Student Perceptions of Engineering Design Across the Curriculum at a Large Australian University

Kevin Sevilla, Jan Meyer, and Chris Perez-Compton
The University of Queensland
k.sevilla@uq.edu.au

CONTEXT

Engineering education is a discipline that seeks to directly prepare its graduates for a seamless transition into industry. This goal has necessitated that universities understand the industry demands of their graduates and create programs that scaffold their students' technical and professional skills accordingly. While previous research has been completed on high-school students' perceptions of engineering, student perceptions of design whilst in school, and across the curriculum, there remains an understudied period in which students have elected to pursue engineering but have yet to be influenced by the university.

PURPOSE OR GOAL

The purpose of this study was to identify student perceptions of design prior to university influence. This focal point's importance is linked to its ability to hear students' perceptions of design independent of curricular influence, then to compare these with students who were approaching the completion of their degree to see what impacts the curriculum had on their perceptions of design. The research question affiliated with these aims was "What are students' perceptions of design in Year 1 and Year 4? In what instances are these perceptions similar and in what instances are they different?"

APPROACH

This study involved the development of an 11-item free-response questionnaire that addressed students' perceptions of design. This questionnaire asked for students to identify reasons that influenced their decision to become an engineering student, articulate what they thought about design, where these thoughts originated, how they identified good design, and, how their perceptions of design had changed over time. The questionnaire was administered to 449 1st year statics students and 154 4th year civil engineering design students for comparison. In total, 603 students completed the questionnaire resulting in approximately 3000 individual item responses.

ACTUAL OR ANTICIPATED OUTCOMES

The results of this study showed the similarities and differences between 1st and 4th year students' perceptions of design. Overall, 1st year students made more references to their perceptions of the importance of their technical contributions to design in connection with how their designs were received; 4th year students, on the other hand, tended to focus mostly on meeting the needs of the design as specified by the client. This emphasis on the client was articulated through repeated references to Australian codes and standards, cost, depth of calculations, and a decreased emphasis on creativity, innovation, and aesthetics.

CONCLUSIONS/RECOMMENDATIONS/SUMMARY

Differences in perceptions of design across the curriculum were to be expected. While the identified differences between 1st and 4th year students revolved around a few specific constructs, the general trends showed 1st year students perceptions of design in broader terms and greater optimism than 4th year students. 1st year students' concerns over their personal technical contribution in connection with the empathy of the client seemed to change to a client-focused model by the end of the curriculum. The philosophical question that this result posits is whether or not this is a desirable outcome for engineering programs or not, and if not, what to do about it.

Student Perceptions of Engineering Design Across the Curriculum at a Large Australian University

Kevin Sevilla, Jan Meyer, and Chris Perez-Compton
The University of Queensland
k.sevilla@uq.edu.au

CONTEXT

Engineering education is a discipline that seeks to directly prepare its graduates for a smooth transition into industry. In Australia, the two primary options for civil engineering graduates are either to become a site engineer, leading eventually to a contractor position, or a design engineer, eventually leading to a consultant-based position. In an effort to prepare its graduates for either career trajectory, the university that this study examined focused on the integration of technical coursework alongside team-based design courses to prepare its students for this transition. While much research has been done on high-school students' perceptions of engineering (Aschbacker, Li, & Roth 2010), as well as student perceptions of design whilst in school (Melnik, & Maurer 2005), and across the curriculum (Williams, Gero, Lee, & Paretti 2011), there remains a very finite and under-studied timeframe in which students have elected to pursue engineering, but have yet to be influenced by the university itself.

PURPOSE OR GOAL

Based on a previous unpublished study that established a proof of concept identifying the need to better understand engineering students' perceptions of design, this study used wording from previous questions and findings from the analysis to inform the development of the instrument.

With existing studies already showing student perceptions of design as a function of their institutional context, research on student perceptions of engineering design at the onset of their curriculum remains largely understudied. To address the gap in understanding student perceptions of design between their enrolment in engineering, and the conclusion of their undergraduate studies, this study will seek to capture students perceptions of design prior to university influence, and then compare these with students beginning their final year of their undergraduate studies. Based on differences in student responses to the questionnaire in this study, inferences can be made about the impact of the design curriculum on student perceptions of design. The research question affiliated with this study is:

RQ 1 What are students' perceptions of design in Year 1 and Year 4? In what instances are these perceptions similar and in what instances are they different?

APPROACH

This exploratory study involved the development of an 11-item free-response questionnaire that addressed students' perceptions of engineering and design. This questionnaire asked for students to identify reasons that influenced their decision to become an engineering student, articulate what they thought about design, where these thoughts originated, how they identified good design, and how these perceptions had changed over time.

The questionnaire was administered to 1st year students at the beginning of their first university lecture prior to the introduction of any technical content. In total, 449 1st year Statics students and 154 4th year civil engineering design students complete the questionnaire resulting in approximately 3000 individual item responses.

While 11 items were created for the questionnaire, each student only received 4-5 of these. For the 1st year students, each questionnaire included items 1 and 2, and two items from 3-10. 4th year students received the same questionnaire as 1st year students with the addition of item 11 (Table 1).

INSTRUMENT

The instrument (Table 1) was developed from a previously unpublished proof of concept and sought to capture student attitudes about why they chose to enrol in engineering, what their thoughts were about engineering design, and how these came to be.

Table 1 Student Perceptions of Engineering and Design Questionnaire

	Question	1st Year Responses	4th Year Responses
1	What is it about what you think engineers do that attracted you to become an engineering student?	449	154
2	What is it about what you think engineering is that attracted you to become an engineering student?	449	154
3	Do you think all engineers think about design in the same way? Explain.	116	41
4	Where did your ideas about design come from?	116	41
5	What do you think about when you hear the word “design”?	113	38
6	What must you understand in order to design?	113	38
7	What do you think other people do when they design something?	112	39
8	Name something that you have designed yourself.	112	39
9	How do you identify good design?	108	36
10	Name something that should be designed that has not yet been designed.	108	36
11	How have your perceptions of design changed between Year 1 and Year 4? [4th Year Only]	0	154

ANALYSIS

Data analysis was completed using exclusively emergent codes and was not linked to any specific theoretical framework. This choice was made deliberately to align with the exploratory nature of the study and the desire to pilot new questions for the ongoing development of an effective instrument to capture student perceptions of engineering design in the future.

The first round of coding involved categorical codes defined by a word of phrase explicitly stated in the item response, followed by a second round of detailed coding in which categorical codes where broken down into more finite codes. This analysis was conducted by two researchers independently using the MAXQDA software package with differences in coding negotiated until an agreement was reached.

Data was analysed both quantitatively and qualitatively. The quantisation process used for this paper was conducted with the help of a word and phrase frequency locator that identified instances of single words and strings of words or phrases in responses. The results of this analysis are illustrated in the following section.

RESULTS

Response rates to each item are listed in Tables 2-8 along with example quotes. With over 3000 individual responses, all statements could not be illustrated, and as a result, only the top 5-6 codes are listed for any particular item. Also, as students often had multiple responses to each item, significant overlap between codes ensued, and thus, the percentages in the tables do not add up to 100%.

<u>Q1: What is it about what you think *engineers do* that attracted you to become an engineering student? & Q2: What is it about what you think engineering is that attracted you to become an engineering student?</u>

Responses to items 1 and 2 were not related to design, but asked students about what attracted them to enrol in engineering. Responses to each item could be summarized in reference to design, intrinsic rewards, problem solving, career opportunities, extrinsic rewards, and the application of math and physics. The results are summarized in Table 2.

Table 2 Q1 and Q2 Response Rates and Example Quotes

Code	Percentage of Responses Year 1 – Year 4	Example Quotes
Design	Q1: 16.9% - 14.8% Q2: 19.7% - 10.4%	"Design and create new structures to fulfil a purpose"
Intrinsic Rewards [Creativity, Challenge, and Internal Rewards]	Q1: 11.0% - 14.2% Q2: 16.2% - 17.7%	Creativity: "Constantly challenged to be innovative" Challenge: "Work on challenging and exciting projects" Internal Rewards: "Doing something interesting and having a part in creating something tangible I can be proud of"
Problem Solving [Problem Solving, Improving Society & Real World Applications]	Q1: 50.1% - 48.5% Q2: 37.3% - 46.3%	Problem Solving: "Problem solvers of real-world issues" Real World Application: "They shape what the world looks like" Improving Society: "Build and design things that allow the world to advance"
Career Opportunities	Q1: 1.9% - 3.3% Q2: 2.9% - 1.7%	"Engineering is so diverse. You can be working out in the field one day and in an office the next."
Extrinsic Rewards [Potential Salary, Travel & Prestige]	Q1: 3.4% - 13.3% Q2: 4.4% - 11.7%	"High salary, high social position"
Physics	Q1: 10.4% - 6.0% Q2: 19.5% - 12.1%	"Engineers are experts in applying the concepts of maths and physics to real world situations."

From the responses to Q1 and Q2, 1^{st} and 4^{th} year students seemed to have difficulty distinguishing between what *engineers do* and what *engineering is*. With the uniformity in responses to both questions necessitating that analysis use the same codes for both questions, the only areas where 1^{st} and 4^{th} year students seemed to differ was on the influence of extrinsic rewards and the importance of math and physics. While extrinsic rewards such as salary and prestige were rarely referenced by 1^{st} year students, roughly 10-14% of 4^{th} year students mentioned it. Alternatively, 1^{st} year students perception of the importance of math and physics were referenced almost twice as often than by 4^{th} years.

<u>Q3: Do you think all engineers think about design in the same way? Explain</u>.

The responses to this question were uniform across both cohorts of students. 93% of 1^{st} year students and 100% of 4^{th} year students stated that all engineers do not think about design in the same way, and that differences were a result of either differences in background, differences in the way people think, difference in project, or general creativity.

<u>Q4: Where did your ideas about design come from?</u>

Table 3 Q3 Response Rates and Example Quotes

Code	Percentage of Responses Year 1 – Year 4	Example Quotes
Existing Designs	42.6% - 31.7%	“Observing the surrounding environment and how things work around me” “Looking at previous structures and how they were designed”
Past Educational Experiences	20.6% - 9.8%	“Graphics classes in school; school projects” “My degree so far and my father’s stories”
TV Shows and Documentaries	17.6% - 9.8%	“From many shows that I have seen” “Documentary ‘Big, Bigger, Biggest’”
Nature	10.3% - 4.9%	“Nature and simplicity, the beauty of nature”
People	5.9% - 9.8%	“My ideas came from my teachers at high school and friends who are already doing engineering.”
Functionality	2.9% - 34.1%	“A desire to achieve what is practical and affordable”

Responses to where students’ ideas about design came (Table 3) from yielded a wide array of responses from 1st year students including designs that had seen in their daily life, past educational experiences, TV, nature, and people. Several 4th year students, on the other hand, seemed to interpret the question in the present tense and often made references to recent design experiences rather than reflect on their past as the question intended.

<u>Q5: What do you think about when you hear the word “design”?</u>

Table 4 Q5 Response Rates and Example Quotes

Code	Percentage of Responses Year 1 – Year 4	Example Quotes
Planning	27.0% - 12.2%	“A thorough plan which through technical and reasonable measures seeks to execute a directive”
Problem Solving	20.6% - 26.5%	“Creating possible solutions to engineering problems” “Problem solving and matching ideas to the current situation”
Creativity & Innovation	43.9% - 44.9%	“Imagination, creation, new innovative ideas”
Objectives, Requirements, and Constraints	4.5% - 16.3%	“Meeting the requirements of society and the client”
Collaboration	4.5% - ~0%	“Collaborating information and brainstorming to create a solution to a current problem”

Responses to what students thought about when they heard the word “design” (Table 4) yielded a high degree of conformity between the 1st and 4th year students. The main differences occurred with 1st year students citing a higher salience of planning in relation to design, and 4th year students citing an increasing regard for “objectives, requirements, and constraints” as was likely encountered during their engineering design studies.

Q6: What must you understand in order to design?

Table 5 Q6 Response Rates and Example Quotes

Code	Percentage of Responses Year 1 – Year 4	Example Quotes
Physics	37.4% - 31.6%	"Forces, motion, physics"
Objectives	29.3% - 29.8%	"Meeting the requirements and purpose of the structure"
Constraints	17.9% - 26.3%	"Available resources, procedures, and issues surrounding the task at hand"
Innovation	8.1% - 5.3%	"The essence and basis of engineering whilst also acquiring the knowledge to think outside the box"
Client Needs	7.3% - ~0%	"What you are designing, for what, for whom, how long, etc."
Previous Designs	~0% - 7.0%	"Knowledge of past designs or similar designs"

Responses to what must be understood in order to design (Table 5) showed high degrees of conformity across all codes. While some differences emerged as 1st year students mentioned client needs and 4th year students mentioned previous designs, neither code emerged in greater than 10% of the responses.

Q7: What do you think other people do when they design something?

Table 6 Q7 Response Rates and Example Quotes

Code	Percentage of Responses Year 1 – Year 4	Example Quotes
Define Objectives	23.8% - 23.1%	"Think about what needs to be achieved and use what is available to them to accomplish it"
Consider Constraints	~0% - 33.3%	"First see what the client wants; follow relevant guidelines and work through parameters; design to give the best value for the money – cheapest option that ticks all boxes and gives functional solution"
Follow Procedures	~0% - 23.1%	"Go through the procedures and steps of their company and follow the relevant standards"
Research	16.7% - ~0%	"They research the theory behind what they want to design"
Plan	33.3% - ~0%	"Plan effectively and constantly improve the design"
Model/Build	27.0% - 10.3%	"Plan, sketch, do a model, and finally do the work to test it"
Aesthetics	~0% - 10.3%	"Consider the aesthetics of the design"

Responses to what students though to the people did when they designed something (Table 6) showed a high degree of variation across codes. 1st year students were far more likely to mention collaboration and teamwork (Plan) and referred to practices linked the design process (i.e. Model/Build). 4th year students emphasized the value of developing design concepts independently, and showed a greater concern for following accepted procedures bound by the constraints of the problem. One 4th year student summed up the process that many others mentioned at least in part, *"First see what the client wants; follow relevant guidelines and work through parameters; design to give the best value for money – cheapest option that ticks all boxes and gives functional solution."*

Q8 Name something that you have designed yourself.

This question was skipped by man students from both cohorts or included a wide array of school-based projects or hobby related projects.

Q9 How do you identify good design?

Table 7 Q9 Response Rates and Example Quotes

Code	Percentage of Responses Year 1 - Year 4	Example Quotes
Simplicity	23.4% - 15.4%	"A design that is equally simple and efficient"
Aesthetics	22.4% - 6.2%	"By its looks and how impressive it is. If I look at something and am baffled at how they could have built it, then I would consider it a good design."
Satisfies Client Needs	14.1% - 12.3%	"Safe and reliable"
Economical	13.7% - 18.5%	"Cheap to manufacture and maintain"
Effective/Efficient	10.7% - 30.7%	"The design must first be effective and efficient"
Functional	8.3% - 12.3%	"Good design is fundamentally functional"
Safety	2.4% - 13.8%	"Safety"

The question of how do students identify good design (Table 7) showed a high degree of variation across most codes. Most notable among the variations of responses was 1st year students placing greater emphasis on simplicity and aesthetics while 4th year students emphasis on the economics of the project, and whether or not the end results was effective, functional, and safe to use. Many 4th year students mentioned the "triple bottom line" which includes the cost, efficiency, and environmental and social impacts of

Q10 Name something that should be designed that has not yet been designed.

This question was unique in that nearly half of all students in both the 1st and 4th year avoided it. This may have been a result of the time constraints of the administration, or some other unforeseen factor.

Q11 How have your perceptions of design changed between Year 1 and Year 4? [4th Year Only]

Table 8 Q11 Response Rates and Example Quotes

Code	Percentage of Responses	Example Quotes
Have Not Changed	4.3%	"Not much"
More Creative and Open-Ended	6.0%	"There is a lot more ambiguity and creativity than I originally thought. I thought it was just about following set instructions/procedures."
Less Creative and More Constrained	33.6%	"It's far less problem solving and more just reading from the standards." "I didn't realize that money was the biggest factor in design; I didn't realize there would be this amount of boring codes."
Greater Technical Complexity	56.0%	"I didn't realize the length and depth of calculations and standards required."

Responses to how students' perceptions about design had changed across the curriculum (Table 8) centred around the greater technical complexity of design in civil engineering and a less creative design process often constrained by building standards. While a small percentage of students stated that their perceptions of design had not changed, and others, that the design was a more creative process than previously thought, the vast majority of students made reference to the technical demands of design remained within the framework set by Australian building standards.

CONCLUSIONS

Overall, this paper represented a preliminary analysis of some piloted questions regarding student perceptions of engineering and design, and showed in what instances differences occurred between students without institutional exposure, and students near the end of their program.

To combine the results across all 11 items, it is clear that 1st year students were different in that they made greater reference to the intrinsic rewards to engaging in and engineering major, and valued both their potential technical contribution along with how their contributions to society would be received. In contrast, 4th year student focused mainly on meeting the needs of the client. This emphasis on the client was articulated through repeated references to Australian codes and standards, cost, depth of calculations, and a decreased regard for creativity, innovation, and aesthetics.

The philosophical question that these results pose is first, why do 4th year students view the salience of the client and accepted design standards over how society will their work, and second, is this a desirable program outcome or not? While a lot of work remains to be done in the area, it is apparent that the next step is to identify when these changes in perceptions occur, and through what systems they take place. If these timeframes and experiences can be identified, then potential intervention efforts could be developed and tailored to meet any set of desired program outcomes.

REFERENCES

Aschbacher, P. R., Li, E., & Roth, E. J. (2010). Is science me? High school students' identities, participation and aspirations in science, engineering, and medicine. *Journal of Research in Science Teaching*, *47*(5), pp.564-582.

Melnik, G., & Maurer, F. (2005, May). A cross-program investigation of students' perceptions of agile methods. *27th International Conference on Software Engineering,* St. Louis, MO. doi: 10.1109/ICSE.2005.1553593.

Williams, C. B., Gero,J., Lee, Y., & Paretti, M. (2011, August). Exploring the effect of design education on the design congition of mechanical engineering students. *Proceedings of the ASME 2011 International Design Engineering Technical Conferences & Computers and Information in Engineering Conference*. Washington, DC, USA.