Enhancing Engineering qualities by adopting the total design approach in final year projects

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Structured abstract

CONTEXT
The final year project is an important part of an engineer's education. This segment of the curriculum provides undergraduate students with an opportunity to apply and extend their skills and knowledge. It provides students with an opportunity to undertake an extensive independent exploration of a particular topic. In addition to applying the skills that are developed in the undergraduate courses, students will develop skills in research, project management and technical communication. The contemporary availability of advanced computerised platforms allows students to experience the comparative analysis of viable solutions in engineering design.

PURPOSE OR GOAL
This paper presents a pilot study on a new approach to final year projects based on the 'total design approach'. This new approach hypothesises that analytical thinking and creativity is enhanced by a holistic approach to engineering design. This paper investigates the enhancements in the learning experience and graduate qualities of students once they are introduced to this new approach.

APPROACH
The main methodology used for data collection was a quiz that was undertaken by different cohorts of final year mechanical engineering students. In addition, observations were recorded by instructors, and selective interviews enabled deeper investigation of the most characteristic inferences.

ACTUAL OR ANTICIPATED OUTCOMES
The outcome of this study showed that enhancement in graduate qualities was acknowledged by students who were introduced to this new approach. This was measured by responses across different cohorts of students.

CONCLUSIONS/RECOMMENDATIONS/SUMMARY
This study concludes that this new approach to final year projects should be implemented as it promotes quality learning experiences and improves the engineering qualities of students.

KEYWORDS
Final year project, total design approach, conceptual design, convergence matrix

Final year project background

The final year project is an important part of the engineering education process and represents the culmination of undergraduate study. It helps students to develop their own approach to undertaking and managing independent research. They learn to formulate a framework for approaching an engineering problem, to undertake a critical review of advanced academic literature to determine the state of the art in a particular scientific or engineering field, to synthesize solution approaches and to prepare technical proposals and reports that communicate their findings to a professional audience. The process of completing a final year project and delivering a thesis document is an essential element in preparation for a professional career. Carrying out the work in a final year project enhances student skills through relevant real-world projects and in research and development. Industry also profits from the collaboration through the transfer of innovation and by gaining an insight into academic developments. In summary, the final year project is an important determinant in developing and improving engineering qualities of students.

The final year engineering project is universally recognised as significant and important to the education of professional engineers. In most cases, whether in Australia or Europe, the final year engineering project is about 6.25% of the total load of engineering programs (Ku, 2010). In mechanical engineering at the University of South Australia (UniSA), it comprises 12.5% of the total load. The study conducted by Jawitz, Shay and Moore (2002) emphasised the need for a systematic approach to the review and improvement of practice with respect to these final year projects. Reliable and valid assessment practices are central to the integrity of the qualifications offered at a university, and are thus an area of focus for quality assurance procedures (Jawitz, 2002). A comprehensive study of final year project practices at various Australian universities by Rasul et al. (2009) identified many issues such as large variations in the ways in which projects are managed and assessed as well as opportunities for enhancing learning and improving project supervision and management. There is a widely recognised need to develop a consensus on what comprises good project supervision, management, assessment and standards (Rasul, Nouwens, Martin, Greensill, Singh, Kestell and Hadgraft, 2009).

The final year project in mechanical engineering at UniSA is undertaken as an individual piece of work. For administrative purposes, it is split into two courses, Project 1 and Project 2, but essentially it is one continuous year-long project. Generally, the final year projects are carried out in collaboration with industry or a research concentration at UniSA. Past projects at UniSA have provided the basis for international journal publications, significant changes in the operations of individual companies, novel patented designs and the formation of a new company. UniSA's final year project courses are offered to local students at the Mawson Lakes campus and to transnational students in Singapore. The project is an assessable part of the student's academic program and is normally undertaken over 12 months and involves approximately 600 hours of student effort.

The total design approach

Many mechanical engineering projects fit into the 'design and build' category. In these projects, students will come up with the design of a new product based on the knowledge gained throughout the course. The engineering design process requires a holistic approach, which involves broad-based skills such as communication, project planning, interpersonal skills, understanding manufacturing issues, etc. The total design approach provides a systematic approach to developing a design that can improve the outcomes in these projects and enhance the learning experience. Hence, the total design approach for final year projects was evaluated at UniSA.

The total design approach was originally developed by S. Pugh and was successfully introduced for final year projects in several UK universities (Tan, 2004). This approach analyses the systematic activities, from identification of market/user need through to the selling of successful products, that are necessary to satisfy that need: it encompasses product, process, people and organisation (Pugh, 1991). The different stages of this approach are shown in Figure 1.

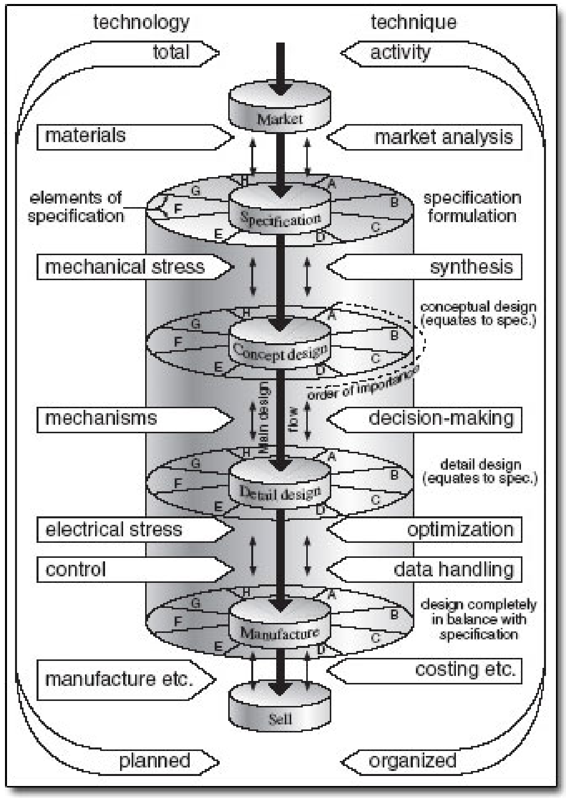


Figure 1: Total design approach (Pugh, 1991)

The important aspects of this approach is the generation of several alternative conceptual designs and the selection of a conceptual design based on the controlled convergence method (Pugh, 1981). A conceptual design represents the sum of all the subsystems and the component parts which are combined to make up the whole system. The generation of all viable alternative design concepts improves the range of choices for the design and produces better outcomes for the project. In addition, this holistic activity enhances the learning experience and graduate qualities of the students.

The major advantage of controlled convergence over other matrix selection methods is that it allows alternative convergent and divergent thinking to occur. As reasoning proceeds and the number of concepts are reduced for rational reasons, new concepts are generated. The evaluation matrix associated with this method is a form of prioritization matrix. Its implementation involves the establishment of an evaluation team and construction of the matrix which contains evaluation criteria versus alternative concepts. A baseline concept is selected and the other concepts are scored against the criteria relative to the baseline. The scoring is done in symbol form and is positive, negative or neutral. The scores are then combined to give a numerical output for each concept, the highest score being the most compatible. The method is an iterative approach and is effective for comparing alternative concepts.

Example – design of a car horn

The task was to design a car horn which would provide an audible warning of the approach of a motor vehicle. The conceptual design step generated 14 different concepts which satisfied the product design specification as shown in Figure 2. All these concepts achieved the same function but each used a different principle and components.

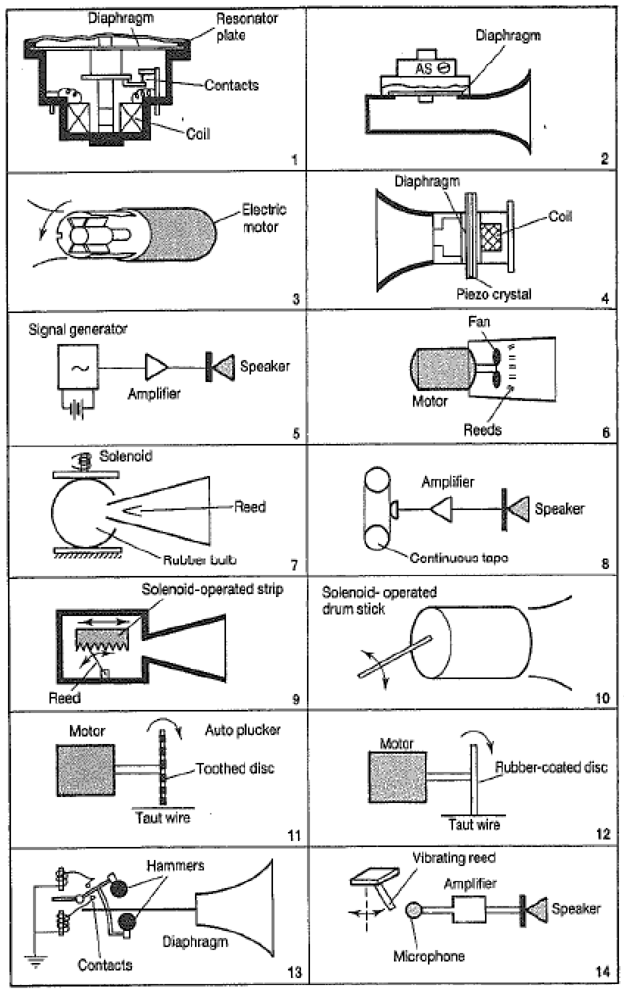


Figure 2: Different design concepts for a car horn design (Pugh, 1991)

Table 1 shows the evaluation chart for the 14 comparable concepts using Concept 1 of Figure 2 as the datum concept. A total of 16 different criteria were used with a plus (+), minus (-) or ‘s’ symbol showing if the concept was, respectively, better or worse than or the same as the datum concept for that particular criterion. Based on this evaluation matrix, Concept 5 was chosen for the detailed design.

Table 1: Convergence matrix for the car horn design (Pugh, 1991)

Criteria \ Concept	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Ease of achieving 105 – 125 DbA		S	–		+	–	+	+	–	–	–	–	S	+
Ease of achieving 2000 – 5000 Hz		S	S	N	+	S	S	+	S	–	–	–	S	+
Resistance to corrosion, erosion and water		–	–	O	S	–	–	S	–	+	–	–	–	S
Resistance to vibration, shock and acceleration	D	S	–	T	S	–	S	–	–	S	–	–	–	–
Resistance to temperature	A	S	–		S	–	–	–	S	S	–	–	S	S
Response time	T	S	–		+	–	–	–	–	S	–	–	–	–
Complexity: number of stages	U	–	+	E	S	+	+	–	–	–	+	+	–	–
Power consumption	M	–	–	V	+	–	–	+	–	–	–	–	S	+
Ease of maintenance		S	+	A	+	+	+	–	–	S	+	+	S	–
Weight		–	–	L	+	–	–	–	S	–	–	–	–	+
Size		–	–	U	S	–	–	–	–	–	–	–	–	–
Number of parts		S	S	A	+	S	S	–	–	+	–	–	S	–
Life in service		S	–	T	+	–	S	–	–	–	–	–	–	–
Manufacturing cost		–	S	E	–	+	+	–	–	S	–	–	–	–
Ease of installation		S	S	D	S	S	+	–	S	–	–	–	S	–
Shelf life		S	S		S	S		–	S	S	S	S	S	S
Σ+ Σ– ΣS		0 6 10	2 9 5		8 1 7	3 9 4	5 7 4	3 12 1	0 11 5	2 8 6	2 13 1	2 13 1	0 8 8	4 9 3

There are several success stories of the application of the total design approach for the design of different products. Among the best-known models for engineering design, Pugh's total design model is considered the best and covers all design aspects (Austin, 1999). Nixon, Dey and Davies (2013) adopted this method for the design of a novel solar thermal collector deriving three novel concepts from the linear fresnel reflector (LFR). These concepts were developed and evaluated through the use of a multi-criteria decision matrix which arrived at an optimum concept which then underwent detailed design. This methodology was found to have wider potential in the fields of renewable energy and sustainable design (Nixon, Dey, & Davies, 2013). Thakker et al. (2009) demonstrated a systematic approach to developing the optimal design of an impulse turbine using a combination of the total design method and a 3-dimensional computer aided design (3DCAD) environment. Seven different conceptual designs of a rotor hub and their concepts were evaluated and compared using several criteria in a convergence matrix. The optimum design was arrived at by combining and refining the alternatives as the design process developed. Furthermore, the optimum design was tested for structural performance using structural analysis integrated within the 3DCAD environment. In this work, the use of the total design approach methodology was found to be helpful in facilitating the evaluation of alternate design routes and they recommended that it be considered in the design or redesign of alternative energy equipment (Thakker, Jarvis, Buggy, & Sahed, 2009).

The introduction of the total design approach in final year project needs careful analysis of each stage of the approach. Among these stages, the conceptual design and convergence matrix stages are the most significant. For each project, several alternative design concepts should be generated in sufficient detail rather than arriving at a single design and progressing to the building/fabrication of the product. In addition, these concepts should be evaluated using the total design approach's convergence matrix to arrive at the best design for the particular product.

Implementation of the total design approach

The total design approach was introduced to two cohorts of final year mechanical engineering students in local and transnational programs in 2013. The students were allowed to start with the traditional approach and after two weeks, the total design approach was introduced. The students' perspectives on the total design approach were assessed by a quiz provided to students in week 10. This involved a total of 22 students comprising 15 transnational students and seven local students.

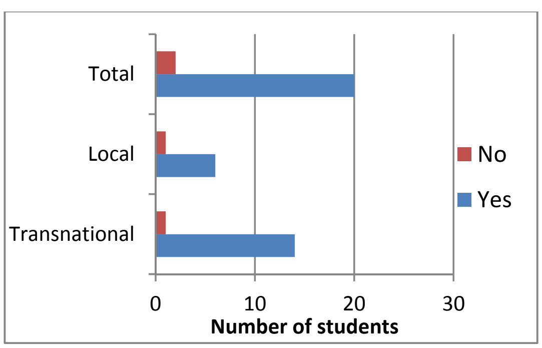
Quiz

The quiz comprised a questionnaire which was designed to obtain feedback from students about the total design approach. The main purpose was to seek students' opinions with regard to the effectiveness of the new approach. The following questions were included:

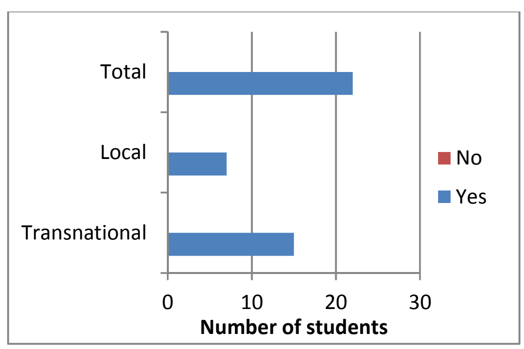
Q1. Do you think that the new approach will help you to achieve a better outcome for your project?
Q2. Do you think that the new approach will make you think of alternative design concepts?
Q3. Will it be difficult for you to implement the new approach?
Q4. Do you think that the new approach can motivate you to extend your knowledge?
Q5. Do you believe that the new approach will help to improve your confidence in carrying out industrial projects or working in industry?
Q6. With adoption of the new approach, will you use any computerised tools for design?
Q7. Do you think this approach will be suitable for a 'design and build' project?

Results

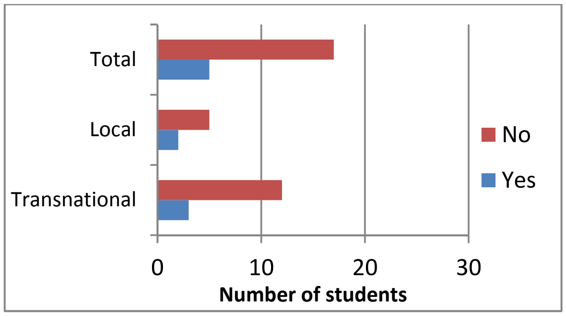
The results of the quiz for the local and transnational programs are given in Figure 3. It was found that the students strongly agreed that the total design approach has good potential to develop their engineering and professional skills and to improve their confidence in dealing with actual industrial problems and working in industry. The majority of students stated that the process was not difficult to implement. Cohorts of both local and transnational students gave similar positive feedback on the new approach.



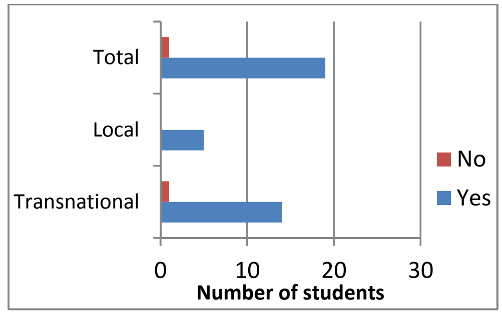
Response for Q1. Better outcomes



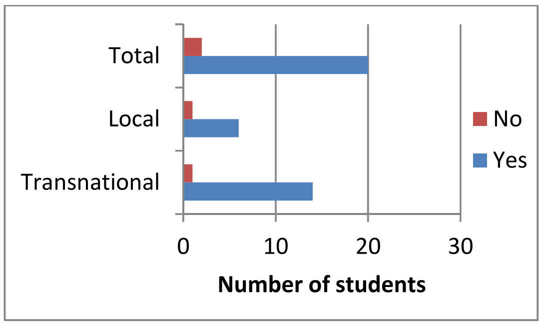
Response for Q2. Alternative designs



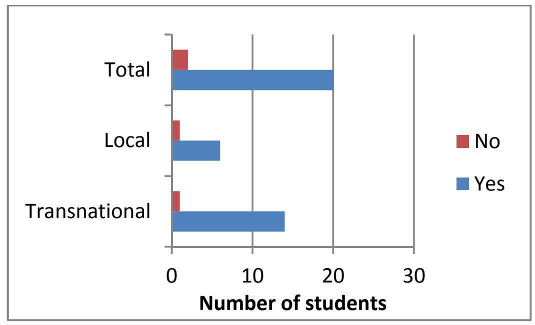
Response for Q3. Difficult to implement



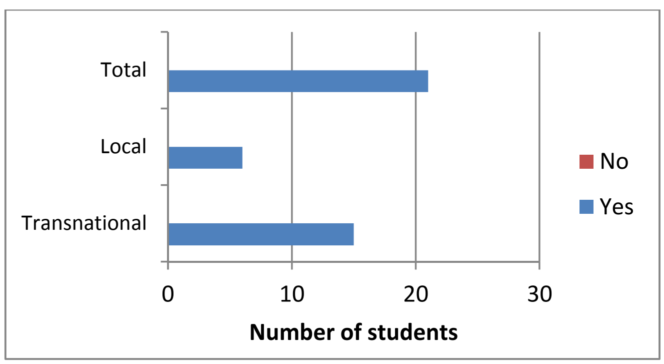
Response for Q4. Motivates



Response for Q5. Improves confidence



Response for Q6. Computerised tools



Response for Q7. Suits 'design and build'

Figure 3: Quiz survey results

Conclusion

This study on the introduction of the total design approach to final year projects at UniSA showed that the students responded positively to its use. Students recognised that the new approach led to new knowledge, improved their confidence to enter industry and enhanced their engagement and learning experience. Based on this work, the implementation of this new approch will continue to be developed for future cohorts of students.

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