublesome knowledge of open-ended problem working during design, enhancing their experience and upskilling them for future employment.

Chapter 9: future work

Recommendations for further study

As this study highlights the fact that women students change their adopted roles within project groups as a result of workload equity and striving for parity at all levels, it would be interesting to determine whether the fact that women students change their role and work patterns in group activities negatively impacts on their development or attainment.

As several cohorts of students have experienced problem-based learning within their programme, some of whom are now undertaking tutoring within the department, it would be valuable to understand how their experience of being tutored in this manner has influenced their own roles and the impact this has on their own tutees.

Given the adoption of team-based learning in chemical engineering programmes, there is value in comparing this mode of working with problem-based learning to more fully understand the impact of each and where they are most appropriately deployed. It may well be that a combination of approaches is required and a wider, longitudinal study would be helpful in this regard.

It would be valuable to conduct a survey of perceived skills development for cohorts now undertaking the realigned problem-solving classes and problem-based learning in earlier years of the programme. This could be combined with a follow-up survey of the graduates who originally completed the undergraduate skills perception survey.

It would be interesting to study, in more detail, how perceptions of confidence in skills develops throughout the university career as well as the impact of skills development on the early years of industrial experience. Graduates do not stop learning once they leave university, and with such a diverse range of activities in the chemical engineering sector, further development of skills is of core importance to the industry. Further, work to understand what definitions are associated with various skills such as *effective communication* and *teamwork* would prove to be helpful for educators.

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Appendix

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

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Staff scoping survey

The purpose of this survey was to assess the expectations of staff with regards to student development during the design project. Staff were asked '*What skills do you think students require to undertake design effectively (i.e. for them to ideally have prior to design)?*' and several responses focussed on the importance of chemical engineering knowledge, which is not necessarily a skill but rather information accrual; related to this, several stated that the application of chemical engineering knowledge was required and this may have been the inference of those that simply stated knowledge (i.e. the presumption that it would be applied in the project). In addition to this, staff highlighted a number of other skills that fall into four main categories: ***communication skills***, including listening, written and presentation skills; ***criticality***, including analysis of literature, critical thinking, problem solving, assimilation and synthesis of information, identifying relevant information, critical evaluation (of self, others and information); ***management***, including time management, project management, leadership, teamwork, cooperation, prioritising tasks; ***creativity***, including how to cope with a lack of information or precision, decision making; as well as a determination to complete the project.

A follow-up question regarding staff perceptions of students' actual skills sets: '*What skills do you think the majority of students bring with them to design (i.e. that they actually have* *prior to design)?'* identified some of the skills highlighted above but nothing outwith the previously acknowledged expectations of staff. Again, technical knowledge was mentioned but this time many staff stopped at just that, while a few mentioned a plethora of the transferable skills outlined above (e.g. teamwork, problem solving, critical thinking, analytical thinking, e-working, information gathering, planning and organisation). The requirement to apply knowledge was tempered in perceived prior skill sets as several staff noted that students often demonstrated low confidence in applying their knowledge, and many said this extended to their transferable skills too; even those that thought this wasn't an issue mentioned that students tend to have difficulty in more advanced tasks e.g. problem solving and critical thinking. Despite creativity and criticality being identified as core to design, it was highlighted that the ability of students to willingly take responsibility or make decisions varies widely; this is compounded by the open-ended nature of design, with many staff recognizing that students often have an unwillingness to accept that of two options neither may necessarily be wrong, and they struggle with the required critical evaluation of which option is, therefore, 'best for them'.

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). Accordingly, staff were asked '*Do you think that the same skills or different skills are required for the two types of design (i.e. detailed and conceptual)?*'and, interestingly, only a quarter of surveyed staff believed them to be the '*Same'*, while the remainder were split between '*Different*', and quite worryingly, '*Not sure*'. This last category scores highly, identifying the fact that even staff actively involved in the teaching of the module (some for over 7 years) are unaware of the subtle differences in the two parts of the class, suggesting that students, who may not engage with the learning outcomes of the module, may be even further unsure of the exact differences between the two projects, possibly reducing development of any skills localised to the two aspects. Those indicating that they thought a difference did exist, commented that the delineation lay with the creativity of conceptual design, which also requires students to cope with 'missing information', while detailed design focussed more on core design skills and technical competencies, suggesting that other transferable skills are ubiquitous throughout.

Staff, seemingly, have the perception that students should be pre-equipped with a diverse range of skills, which some do possess but when asked '*Do you think students will need to develop new skills during design (i.e. during the whole design process)?*' all but one staff member said '*Yes*' students will need to develop new skills, suggesting that whether they have any prior skills or not, new skills development is still required and no students is fully 'pre-equipped' for design. It should be noted that the one person who answered '*No*' went on to discuss the skills that students develop in design, indicating some incongruity of thought. Unsurprisingly, all staff were affirmative in their response to '*Do you think students will need to expand on existing skills during design (i.e. during the whole design process)?*' strengthening the idea that students undergo skills development and enhancement during design. The follow-up question '*What skills do you think students will need to develop or expand during design (i.e. during the whole design process)?*' highlighted many of the skills mentioned above (project planning, time management, group working, technical knowledge, communication skills, decision making, making assumptions, problem solving, information/data gathering, judgement, reporting and critically evaluating information and report writing) but also identified new explicit areas, including 'thinking like a chemical engineer', meeting management/administration, e-working, self confidence in teams and working under pressure. This corresponded well with '*What skills do you think students actually do develop or expand during design (i.e. during the whole design process)?*' where staff listed all the responses above, including the newly identified skills, and added meeting deadlines, leadership skills and effective planning; this broadening of the identified skill set may be related to longer consideration of the skills involved as the survey progressed, indicating that full capture may not have occurred in the first stage of the questionnaire. As this was a scoping exercise, then all suggestions have been used to equally assist in the development of the quantitative undergraduate student surveys for the 2014-15 cohort.

As a vocational degree, it is often suggested that chemical engineering departments should focus on producing employees equipped for the chemical engineering sector, whereas the academic focus, at least at Strathclyde, looks to produce highly numerate and skilled employees for a range of sectors and further study. Hence, staff were asked '*Do you think that skills development during design should be aligned to industrial needs for graduates?*' and, interestingly, all those supervising detailed design, which is more technical, responded '*Yes*'; the conceptual design supervisors were more divided between '*Unsure*' and '*No*'. This polarisation of opinion is not unexpected as there is a tendency for those with a first degree in chemical engineering to supervise detailed design, while conceptual design is overseen by staff from a range of first disciplines including physics, maths and chemistry, which are traditionally non-vocational subjects. Staff answering *'Yes'* to this question expanded by discussing the industrially related skills that they thought should be aligned, which included many of the transferable skills discussed above (communication, project planning, time management, group/team-working). Many of the creative aspects of conceptual design were highlighted: decision making, problem solving, gathering information, isolate relevant information, decision making, critical evaluation of self and others' work, creativity, synthesis and application of understanding. Technical knowledge was mentioned, again as a standalone item without reference to application. Interestingly, previously unidentified skills were mentioned, but were more about 'physical' training rather than skills development e.g. use of industry standard software and design codes but, more than one staff member highlighted that, there is a wide range of employers so the Department should avoid being too specific and seek to align the actual design problems to industry in an attempt to help students appreciate the relevance of the projects.

When asked '*Do you think distance learning students have different skills prior to design than full-time students?*' half of staff responded '*Yes*', and all but one of the rest were '*Not sure*'; the latter correlating with the fact that few staff have taught distance-learning design and most focus on full-time student teaching only, hence, there is limited value in the high affirmative response rate, other than the staff's perceived expectations of 'on the job' training.

Undergraduate student scoping survey

To complement the assessment of staff perceptions of skills requirement and development in *Design*, undergraduate students, including full-time and distance-learning students, embarking on the design project in January 2014 were also surveyed. It should be borne in mind that, of the survey respondents (n = 31), eleven had undertaken some form of industrial placement and differences in the responses of students, with respect to this prior experience, are highlighted in the following discussion. Students were first asked '*What skills do you think you will need in advance to undertake the design project effectively?*' and many responses were similar, at the macro level, to the staff survey but lacked detailed explanation of what the high-level descriptors suggested. For example, a vast majority said ***communication skills*** but only one expanded on this to include listening to and reasoning with colleagues. ***Creativity*** and ***criticality*** were also mentioned, again as standalone descriptors, as was ***research***, which often did not define what mode or focus was required.

Chemical engineering students are explicitly taught ***problem solving*** in all cohorts but it was interesting to note that, while this was a popular response, it was only the full-time students who made this suggestion, suggesting that there is greater emphasis to full-time students of the importance of the skill, which does not seem to fully translate to the distance learning cohort. The skill was again named as a discrete entity without explanation of what problem solving may entail; there is an assumption that students understand these terms but, if the full-time students are being told that problem-solving is important, maybe they are simply reiterating what they believe is an expected attribute without full cognisance of its application or impact.

Management was again mentioned, including time management, project management, equitable workload, teamwork, cooperation, organisation, planning/prioritising tasks and leadership, although it was exclusively students with industrial experience who also mentioned decision making and negotiation, possibly highlighting their importance in industry or, more like, their relative inattention during academic study. It was reassuring to see that a significant number of students identified that a good work ethic was required; although not essentially a skill, it is a mind-set that is advantageous when undertaking such a milestone project.

Students stated that IT skills, most notably proficiency in chemical engineering relevant software (e.g. Aspen or Mathcad) would be beneficial, but this is again more related to information accrual, and chemical engineering knowledge also was listed as a skill, although a few students did imply application was required rather than just implicit information accrual. It was interesting to note that those with industrial experience placed more emphasis on chemical engineering knowledge (including very specific items) than the inexperienced students, which disagrees with the findings of previous work where the import of knowledge diminished with post-graduate experience [32], reflecting the academic nature of the project.

Having identified the skills that they may need, students were asked '*What skills do you think you are bringing with you to the design project (CP407/CP413)?'* and a not insignificant number responded with the same skills as identified in the previous question, meaning that they either believe themselves to be ideally skilled to design or that, by listing their own, known skills, they have no appreciation of any other skills. Again students mentioned communication and management, along with some of the sub-skills therein, but there was a tendency, again, to summarise whole skill sets with one word e.g. communication; by contrast, only one student said that they brought problem solving abilities, despite the full-time cohort almost unanimously stating this was required, and the fact it is explicitly taught in semester one, preceding *Design*.

The concept of a good work ethic was echoed by many and it is notable that several of the industrially experienced students also stated their level of experience and area of expertise, more akin to a curriculum vitae. Technical knowledge was again mentioned, as well as computing proficiency and, while many stated innovation or initiative, no one student explicitly stated creativity or criticality.

When asked '*…do you think that the same skills or different skills are required for the two types of design?'* a handful of students were '*Not sure*' and the remainder were split equally with no appreciable difference with prior industrial experience. Of the students who indicated that different skills were required, most cited there was variance in the way of thinking that would be required for conceptual design, describing it as innovative, creative or lateral thinking, also with a need to undertake research. By contrast, the students indicated that it was only the depth and application of technical 'know-how' that set detailed design apart.

Nearly all students agreed that they '…should develop new skills during design' and '…expand on existing skills during design', hence, the follow-up question of 'What skills do you think you should develop or expand during design?' elicited a number of responses but the vast majority focussed in the skills already discussed. However, it is noteworthy that some students discussed refinement of skills and confidence building in these skills as something they would like to expand upon during design. The new skills identified, by a few students, were industry standards knowledge and compliance, safety and process control, which are again more related to information accrual, but also the highly valuable skills of delegation, collaboration and designing in a real world scenario, suggesting that these may have been implied in the macro-descriptors used previously.

A third of respondents had industrial experience prior to *Design* and all agreed that *'skills development during design should be aligned to industrial needs for graduates',* with all other respondents bar one stating that they were '*Not sure*', hence, it is recognised by all subsets that there is a need to align teaching with their desired end-goals, which is in some contrast to the staff responses. The skills that they '*consider to be industrially related and that should be aligned to design*' were along the same lines as those previously discussed but, for the first time, students explicitly mentioned 'thinking outside of the box', resource management, meeting deadlines and self-evaluation; while several others felt that aligning the actual project to a desired industrial sector, possibly even by allowing students selection of their project, would help them be more confident in applying for jobs and entering the workplace.

Students were also encouraged to voice any additional anxieties, and several were concerned with the following: possibility of being unable to find suitable supporting data to make decisions or design specific unit operations; the composition of groups to include members to balance their own skill set, and relatedly, an imbalance of either group work allocation or work-rate (interestingly both in that others would be slow and that they may be left behind by colleagues); understanding the marking criteria; a lack of practice in design; the level of supervision that would be offered. Distance learning students specifically stated managing their groups remotely, however this is the mode by which they have interacted solely during their degree to date and is a growing mode of interaction in industry so may, by others, be considered an advantage. A few students were less negative and mentioned that they expected to mature during the process and build confidence in their own abilities.

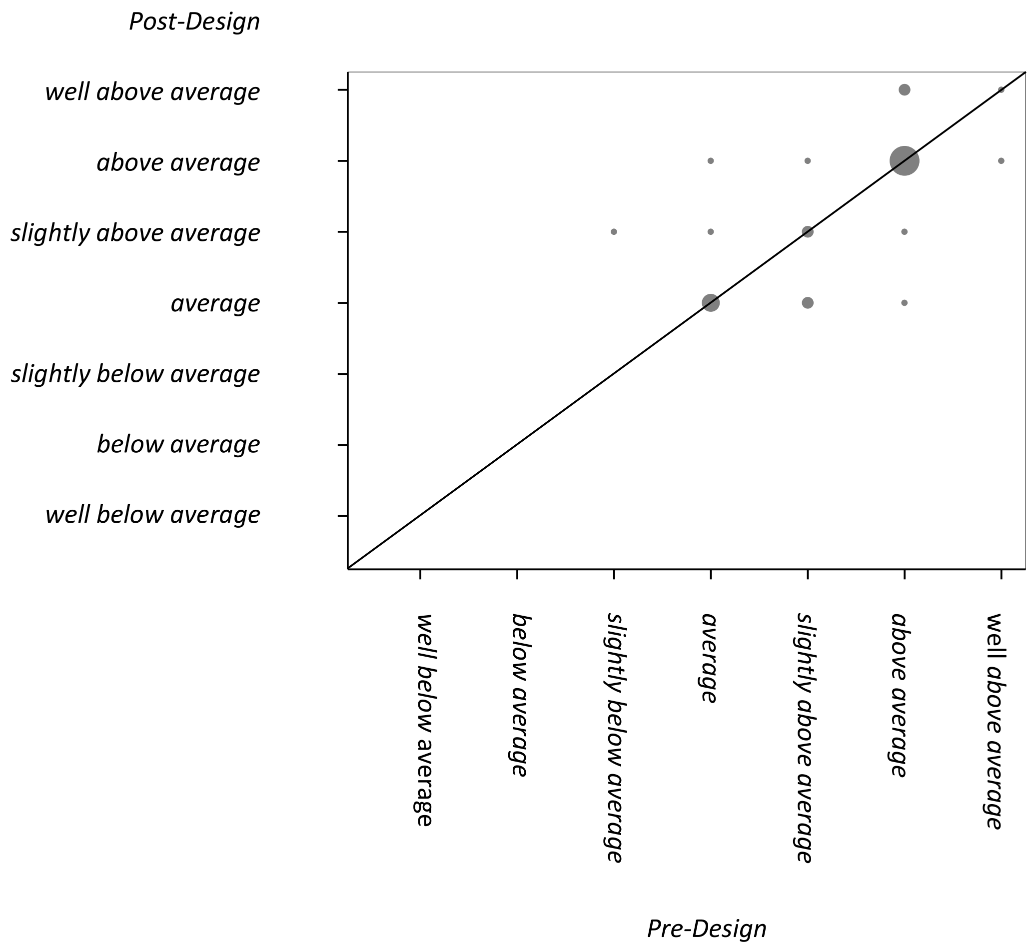

Figure A1: Bubble plot collating Likert responses of the 22 students that answered both pre- design (x-axis) and post-design (y-axis) surveys for listening ability.

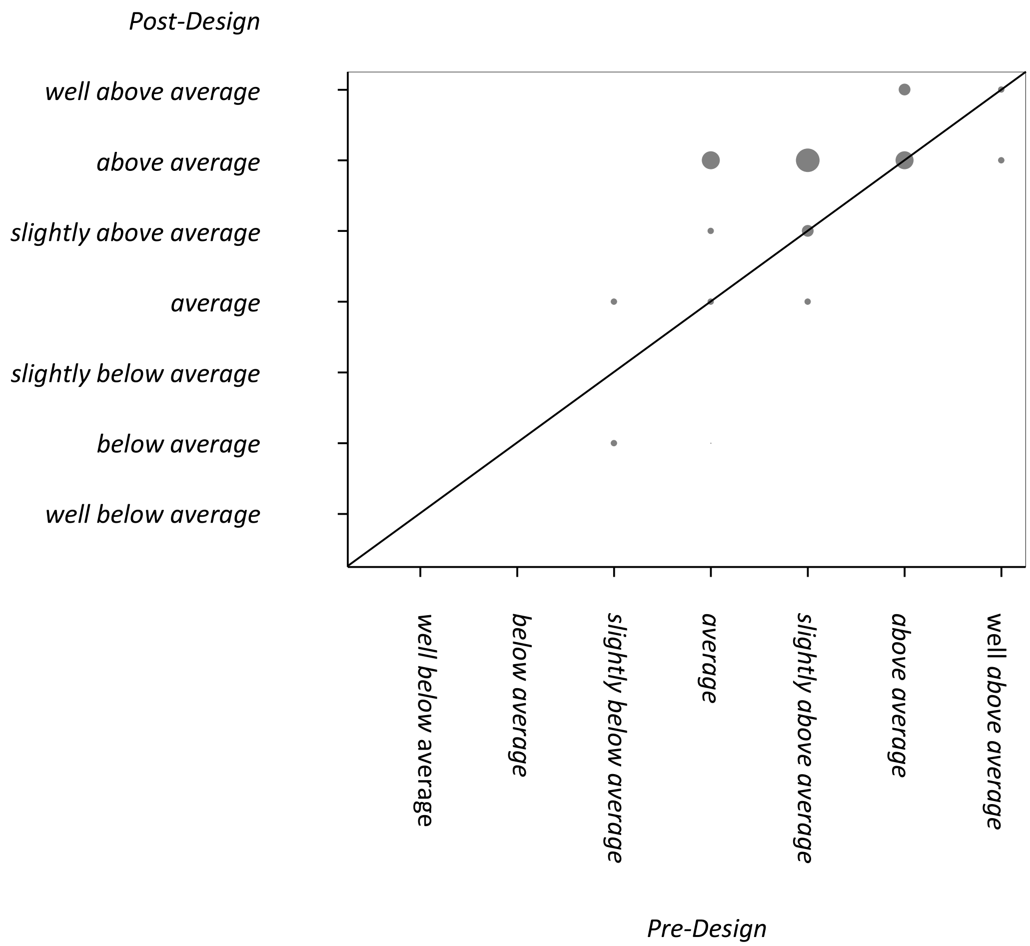

Figure A2: Bubble plot collating Likert responses of the 22 students that answered both pre- design (x-axis) and post-design (y-axis) surveys for time management ability.

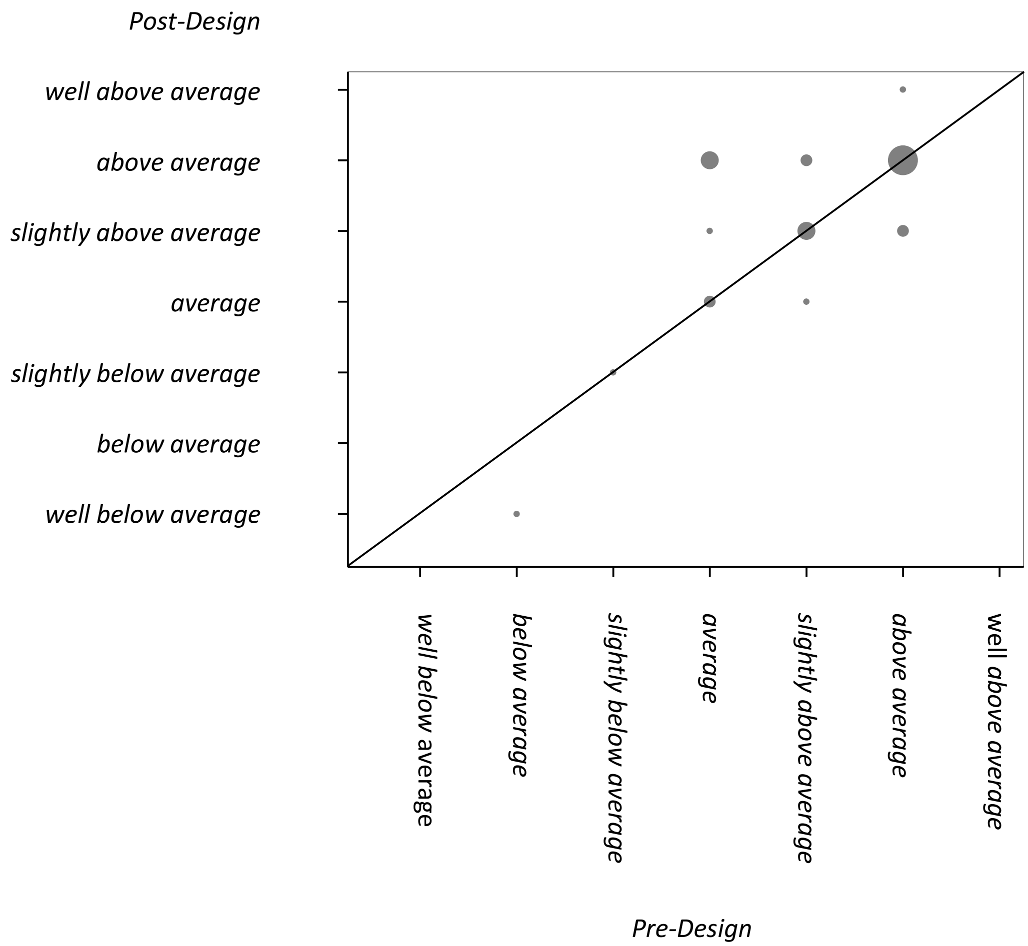

Figure A3: Bubble plot collating Likert responses of the 22 students that answered both pre- design (x-axis) and post-design (y-axis) surveys for leadership ability.

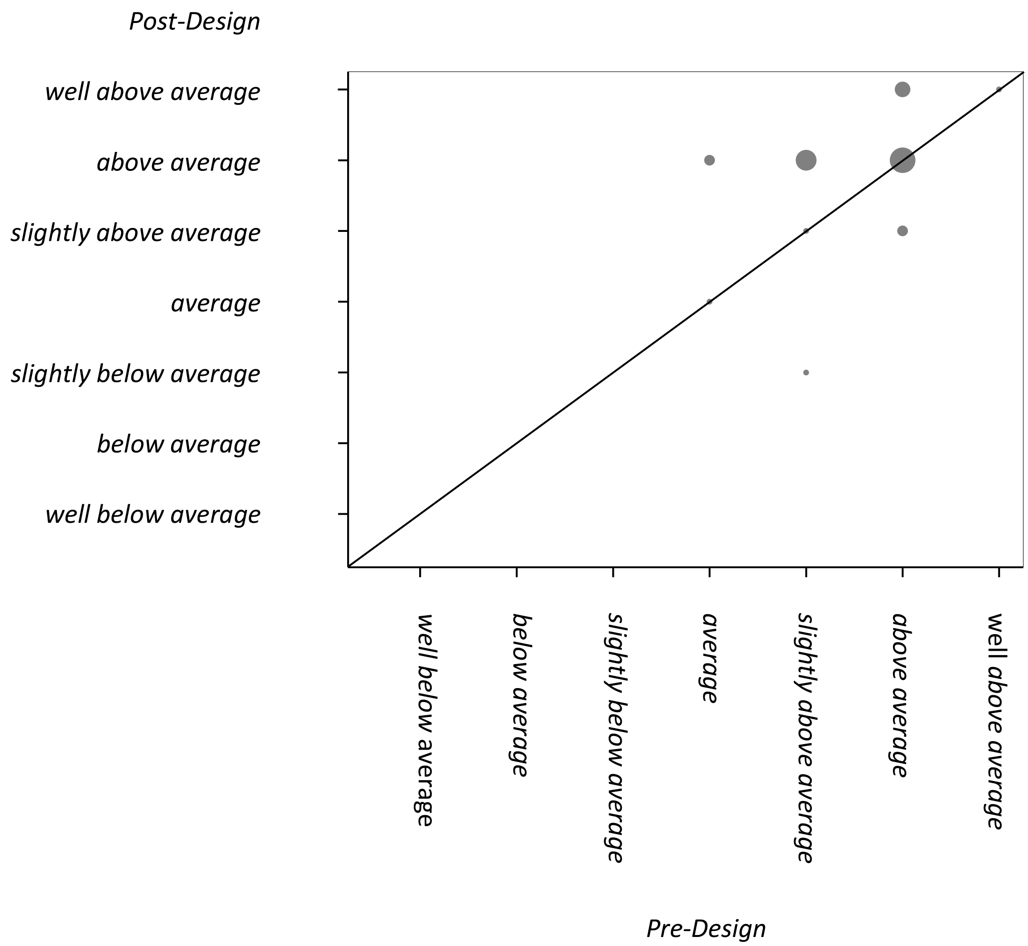

Figure A4: Bubble plot collating Likert responses of the 22 students that answered both pre- design (x-axis) and post-design (y-axis) surveys for ability to work with others.

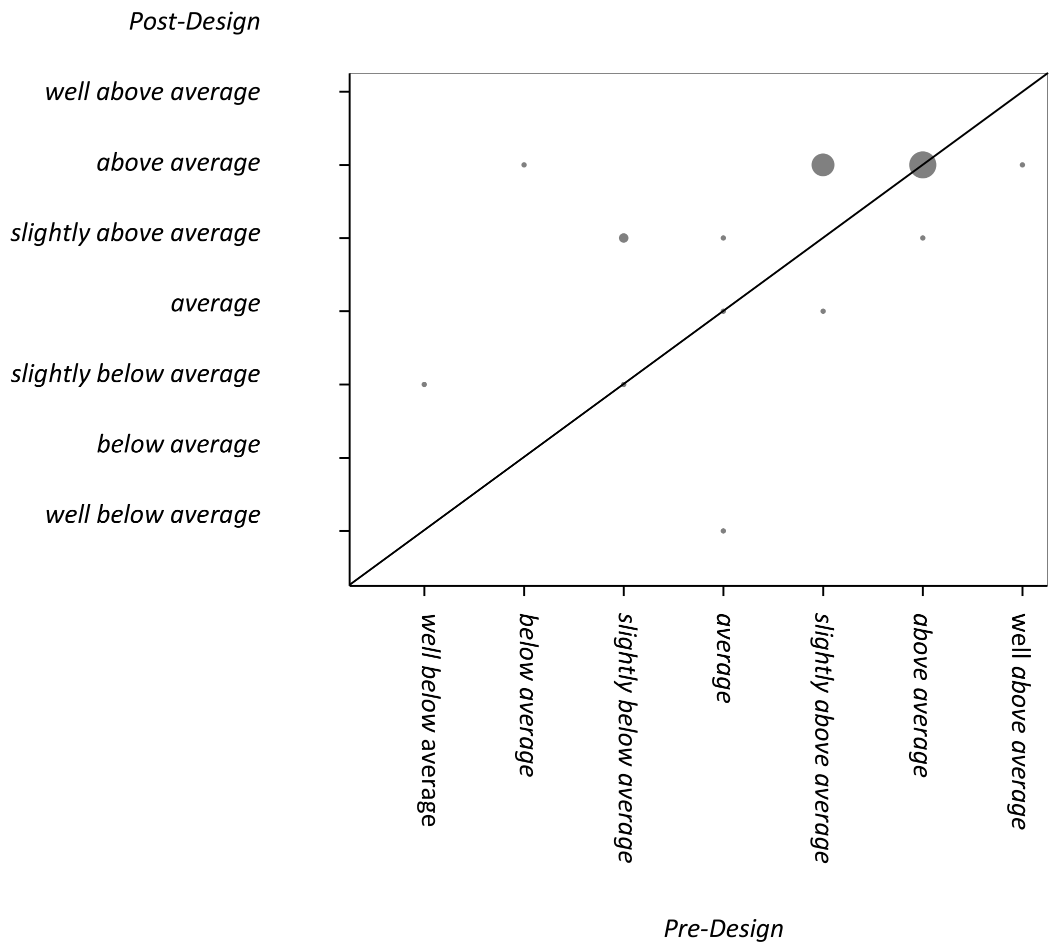

Figure A5: Bubble plot collating Likert responses of the 22 students that answered both pre- design (x-axis) and post-design (y-axis) surveys for decision making ability.

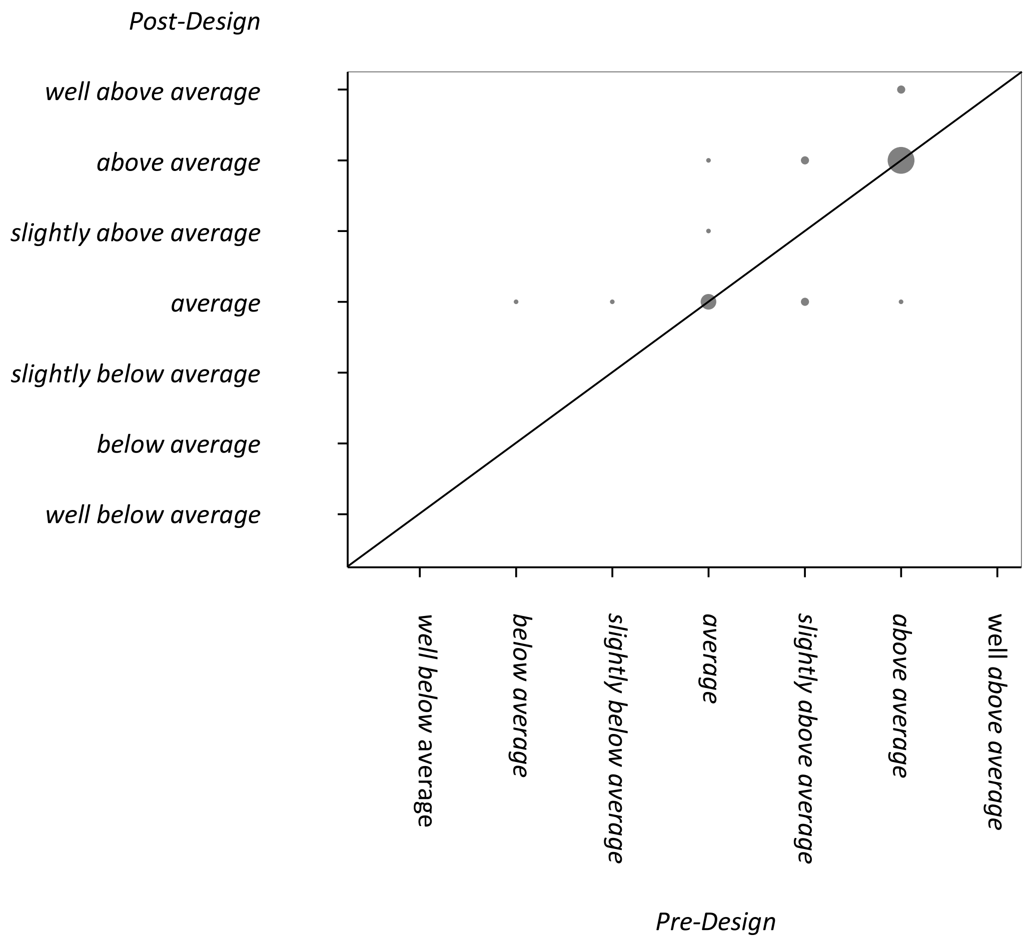

Figure A6: Bubble plot collating Likert responses of the 22 students that answered both pre- design (x-axis) and post-design (y-axis) surveys for word processing ability.

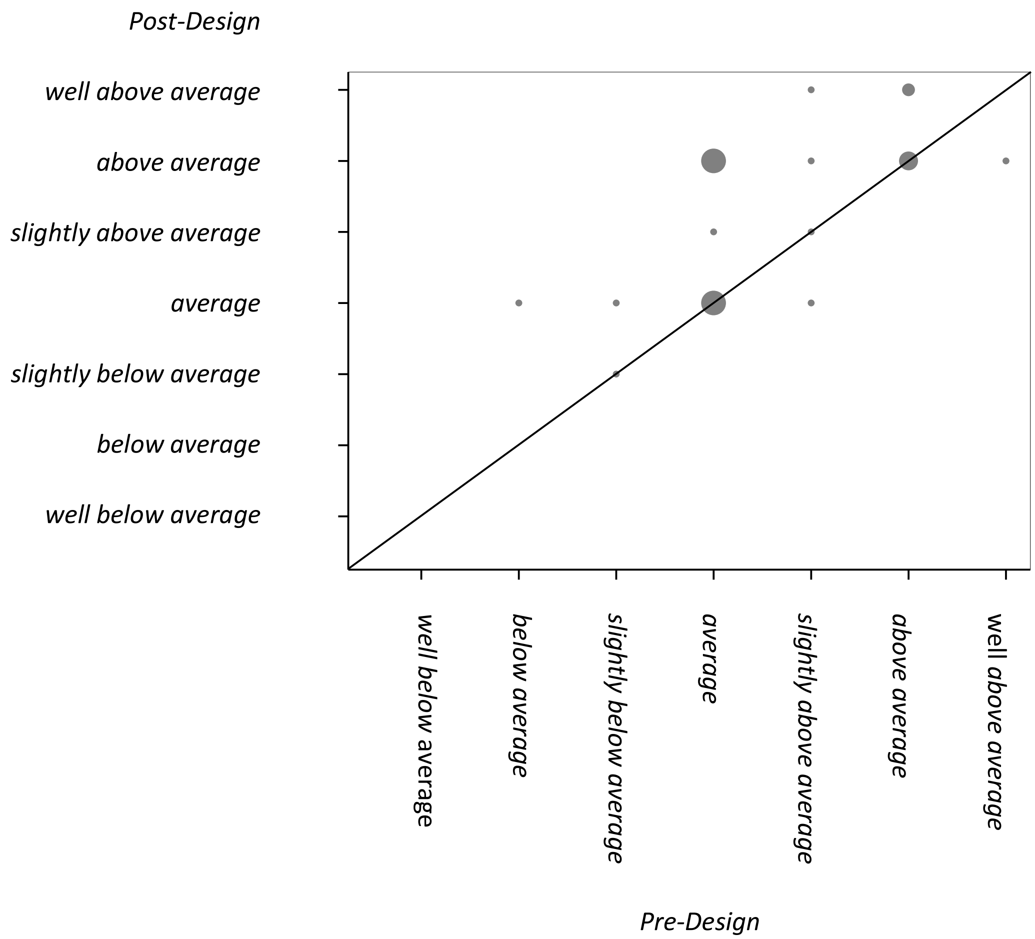

Figure A7: Bubble plot collating Likert responses of the 22 students that answered both pre- design (x-axis) and post-design (y-axis) surveys for information technology ability.

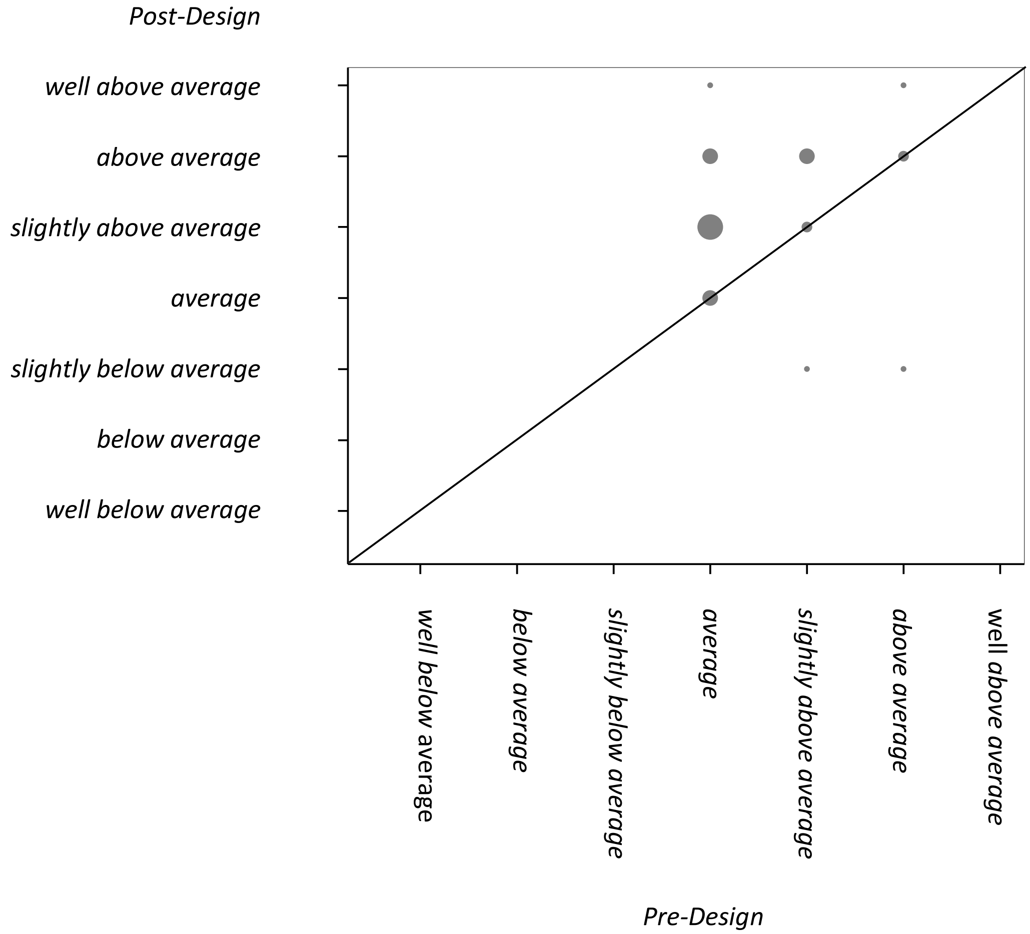

Figure A8: Bubble plot collating Likert responses of the 22 students that answered both pre- design (x-axis) and post-design (y-axis) surveys for ability to research the literature.