Understanding Student Engineers Perceptions of Their Own Capacity for Thinking Creatively and Analysing Problems

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SESSION C3: Integration of teaching and research in the engineering training process

CONTEXT Insight into student understanding of their own learning is a key element in being able to design and implement effective approaches in student-centred learning. In this paper we examine the findings of a preliminary study into student perceptions of their own capacity for thinking creatively and analysing problems. This study serves as a pilot to a larger joint University study between Queens University, Canada and The University of Adelaide, Australia involving engineering-design students. Results of the pilot study will inform the conduct of a proposed longitudinal study, projected to be administered over a three year period.

PURPOSE The purpose of this study is to investigate student understanding of their own capacity to develop skills in thinking analytically and creatively in a second-year mechanical engineering design course.

APPROACH A two part instrument based on, but not replicating, Student Experience of Learning and Teaching (SELT) questionnaires has been administered to second-year undergraduates studying Design Practice in Mechanical Engineering. The questionnaires were designed to elicit information relating to student opinion, experience and self-assessment of their capacity for thinking creatively and analytically. The survey instrument is both quantitative and qualitative in nature and is prefaced by a small section for collection of demographic data. A mix of open-ended questions and likert-scale questions were included.

RESULTS A preliminary examination of the results of the two-part survey reveals an enormous depth of data indicating detailed self-assessment reflections from the participants. This paper focuses on the qualitative responses, using an open-coding method, commensurate with grounded theory, through which themes emerge from the data. Results of the open-coding indicate initial identification of their preferred approaches to problem investigation, as well as a recognition of their capacity to further develop critical and creative thinking. Preliminary analysis of quantitative data is also provided in this discussion.

CONCLUSIONS One hundred and twenty two students representing 54% of the class responded to the pre self-assessment survey and one hundred and four students (47% of the class) responded to the post self-assessment survey. The approximately 3,000 student responses, to the pre and post questionnaires, indicate the preparedness of students to engage in reflective practice related to their own learning. Whilst open coding of the responses provides some level of understanding of how students characterise this learning, the degree to which the learning has had a positive effect is yet to be examined in detail. However, it is evident that a significant number of students identify that their capacity for creativity and problem analysis increased over the semester long course.

KEYWORDS Critical and creative thinking, self-assessment, assessment for learning, and research as learning.

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Introduction

Strong connections between creative thinking and problem solving in engineering have long been recognised. However, despite the emphasis placed on creativity as a 'key capability that engineering students should master' (Zhou, 2012), less is known about students perceptions on their own understanding and development of creative capacity in engineering.

According to Cropley and Cropley (2009) in engineering, the success of the Russian satellite 'Sputnik I', in 1957, was linked to 'superior creativity' of Russian engineers. Dickson (2001, cited in Cropley, 2016) identifies this event, characterised as 'Sputnik Shock', to be the catalyst for recognition and inclusion of creative approaches as an essential part of engineering problem solving. 'Sputnik Shock' was considered

> *'…pivotal to the process of linking creativity (the generation of effective novelty), innovation (the exploitation of effective novelty) and engineering (the design and development of technological solutions to problems) in a systematic and scientific way.'*

This process has generated a growing body of knowledge around recurrent themes and connections between divergent thinking, innovation, creativity, problem solving and the engineering design process (see for example Dym and Little, 2004, Snider *et al.,* 2013, Howard *et. al.,* 2008). Additionally, the importance of creativity as a key capability of future engineers has been discussed by numerous bodies including the (US) National Academy of Engineering (2004), which names creativity as one of nine attributes essential to 'The Engineer of 2020' and by UNESCO in their 2010 report 'Engineering: Issues, challenges and opportunities for development'.

The importance of creative and critical thinking in engineering problem solving is also acknowledged by Engineers Australia (2013), in the Stage 1 Competency Standard for Professional Engineers. Competency 3.3 ' Creative, innovative and pro-active demeanour', encapsulates this in the expectations that engineers apply 'creative approaches to identify and develop alternative concepts, solutions and procedures…'. However, the development of approaches to foster creativity amongst engineering students' remains poorly understood (see for example Ballie, 2002, Cropley, 2016). Therefore, to inform learning and teaching practice in creative and critical thinking it is important to firstly gauge students own perceptions of their understanding, and of their own learning approaches.

As part of a larger study into the development of students' analytical and creative skills in the context of a second-year design course, this paper reports on a preliminary investigation into students' self-perceptions of their own learning in these areas. This study also serves as a pilot to a larger comparative study between Queens University, Canada and The University of Adelaide (UoA), Australia. Results of the pilot study will inform the conduct of a longitudinal study, projected to be administered over a three year period.

Methodology

The design of this research study is based on grounded theory and principally reflects a social constructivist approach (see for example Vygotsky, 1978, Wood *et al.,* 1976). Grounded theory has been chosen because of its use in understanding social phenomena. Using a grounded theory design was also decided upon because of the action based nature of the approach, and because this approach is reflective and co-participatory; involving both the respondents (students) and the researchers (educators) in the processes of learning. As students complete the surveys they are prompted, by the nature of the questions, to engage in higher order reflective practice, including evaluative and analytical reflection on their learning. In a similar manner to that of inquiry-based learning, the methods used in this research study are constructivist and presume a social context within which students' perceptions of their learning and specific capacities in different areas are formed. For the purposes of this study, the social context is assumed to be the “classroom”.

Adapting some aspects of the of Queens University, Student Assessment of Teaching (USAT) questionnaire to the context of a second-year design course a two part questionnaire was administered to undergraduates studying Design Practice (Mech. Eng. 20) at The University of Adelaide. The questionnaires were devised to elicit information relating to student opinion, experience and self-assessment of their capacity for thinking creatively and analytically. Whilst the survey design is based on USAT, the form and intent of the design has a direct correlation to the Student Experience of Learning and Teaching questionnaire of The University of Adelaide (SELT), in that both surveys contain a mix of Likert scale measures and open-ended questions. The similarity of the questionnaire styles was intentionally chosen to provide a sense of familiarity and promote a more relaxed atmosphere for student respondents.

To ensure anonymity of the respondent’s names were removed from the submissions. A research assistant external to the course was engaged for this part of the process and for the open-coding. Students from within the course have, subsequent to course completion, been involved in analysis and discussion of the data.

Questionnaires

For the current study, the first of the specifically designed questionnaires was administered to the target populations within the initial week of commencing the second year Design Practice (Mech. Eng. 2100) course. The second questionnaire was then administered at the end of the course and before examinations.

Self-Assessment Survey 1 (SAS1)

This survey instrument, consisting of 13 questions, was the first to be administered. The following four open-ended were designed to help students contextualise the nature of the survey.

1. *What capacities and abilities do you, personally, possess and which you consider contribute to you being an effective student engineer? Include reasons why you think each one contributes to your effectiveness.*
2. *How do you feel about having to study Design Practice as a core course?*
3. *What are your explicit goals for completing Design Practice?*
4. *How will you recognise if you have met your goals?*

The Likert scale statements were designed to provide students with a scale on which to quantitatively rate their own understanding of thinking critically and creatively in relation to problem solving upon entering the course, for example;

5. *I am easily able to devise alternative solutions to engineering problems.*
6. *I am easily able to apply the design method to solving engineering problems.*

8. I can readily identify constraints and define specifications related to engineering problems.

9. *I have high level skills in thinking analytically*

Four of the quantitative statements were followed by opportunities for the respondents to comment on reasons or examples to elucidate their answers.

10. I am a highly creative thinker.

Provide example(s) to illustrate your answer.

11. I have high level skills in solving complex problems

Provide example(s) to illustrate your answer.

12.Thinking creatively is a valuable skill for professional engineers.

What practices, processes and 'tools' do you employ to promote creative thinking in your own engineering studies?

13.Engineers use a broad number of processes and 'tools' to optimise their capacity to solve complex problems.

What practices, processes and 'tools' do you employ to promote your own capacity to solve problems?

Self-Assessment Survey 2 (SAS2)

This survey instrument, consisting of 16 questions, was administered as the end of the semester. The first four questions are deemed exit information, requiring the respondents to engage in higher order reflections by justifying their assessment.

1. Did your understanding of your own capacities and abilities, which you consider contribute to being an effective student engineer, change over the course of your studies in Design Practice?

In what ways?

2. Did your feelings about studying Design Practice change over the course of your studies?

Please explain why / how.

3. Did your explicit goals for completing Design Practice change over the course of your studies?

Please explain why / how.

4. In what ways have you now have met your goals?

The eleven subsequent questions refer directly to student's individual perceptions of their own learning and how it may have changed over the semester; in this case their perceptions are rated upon completion of the course. Four of these questions are quantitative with answers to be recorded on a seven-point Likert scale, designed to enable students to attach a measurement against their response.

7. My capacity to identify constraints and define specifications related to engineering problems has increased.

9. Over the course of Design Practice my ability to think about what I am doing and why, when solving engineering problems, increased.

10. As a result of Design Practice, I am confident that I can advance my own practice in solving engineering problems.

11. My capacity to draw conclusions from my experience, activities and outcomes, and extrapolate to other situations has increased as a result of studies in Design Practice.

Seven questions are designed to elicit a measure of agreement or disagreement to a statement (on a separate likert-scale) plus opportunity for qualitative comment, providing opportunity for the students to qualify their reasoning (on level of agreement/diagreement).

5. My capacity to devise alternative solutions to engineering problems has increased.

In what ways?

6. My capacity to adapt the design method to non- engineering problems, in order to optimise potential solutions has increased.

Please provide examples.

8. Reflecting on your skills at the beginning of the course; how would you rate yourself at that time, "I can readily identify constraints and define specifications related to engineering problems."

Why do you think this has changed / not changed?

12. My capacity to think creatively and apply creative ideas to complex technical problems has increased as a result of my studies in Design Practice.

Provide example(s) to illustrate your answer.

13. I enjoy solving complex engineering problems

Provide reasons for your answer

14. My self- motivation to learn has increased over the course of Design Practice.

Provide evidence from your experience or activities to exemplify your answer

15. My desire to further develop skills in thinking creatively and problem solving has increased over the course of Design Practice.

How might you apply these skills to other areas of your studies or life?

The final question relates to recommendations of ideas for further fostering students' capacity to think creatively.

16. Please suggest ideas for how you think we could help students develop their capacity for creative thinking and complex problem analysis.

The nature of this question falls within the highest level of reflective practice; concluding reflection, 'a reflection that draws conclusions' from the students 'experience of the activity' (Dowling *et al.,* 2013, p.196).

Method of Analysis

Over 3,000 responses, from students' to the pre and post course self-assessment questions, were recorded. This paper focuses on the qualitative responses, using an open-coding method, commensurate with grounded theory, through which themes emerge from the data. The nature of grounded theory dictates that the method of analysis of the data is interpretive. To assist in the analysis, the researchers need to be engaged in a continuous process of reading, reflecting and reviewing in order to confidently identify, record and propose relationships between themes, concepts and categories emergent from the data.

As SAS1 contained demographic data, it introduced a risk of researcher bias in the grouping of long answers. Therefore, for the data analysis, the demographic information from SAS1 was removed to prevent bias from influencing the coding.

Beginning with the first question, the data were then grouped in the following fashion.

1. After reading through the data several times and making notes on the properties of tentative groupings, the first 40 respondent answers were re-read as a sample and a series of 2-4 discrete themes were identified. Note that NA (Not applicable) is not a theme, but is considered a valid response.
2. The data, related to each question was then classified according to the appropriate theme.

This process was repeated in a similar manner for the SAS2 dataset, with the exception of demographic data, which was not part of the SAS2 dataset. In this case a series of 2-5 discrete themes were identified.

Results and Conclusion

Results of the open coding indicate initial identification of students’ preferred approaches to creativity and problem investigation, as well as a recognition of their capacity to further develop critical and creative thinking. For each question between two and five themes emerged. Across the responses in SAS1 29 separate themes have been identified through the initial open coding, and an additional 40 themes have emerged from the responses in Survey 2. Whilst a more detailed level of coding is yet to be undertaken, some preliminary analysis has been attempted with qualitative, open-ended questions, selected to allow the direct comparison between Survey 1 and Survey 2, listed in Table 1. The themes listed are ranked and the number of responses are indicated in brackets.

Table 1. Evolvement of themes between Survey 1 and 2.

1. ***Capacities and abilities, which you consider contribute to being an effective student engineer***				
S-1	1. Developmental (42)	2. Analytical (38)	3.Team (11)	
S-2	1. Understanding (48)	2. Skills (27)	3. Teamwork (15)	4. Communication (3)
2. ***Feelings about having to study Design Practice as a core course***				
S-1	1. Practical (41)	2. Intellectual (40)		
S-2	1. Understanding (44)	2. Interest (19)	3. Workload (11)	4. Team (9)
3. ***Goals for completing Design Practice***				
S-1	1. Developmental (57)	2. Academic (25)	3. Competitive (9)	
S-2	1. Developmental (46)	2. Academic (25)	3. Competitive (6)	
4. ***How will you meet / have you met your goals?***				
S-1	1. Academic (41)	2. Developmental (37)	3. Competitive (7)	
S-2	1. Developmental (60)	2. Academic (29)	3. Competitive (7)	

Themes for both Q1 (*Capacities and abilities, which you consider contribute to being an effective student engineer*) and Q2 (*Feelings about having to study Design Practice as a core course*) significantly evolved between Survey 1 and Survey 2. Themes changed and their number increased from 3 to 4 for Q1 and from 2 to 4 for Q2 suggesting change in students’ perception of the course and its requirements associated perhaps with increased level of understanding allowing more detailed assessment. In Q1 in Survey 1 majority of students listed developmental abilities (e.g. logical thinning, self-discipline) and analytical abilities (maths, physics) as most important with some students also emphasizing the importance of working in a team. In Q2 in Survey 1 students anticipated the course to expose them to both practical (e.g. application of theory to practical problems) and intellectual (e.g. learning specific design skills) development. In Survey 2 answers to both Q1 and Q2 shifted to more general understanding (understanding of Design Process with its many aspects and complexities including problem solving skills and creative thinking) making it by far the largest theme.

Themes for Q3 (*Goals for completing Design Practice*) did not change significantly with developmental theme by far largest followed by academic and competitive groupings.

Interestingly in Q4 *(How will you meet / have you met your goals?)* there was a big shift from academic to developmental theme between Survey 1 and 2 with students realizing that the main indicator of achieving their goals was their ability to learn how to tackle engineering problems rather than high marks. This realization was reflected in the Survey 2 quantitative questions (summarized in Table 2) and many comments.

Table 2. Survey 2 – Summary of Likert scale statements

Statement	Agree %	Neither %	Disagree %
5. My capacity to devise alternative solutions to engineering problems has increased.	84	15	1
6. My capacity to adapt the design method to non-engineering problems, in order to optimise potential solutions has increased.	62	36	2
7. My capacity to identify constraints and define specifications related to engineering problems has increased.	88	11	1
8. Reflecting on your skills at the beginning of the course; how would you rate yourself at that time, "I can readily identify constraints and define specifications related to engineering problems."	51	33	16
9. Over the course of Design Practice my ability to think about what I am doing and why, when solving engineering problems, increased.	83	16	1
10. As a result of Design Practice, I am confident that I can advance my own practice in solving engineering problems.	76	23	1
11. My capacity to draw conclusions from my experience, activities and outcomes, and extrapolate to other situations has increased as a result of studies in Design Practice.	75	23	2
12. My capacity to think creatively and apply creative ideas to complex technical problems has increased as a result of my studies in Design Practice.	70	27	3
13. I enjoy solving complex engineering problems.	78	21	1
14. My self- motivation to learn has increased over the course of Design Practice.	65	32	3
15. My desire to further develop skills in thinking creatively and problem solving has increased over the course of Design Practice.	77	19	4

The quantitative questions in Survey 2 indicate students' belief that their ability to solve engineering problems improved over the course of Design Practice. Q9 referring to overall ability to solve engineering problems received 83% broad agreement, this was supported by Q5 referring specifically to capacity of devising alternative solutions (84% broad agreement), and Q7 referring to capacity to identify design constraints and define specifications (84% broad agreement).

While asked if the course helped them to develop creative thinking in relation to technical problems the broad agreement was also high (70% for Q12) with related Q11 on ability to extrapolate their experiences with 75% broad agreement and Q10 (ability to advance practice in solving engineering problems) with 76% broad agreement. In Q6, which received a slightly lower but still high 62% broad agreement, students were asked if their ability can be extrapolated to more general non-engineering problem solving. Q8 asked to reflect on their ability to solve engineering problems at the beginning of the course and only 51% of students believed that they could readily identify relevant constraints and define specifications at that time with unusually high broad disagreement of 16%.

Questions 13, 14 and 15 aimed to gauge how students' general attitudes towards solving engineering problems and their willingness to further their skills changed over the course of Design Practice. In Q 14 most students believe that their self-motivation to learn increased (65% broad agreement) and in Q15 they claim that their desire to further develop skills in thinking creatively and problem solving has increased (high 77% broad agreement). According to Q13, 78% of students enjoy solving complex engineering problems.

A more detailed level of coding and analysis of the data is yet to be undertaken. However, initial coding has revealed diversity of emergent themes that reflect the depth and richness of student understanding related to each question, and to perceptions of their capacity for creative and critical thinking related to engineering problem solving. As stated by one student 'the creative side of my brain was activated and I can now visualise how gears, belt drives and bearings work and think of new and innovative ways to improve/change a design to suit a different application'.

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