Evaluation of a redesigned Engineering degree founded on project based learning

Mark Tunnicliffe & Nicola Brown
School of Engineering and Advanced Technology, Massey University, New Zealand.
Corresponding author email: m.c.tunnicliffe@massey.ac.nz

CONTEXT: In 2012, Massey University of New Zealand offered a redesigned Bachelor of Engineering (Hons.) [BE (Hons.)] degree, using a curriculum based on the CDIO standards (www.cdio.org). It was redesigned at a time when the School of Engineering and Advanced Technology (SEAT) at Massey University had embarked on a strategic review of its offerings, and it replaced a well-established engineering programme. The Project Based Learning (PBL) ‘project spine’ was introduced, which consisted of a series of PBL courses throughout the BE (Hons). This was intended to address the need for graduates who are ‘rounded’ with stronger professional skills.

PURPOSE: This study was undertaken to determine whether the change to the structure of the BE (Hons.) programme had increased the alignment of graduates’ skills with the Washington Accord Attributes, particularly regarding professional skills, thereby increasing the relevance of the graduates to employers.

APPROACH: With ethics approval, this study was conducted using an anonymous on-line survey sent to the final year cohort of students following final examinations. This was done for the last cohort of students prior to the redesign and, for the first two cohorts after the redesign was implemented. The survey included questions rated using a Likert scale. Open-ended questions were also asked. Primary feedback was sought on a self-evaluation against the graduate competencies. Feedback was also sought on teaching, evaluation of the degree for the graduate competencies, feedback on assessments, staff and overall experiences. Staff that supervised individual student final year projects were also sent an anonymous on-line survey, where staff evaluated the supervised student against the graduate attributes using a Likert scale. Results for the three years are reported, including a statistical analysis of Likert scale questions, comparing the differences between means and testing for significance. Open-ended questions were reviewed to provide qualitative analysis of the data.

RESULTS: Although histograms of the self-evaluation responses by students rating their competency against the graduate attributes would suggest that the cohorts following the redesign rate themselves more highly for each attribute, statistical analysis suggests that the only significantly improved attributes (at 0.05 significance) are of a student being able to design solutions for complex engineering problems and their ability to assess societal, health, safety, legal and cultural issues. In comparison, histograms of staff evaluations do not suggest any differences in cohorts. However, analysis shows that students in the redesigned BE (Hons) programme are able to apply ethical principles and commit to professional ethics better than previously. Results suggest that the redesigned programme has a better balance of practical work and theory (at 0.05 significance), but the rate of feedback on assessments is worse compared with the old structure (at 0.05 significance). Overall students do not rate the restructured degree worse or better than the older degree.

CONCLUSIONS: Qualitatively, the redesigned BE (Hons) appears to give students more confidence in their ability as Professional Engineers. It is significant that their judgement of professional skills around applying engineering solutions to societal and cultural concerns has improved. It is also significant that the balance of practical and theoretical aspects of the degree appear to have improved, showing that a PBL-based engineering degree is assisting in reducing the gaps between original graduate attributes and the required graduate attributes. Further surveys of cohorts using more targeted surveys will confirm whether this is the case.

KEYWORDS : Project-based learning, engineering graduate attributes, soft skills, professional skills

Introduction

Massey University of New Zealand offered a redesigned Bachelor of Engineering (Hons.) [BE (Hons.)] degree, using a curriculum based on the CDIO standards (www.cdio.org), in 2012. A strategic review in 2010 of Massey University's School of Engineering and Advanced Technology's (SEAT) offerings resulted in the redesigned degree designed to ensure it offered a unique learning experience. The redesigned degree was aligned to revised accreditation criteria of the Institution of Professional Engineers of New Zealand (IPENZ). IPENZ had developed a National Engineering Education Plan, released in 2010 (IPENZ, 2010), which had identified the graduate attributes required from engineering education to increase the relevance of graduates' skills to what employers required and aimed to reduce the gaps between graduate attributes and professional competencies of the International Engineering Alliance (IEA, 2013) and the then current IPENZ accreditation criteria and graduate profile (Anderson and Goodyear, 2011). The curriculum architecture was developed with the consultation of faculty, industry, students and alumni, using focus groups and can be conceptualised as shown in Figure 1:

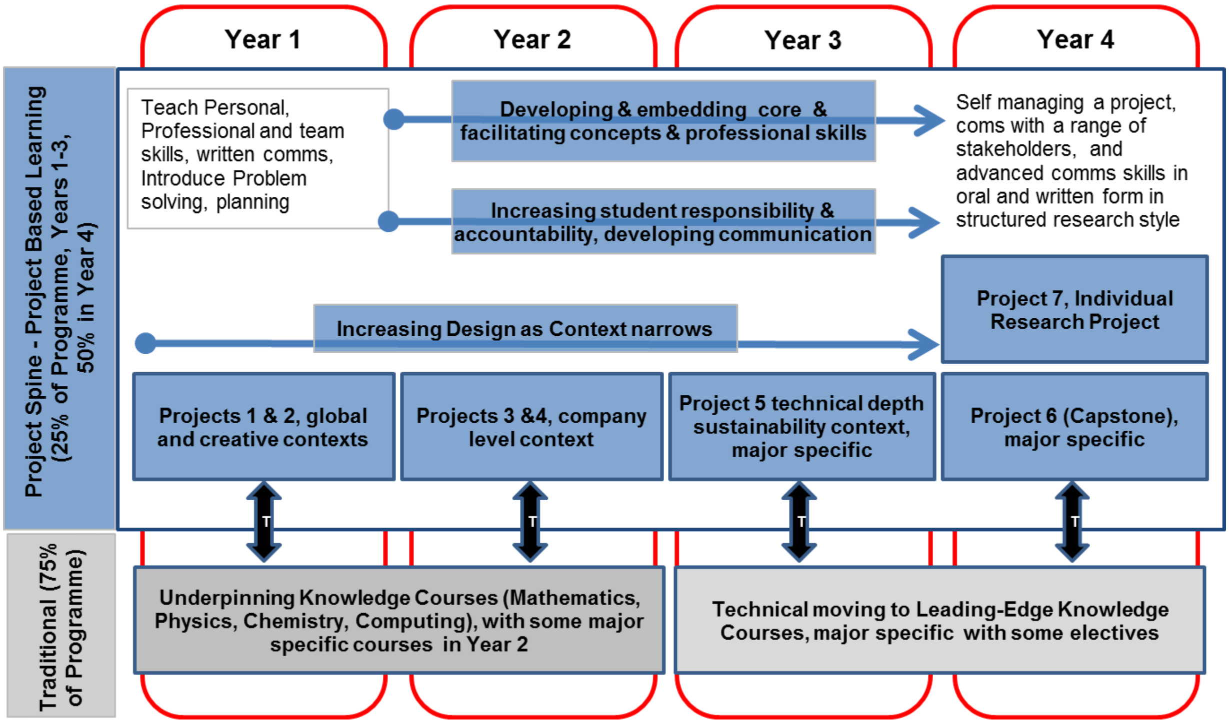

Figure 1 The BE (Hons) Curriculum Structure - post 2012

Before 2012 there were 15 majors within the programme but this was reduced to 4 following the redesign. The old programme, that had been in existence and evolved over 40 years, had a series of projects across the 4 years, but these were largely associated with specific papers (or subject areas). There was no serious intent to integrate subject areas - at least until the final year. For most engineering options there was a final year double semester 'design project,' which varied from major to major and could be individual or team based. There was no specific emphasis on the development of 'soft' or professional skills though some courses may have emphasised them at times. The new programme has a:

- Focus on project based learning in teams across all 4 years (25% of the programme)

- Where the projects are designed to integrate and apply knowledge learned in a specific year and,
- Where the projects are designed to introduce and embed problem solving principles in a range of contexts, and
- Where complexity and autonomy increase across the 4 years - leading to the final year capstone and research projects

The Project Based Learning (PBL) 'project spine' adopted by the redesigned programme was intended to address the need for graduates who are "rounded" with stronger "soft" or professional skills around teamwork, ethical considerations, sustainability, management and leadership, life-long learning and have a greater practical appreciation of the theoretical knowledge that they were being taught, as this mode of learning is believed to develop these skills more than a traditional learning approach (Mills and Treagust, 2003, Hadim and Esche, 2002). Project-based Learning in each year of an engineering programme is seen as the fourth principle towards guiding the transformation of Engineering Education for the greater engagement of students (Beanland, D; Hadgraft, R.; Mulder, KF; Desha, C.J.; Hargroves, K.J.; Howard, P. & Lowe, D., 2013). The 'project spine' has also allowed a practical implementation of the CDIO syllabus in this redesigned degree (Anderson and Goodyer, 2011).

The study aimed to evaluate changes in our graduates' proficiencies before and after the redesign, and identify areas for further improvement, using online surveys of both students and staff who had supervised those students. The study should also show whether the change to PBL has been effective in addressing the required professional attributes of an engineering education and will be of relevance to those in engineering education looking to introduce PBL.

Methodology

Students who had completed their Bachelor of Engineering in 2014, 2015 and 2016 were invited to take part in an online survey. The 2014 cohort had completed their degree prior to the degree redesign, while the 2015 and 2016 students completed the redesigned degree. In addition, staff who had been supervising these students during their final year project were also asked to evaluate their students' ability against the graduate attributes. The purpose of this was to provide an independent view of student performance from a staff member who had worked closely with the student on a yearlong project. This research was reviewed and approved by the Massey University Human Ethics Committee, Application SOB 14/51. The survey was administered independently and all identifying information was removed before the researchers were given access to the data.

The questions are based on the graduate attributes taken from the Washington Accord (the use of which is seen as the first principle in guiding the Transformation of Engineering Education, Beanland, D. *et al.* (2013)). These attributes are used by IPENZ for accreditation.

Students were asked to evaluate their ability in relation to each of the graduate attributes listed in Table 1. They were then asked to evaluate how well they felt the Massey University Engineering degree prepared them to achieve each of the attributes. Both of these questions were rated on a five point Likert scale with the options strongly disagree, disagree, neither disagree nor agree, agree, and strongly agree available for selection.

The following statements were then rated using the same Likert scale to gain further feedback:

In general the quality of lecture was high

In general the quality of practical exercises (e.g. labs) was high

The balance between lectures and practical exercises was about right

The balance of final exams and assessments during the semester was about right

The rate of feedback on your assessments was acceptable

The quality of feedback you received for your assessments was acceptable

Staff are experts in their fields

Staff are able to effectively communicate their expertise

Staff are friendly and approachable

The students were asked how they would rate their overall experience at Massey University and what the likelihood is that they would recommend Engineering at Massey University to others. These statements were rated using the Likert scale of poor, fair, good, very good and excellent.

Table 1: Graduate attributes used in survey

Key aspect referred to in this paper	**Full description given in survey**
Apply knowledge	Apply knowledge of mathematics, natural science, engineering fundamentals and an engineering specialisation to the solution of complex engineering problems.
Analyse	Identify, formulate, research literature and analyse complex engineering problems reaching substantiated conclusions using first principles of mathematics, natural sciences and engineering sciences.
Design	Design solutions for complex engineering problems and design systems, components or processes that meet specified needs with appropriate consideration for public health and safety, cultural, societal, and environmental considerations.
Investigate	Conduct investigations of complex problems using research-based knowledge and research methods including design of experiments, analysis and interpretation of data, and synthesis of information to provide valid conclusions.
Create	Create, select and apply appropriate techniques, resources, and modern engineering and IT tools, including prediction and modelling, to complex engineering activities, with an understanding of the limitations.
Societal	Apply reasoning informed by contextual knowledge to assess societal, health, safety, legal and cultural issues and the consequent responsibilities relevant to professional engineering practice and solutions to complex engineering problems.
Sustainability	Understand and evaluate the sustainability and impact of professional engineering work in the solution of complex engineering problems in societal and environmental contexts.
Ethics	Apply ethical principles and commit to professional ethics and responsibilities and norms of engineering practice.
Teamwork	Function effectively as an individual, and as a member or

Key aspect referred to in this paper	Full description given in survey
	leader in diverse teams and in multi-disciplinary settings.
Communicate	Communicate effectively on complex engineering activities with the engineering community and with society at large, such as being able to comprehend and write effective reports and design documentation, make effective presentations, and give and receive clear instructions.
Management	Demonstrate knowledge and understanding of engineering management principles and economic decision-making and apply these to one's own work, as a member and leader in a team, to manage projects and in multidisciplinary environments.

The staff were asked to evaluate each of the students they supervised during their final year project against the graduate attributes given in Table 1 and the Likert scale of strongly disagree, disagree, neither disagree nor agree, agree, strongly agree were available for selection. They were then asked to list key strengths and areas that the students needed to improve on. This was completed separately for each student.

A statistical analysis of Likert scale questions was conducted. The responses were scored 1-5 (1 being strongly disagree or poor, 5 being strongly agree or excellent) for each question and averaged. The differences between means were compared and tested for significance using a one-tailed t-test at 0.05 significance (5% confidence level (CL)), using a pooled variance, following the methods presented in Welkowitz, J., Ewen, R. B., & Cohen, J. (2002). The null hypothesis (H0) was that the means of the numerical response were the same between the cohorts, whereas the alternative hypothesis (H1) was that the mean of the responses for 2015-2016 was greater than the mean for 2014 – this implies that the redesign has created a positive effect. Open-ended questions were reviewed to provide qualitative analysis of the data to establish themes in the answers given by the students and staff.

Results and discussion

Student self-evaluation against graduate attributes

The numbers of student responses received were 19 in 2014 (15 completing the survey) from a cohort of 79 students, 6 in 2015 (3 completions) from a cohort of 85, and 23 in 2016 (16 completions) from a cohort of 89. As it is believed that there should be no difference in responses between 2015 and 2016, these results were combined due to the low numbers of responses in 2015. Students evaluated themselves against the graduate attributes shown in Table 1. A summary of the results for the self-evaluation is given in Figure 2.

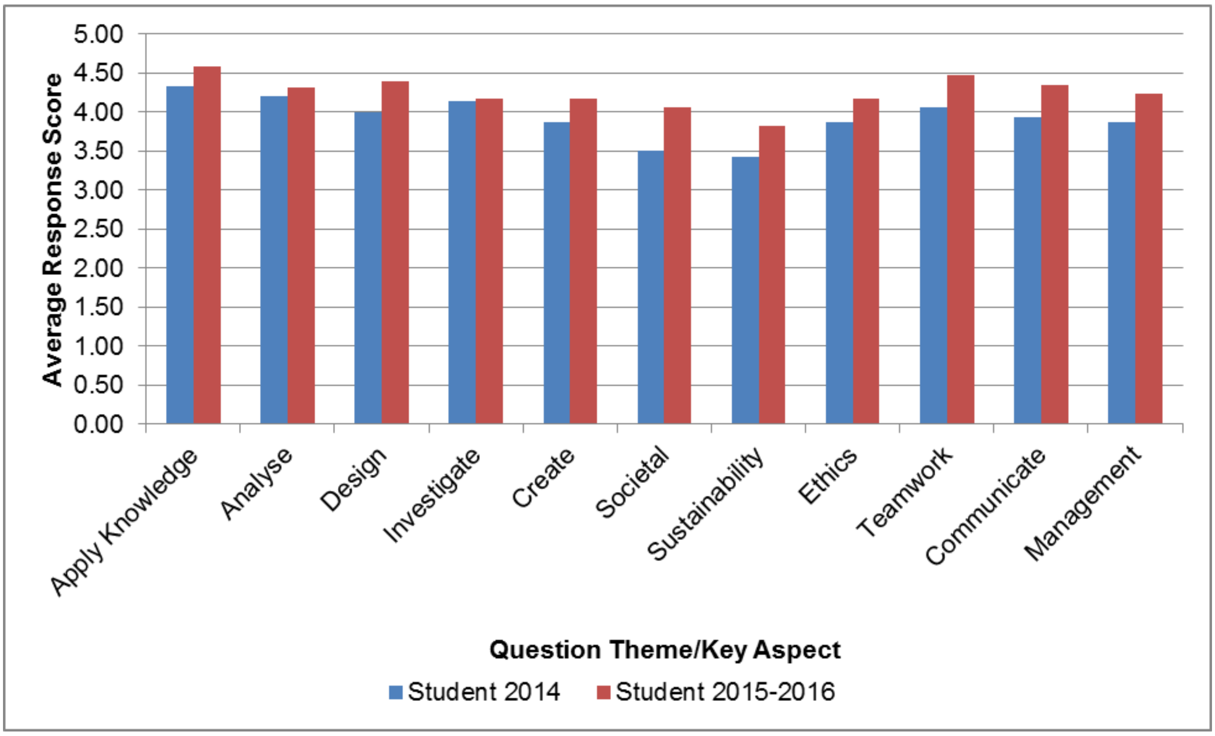

Figure 2 Student self-evaluation against the graduate attributes for BE (Hons)

It is observed that the students completing the redesigned degree from 2015 and 2016 rate themselves more highly against every attribute than the students from 2014. The largest percentage differences were approximately 9-10% for the assessment of Design, Sustainability, Teamwork, Communication and Management and, 15% for Societal attributes. A perception of strong ability in professional skills such as teamwork, communication and management is consistent with the observations of Lima *et al* (2006) when using Project-led education in an engineering programme and with the expected benefits of PBL (Frank *et al*. 2003, Mills and Treagust, 2003, Helle *et al*. 2006).

However statistical analysis of the results showed that there was only significant difference between the means of responses at 5% confidence levels, for the aspects of Design and Societal attributes. That students might be more confident in Design is consistent with the redesigned degree that uses a higher number of projects requiring students to design a solution. Societal attributes are consistent with the emphasis in the redesigned degree around context, sustainability and ethical considerations that are dependent on each other. It might be reasoned that there should be significance for aspects related to “teamwork” and other professional skills’ since ‘design’ occurs in situations that are complex socially (Palmer and Hall, 2011, Dym *et al*, 2005). Yet, although the students in 2015 and 2016 appear to rate themselves more highly, it is not clear that there is a real difference between the cohorts. The variance or spread in mean values of responses was often higher for 2014 and this can lead to a lack of significant difference. The larger variance might occur because the professional skills did not have the same emphasis in the older degree structure and therefore were not as well understood by that cohort.

Staff evaluation of students against graduate attributes

There was an evaluation of 32 students from 2014, 6 from 2015 and 22 from 2016 (combined into one group of 28 for analysis) by academic staff. Staff evaluated students against the graduate attributes shown in Table 1. A summary of the evaluation by staff is given in Figure 3.

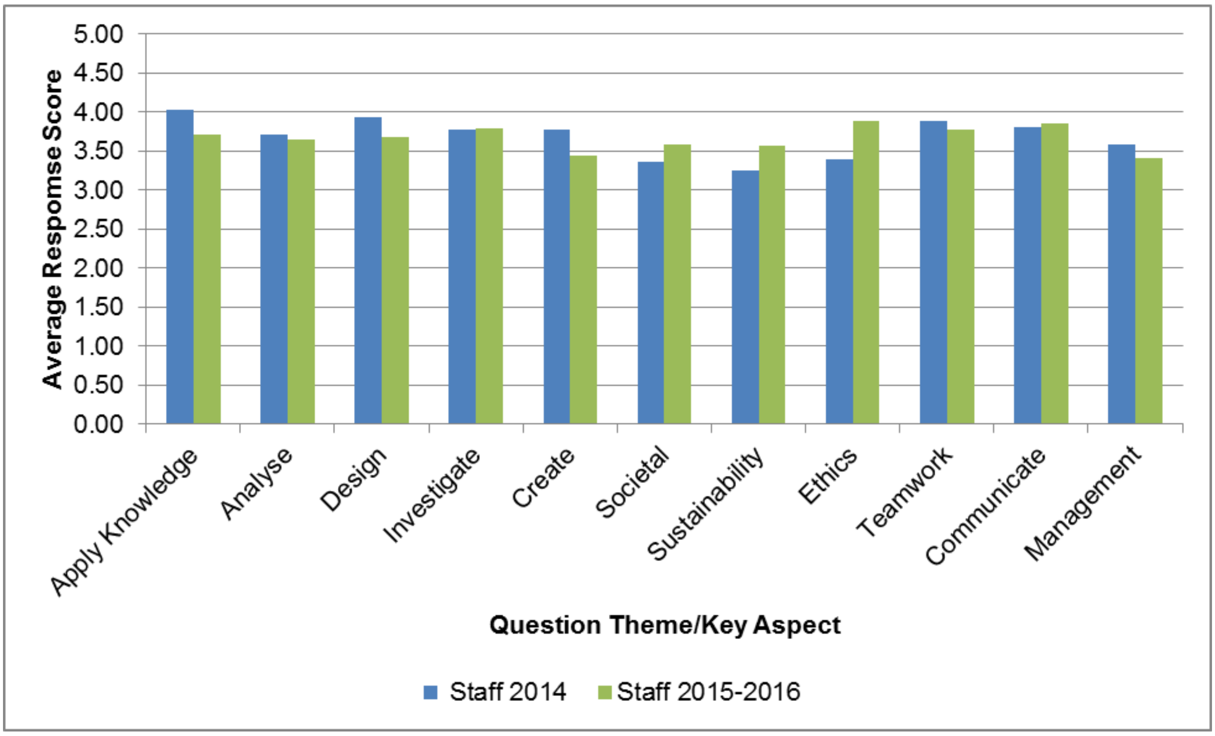

Figure 3 Staff evaluation of the student against the graduate attributes for the BE (Hons)

The staff evaluation of the student's ability against the graduate attributes contrast with the students' self-evaluation. Here the staff rate the 2015-2016 cohorts as less able in some of the attributes – those attributes associated with applying knowledge, analysing, design, creativity, teamwork and management. There is some agreement with the student self-evaluations as they rate the 2015-2016 cohorts more highly with respect to societal, sustainability and ethical attributes. Statistical analysis showed that at the 5% confidence level the only significant difference was around the ethical attributes (i.e. "This student is able to: Apply ethical principles and commit to professional ethics and responsibilities and norms of engineering practice.") Whether the staff or students are correct about improvements from the old degree to the redesigned degree cannot really be known. However staff comments for 2015-2016 on "what areas do you feel this student needs to work on?" reveal that the result on "applying knowledge" is seen as an issue. For example, staff made six comments on this theme such as; "Apply knowledge from other courses to projects" and "Applying the principles of science to the problem"

These comments were not made for the 2014 students. Written communication was a common area of improvement for all cohorts (5 comments in 2015-2016 and 8 comments in 2014). The result for teamwork is difficult to gauge as the final year project for individual students has changed between the old and redesigned degree from a design-build-test project to a research project. The redesigned degree introduced a final year team-based design-build-test Capstone project. Staff may not have seen the students working in the team in their final year, but it may also mean that students are compartmentalising learning to a course rather than across their work, which is similar to observations made by staff.

Student Evaluation of the Degree with respect to the graduate attributes

The students of 2015-2016 rated that the redesigned degree prepared them better for every graduate attribute except 'investigation' compared to the 2014 cohort. Table 2 shows the attributes that showed a significant difference in mean scores at 5% CL. Scores ranged from 3.17 to 4.25 (2014) and 3.75 to 4.62 (2015-2016). The average increase in means was between 2% ('create') and 21% ('societal'). 'Investigate' showed a reduction of 2%.

Table 2: Student evaluation of the degree with mean rating

Key Aspect	Cohort Mean Score (1-5_	
	2014	2015-2016
Design	3.67	4.38
Societal	3.17	4.00

For key aspects ‘design’ and ‘societal’ the mean value of the response was significantly different at 5% confidence levels. This could be due to a greater awareness of some concepts for the redesigned degree – the students in this degree are exposed to the concepts of societal context, sustainability and teamwork more often than before. The response for ‘design’ is likely to be an indication of the increased design content using PBL.

Student Evaluation of the Teaching, Assessments, Staff and Overall Experience

The number of students answering these sections of the survey was approximately half of the responding students overall. Only results significant at 5% confidence levels are shown, with the exception of the overall degree rating.

Table 3: Student Evaluation of Degree with Mean Rating for Questions

Question to evaluate	Cohort mean score (1-5)	
Please evaluate the following statements based on your experience throughout your Engineering studies at Massey University.	Student 2014	Student 2015-2016
The balance between lectures and practical exercises was about right	3.46	4.43
The rate of feedback on your assessments was acceptable	3.23	2.14
Overall how would you rate your experience here at Massey	4.50	4.40

Between cohorts there were no differences in how the students rated staff being experts, being approachable and communicating effectively. The results for teaching showed that the students felt there was much better balance between practical work and lectures in the redesigned degree though the quality of the practical work and lectures was similar. Students in 2015-2016 commented that “the amount of practical experience…is much higher at Massey” and “…appreciated the smaller class sizes and practical skills I have learnt”. This is in contrast to 2014 where comments were “there not a lot of practical exercises” and “…there were lots of lectures which did not have practical exercise and had only theory…” The main increase in practical work has been through using the project spine in the redesigned degree. This is encouraging, suggesting an improvement in the degree structure. Practical work has been seen to be one of better aspects of PBL (Palmer and Hall, 2011).

Feedback on assessments is clearly an issue in the redesigned degree. Although the quality of feedback was not significantly different, the rate at which feedback was returned was rated much lower by 2015-2016 compared to 2014; similar feedback issues have been observed elsewhere (Palmer and Hall, 2011, Lima *et al*. 2007). Seven out of ten students in 2015-2016 comments on feedback concerned the slow rate of return of feedback and its poor quality.

The overall evaluation of the degree showed that the 2015-2016 cohorts rated their experience and the degree slightly worse than the 2014 cohort but this difference is not statistically significant at 5% CL. It suggests that the redesigned degree has not yet achieved a desired outcome of a degree with greater engagement and appeal for students compared to the old one. As the students of 2015 and 2016 were the first ones through the redesigned programme any implementation difficulties would have been perceived negatively.

Conclusions

Qualitatively, the redesigned BE (Hons) appears to give students more confidence in their ability as Professional Engineers. It is significant that their judgement of professional skills around applying engineering solutions to societal and cultural concerns has improved. Although the trends shown were not significant, it is an indication that the students understand and are more aware of the importance and use of professional skills in terms of ethical, sustainability, teamwork and managerial considerations as well as a greater appreciation of design aspects, which has been shown elsewhere (for example Frank *et al*, 2003). Staff believe some aspects around professional skills have improved but are unchanged or worse in other aspects such as in the application of knowledge. It is also significant that the balance of practical and theoretical aspects of the degree appear to have improved, and improvement in these areas shows that a PBL-based engineering degree is assisting in reducing the gaps between previous graduate attributes and the required graduate attributes. Further surveys of future cohorts will be more targeted with specific questions for areas of improvement.

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