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# Developing Engineering Sense through Holistic Engineering Education

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## CONTEXT

Both engineering industry and academia have long debated the skills a graduate engineer needs to enter the workforce, as there is a delicate balancing act of ensuring enough technical rigour in addition to societal relevance. Literature indicates that industry requires engineering graduates to possess a holistic understanding of engineering problems and solution pathways. This is occurring generally to a limited degree and hence intervention is required.

## PURPOSE

The pilot research project reported herein has investigated the concept of 'Engineering Sense' as well as methods of developing this 'sense' in students in undergraduate engineering degrees.

## APPROACH

The research has focussed on the subject ENG10757 Applied Mechanics, the first in the scaffolded structural engineering subjects offered at Southern Cross University in the undergraduate civil and mechanical engineering degrees that are currently offered. Lesson material was designed to introduce conceptual holistic information related to three topic areas deemed relevant to developing engineering sense, namely, (i) the subject topic content, (ii) industrial requirements of the engineering profession, and (iii) students' motivations towards study. Three teaching techniques were also used, namely, elaborative rehearsal learning, meaningful learning, and the humanistic approach. Formative surveys were also used to assess the students' abilities, motivations to study, and development in their understanding on a holistic conceptual basis as a result of the lessons. The surveys were also used to inform lesson development.

## RESULTS

The results of the project indicate an increase in conceptual knowledge of the three topic areas. Through including holistically focused content within traditional technical topics, in addition to identifying student motivations and educating students on the broad requirements of engineers in the twenty-first century, students developed an understanding, built knowledge and changed views on what is required of engineers.

## CONCLUSIONS

This pilot research project has investigated the development of students' knowledge base of technical topics in a holistic manner. This has been achieved through broadening student understanding of the engineering profession, as well as influencing motivations of learning towards what could be described as developing engineering sense. The methods utilised have provided positive results toward a holistic understanding within the bounds of the project. Future projects may extend the ideas generated herein.

## KEYWORDS

Holistic engineering education, elaborative learning, engineering education, engineering sense, meaningful learning.

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## Introduction

Engineering education has been a topic of discussion within industry and academia for decades. As industry changes with new materials, processes and technologies, our education systems are required to develop and produce graduates and professionals who are able to operate in this changing environment. Future engineers need to be equipped to work in a systems-based multi-disciplinary industry that operates in a global environment. This is an environment displaying unique challenges. As engineers are now required to solve the problems of climate change, resource depletion, population growth, and environmental pollution (McMasters, 2006). As a result, engineers require expert knowledge and the ability to integrate complex environments as change agents. In addition, engineers need to be technically competent, innovative, and creative leaders (King, 2007; McMasters, 2006).

As Goldberg (2010, p. 10) states,

*“The signs are clear that the old paradigm is breaking down and that new ways of thinking about what it means to be an engineer are emerging...Against this backdrop, the need for conceptual clarity is greater for engineers now than it has ever been.”*

The ongoing question is ‘How can engineering education provide the graduates that industry needs?’

The debate on *what* is needed in the education of tomorrow’s engineers has also changed over the decades. It has included the original master-apprentice model, a focus on the engineering sciences after world war two and outcomes based accreditation between 1990 and 2000. Since 2000, the debate has focused on the application of learning and social behaviour theories, the information and computational technologies revolution, holistic engineering education that includes a broad base of subjects, and a combination of knowledge, skills and professional values (Bucciarelli & Drew, 2015; Graaff & Kolmos, 2014; Rugarcia, Felder, Woods, & Stice, 2000).

The original question of this study focused on the development of ‘engineering sense’ through undergraduate engineering degrees in response to the above concerns. Current engineering literature agrees that the most effective method of producing industry ready graduates is to provide a broad based education, which includes the liberal arts (Goldberg, 2010; Bucciarelli & Drew, 2015; Grasso, Burkins, Helble, & Martinelli, 2010; Hynes & Swenson, 2013; Kessissoglou & Prusty, 2009). Current education literature reports that learning and teaching styles and students’ personal motivations play a significant role in student outcomes (Snowman, Dobozy, Scevak, Bryer, & Barlett, 2009). An opportunity exists to fill an apparent knowledge gap by providing holistic content within technical subjects.

The aim of this pilot research project was to develop holistically based teaching content to complement selected technical topics in the subject ENG10757 Applied Mechanics at Southern Cross University. The term ‘holistic education’ in this paper refers to building student understanding using holistic information embedded within technical subject matter. It hypothesizes that the method used will increase students’ conceptual abilities and aid in the development of their ‘engineering sense’. The method included the presentation of two lessons to first year mechanics students in addition to information gathering arising from three surveys. The term ‘lesson’ used within this report refers to the class material produced for this research and presented to the students. The lesson delivery was based on conceptual relatable subject content. For example, the actual forces that act on structures, wind, water, ground, equilibrium on a broad scale and practical exercises in which students are provided with the opportunity to develop a personal experience of the science of mechanics within their own body such as isometric exercises. In addition, each survey took approximately 10-15 minutes for students to complete. The learning styles of elaborative rehearsal learning and meaningful learning were considered while the humanistic approach to teaching was engaged (Snowman, et al., 2009). There appears to be no evidence that the

adopted approach to developing holistic engineering education has been suggested or attempted before.

It is hypothesized that the outlined approach herein will improve students' conceptual learning and understanding of technical content. Through this method a deeper thought process is envisioned to be encouraged in order to enable learning to be structured and developed throughout engineering degrees as the subject material become more complex. The lessons developed in this study were delivered in a way that deep conceptual understanding could be nurtured by providing contextual holistic information. This was intended to support students to think like engineers.

Survey results obtained towards the end of this project indicate an increase in holistic conceptual understanding of the topics, a change in motivation to learning, and a developed understanding of the reality of what skills are required of engineers in the 21st century (Figure 1).

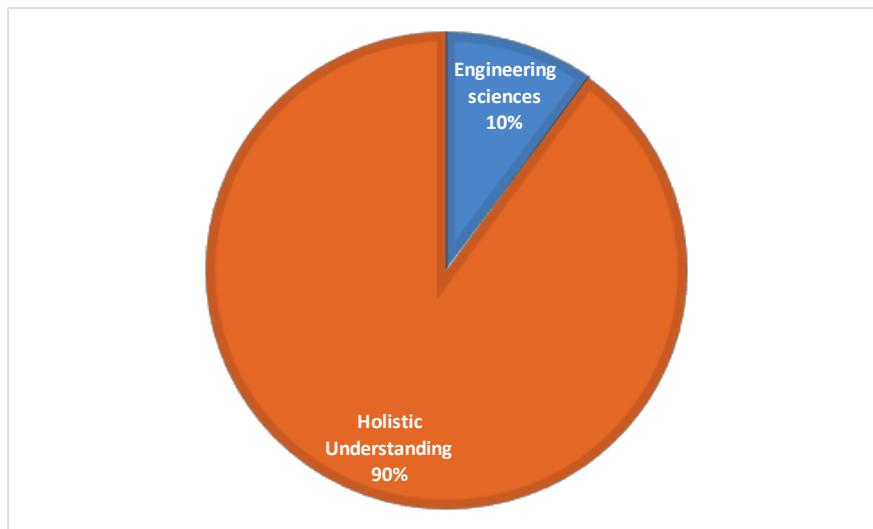


Figure 1: What is expected of engineers in the 21<sup>st</sup> century?

## Personal Reflections

The first author of this research is a final year undergraduate student at Southern Cross University who has undertaken the Applied Mechanics subject in question and the subsequent scaffolded structural engineering subjects as part of a civil engineering degree. It was the experience of progressing through the degree that prompted the approach utilised herein. The difficulties students have with mechanics subject material are common throughout the sector (Kessissoglou & Prusty, 2009). Progressing through subjects without a deep and workable understanding of the foundational topics made subsequent scaffolded subjects difficult to comprehend. There was a feeling of being held-back on advanced subjects because the foundation information was not solidly grasped. There were many times when the first author could see that more rounded, conceptual information would have assisted in the development of learning and understanding technical subjects that seemed abstract and difficult to relate to the real world. Feeling one step behind due to this was a demotivating experience at times.

## Method

The definition of holistic engineering education in this instance is in line with the description by Grasso, Burkins, Heble and Martinelli (2010). It involves conceptualising the fundamental concepts of core subjects of engineering degrees through human, social and ecological frameworks. The research reported herein has taken a similar approach by producing

mechanics subject related material that has a holistic basis to complement the traditionally pure technical based content. This serves three main purposes, namely, (i) applying teaching methods to provide information and knowledge from everyday life that students can relate the technical information to, (ii) allowing the structuring of engineering knowledge through encouraging a perceptive way of looking at life around us, and (iii) engaging the ways in which we learn and the natural method of information transfer into the long-term memory.

This research has considered teaching and learning styles in the approach to the lesson structure and content for the two lessons. Student learning is supported by building upon what is known and understood, and it is connected to students' experience of life. Learning undertaken this way ensures that the information stays in the working memory, maintains relevance and is built upon. Elaborative rehearsal learning is a process in which we relate new information to information stored in our long-term memory and facilitates information availability in the working memory (Snowman, et al., 2009). Meaningful learning occurs when new information is made relevant to the student by relating the information to prior experiences and knowledge that are stored in the long-term memory. Through connecting to what is available in the knowledge base, the student can actively engage in the learning by associating the new idea with what they have already experienced. Meaningful learning is considered a powerful tool in complex learning (Snowman, et al., 2009; Wood, Groves, Bruce, Willoughby, & Desmarais, 2003). Both elaborative rehearsal learning and meaningful learning processes have been considered in this study. The humanistic approach to teaching and learning pays particular attention to student needs or values and self-perceptions via supportive classroom environments. It is an approach that has been found to activate students desire to learn to their potential and produce a range of positive effects (Snowman, et al., 2009).

Lessons were delivered to first year mechanics students. The class was comprised of twenty-one students ranging from high school leavers to mature age students. The lessons ran for one hour each and included subject matter that provided holistic and conceptual information relating to the topic content of their usual class and the bigger picture of mechanics and engineering in the twenty-first century (Table 1). Survey questions aimed at determining student understanding were included during the lessons. Using formative lesson design, the content of the second lesson was determined in part by answers to the first two surveys given in lesson one.

**Table 1: Lesson and survey plan.**

<b>Lesson</b>	One (1 hour)	Two (1 hour)
<b>Lesson topics</b>	- Holistic content on forces - Attitudes to learning: motivations	- Holistic content on equilibrium 21 <sup>st</sup> century engineering industry
<b>Survey<sup>1</sup></b>	One (Beginning of lesson) Two (End of lesson)	Three (End of lesson)
<b>Related Mechanics Topics</b>	Forces, free-body diagrams, loads.	Equations of equilibrium, centre of gravity, centroids.

<sup>1</sup> 10-15 minutes per survey

## Lessons

The lessons were delivered through PowerPoint presentations and interactive exercises, and the content was designed to provide a memorable experience for students. To facilitate information transfer into the working memory in a holistic manner, pictures, video, and discussion around the lesson topics were incorporated. For example, when discussing wind,

pictures of strong winds and damage from tornados were used. Some video content was embedded into the presentation, and the students were also guided through physical isometric exercises to demonstrate concepts that they could connect to for deeper learning.

### *Lesson One*

The first lesson focused on forces in mechanics and what they actually are in engineering. For example, wind, the weight of a structure, and where other types of forces are found such as nature, our physical bodies and emotions. The lesson included active exercises to engage students and provide them with a physical feeling and experience of the lesson content. It provided information and questioning on students' approach to study and the effect of motivations.

### *Lesson Two*

The results from survey one and two provided formative information for the design of a second lesson. The results indicated that students had difficulty with the concepts of equilibrium, and there was a perception that the technical mathematical aspects were the most important of their engineering study. Therefore, to assist with the difficulties students were having and to address the misconception of engineering, the second lesson focused on both the holistic nature and technical details of equilibrium, and the reality of engineering's broad requirements in industry. The lesson included examples where equilibrium can be found in life around us, for example, structures, nature, the human body, life, business and economics, equations of equilibrium, centre of gravity, and moment of inertia. It also included the wide ranging demands on engineers, good communication, and understanding of finance, humanities, and politics. In addition, lesson content included discussion on our attitudes and motivations towards study and learning to develop student self-awareness.

## **Surveys**

The sequencing of the surveys is shown in Table 1, and students were requested to complete the written surveys in class.

### *Survey One and Two*

The intention of the first survey was to gain specific information related to the research hypothesis, namely, the development of student conceptual understanding of mechanics subject material. It included questions to indicate an understanding of units which are foundational to later structures-related subjects, moments which are known problem areas for students, motivations to study, and conceptual understanding of mechanics topics. Survey one was given at the beginning of the lesson and survey two was given at the end of the lesson. Some answers were repeated to assess changes based on the content of the lesson.

### *Survey Three*

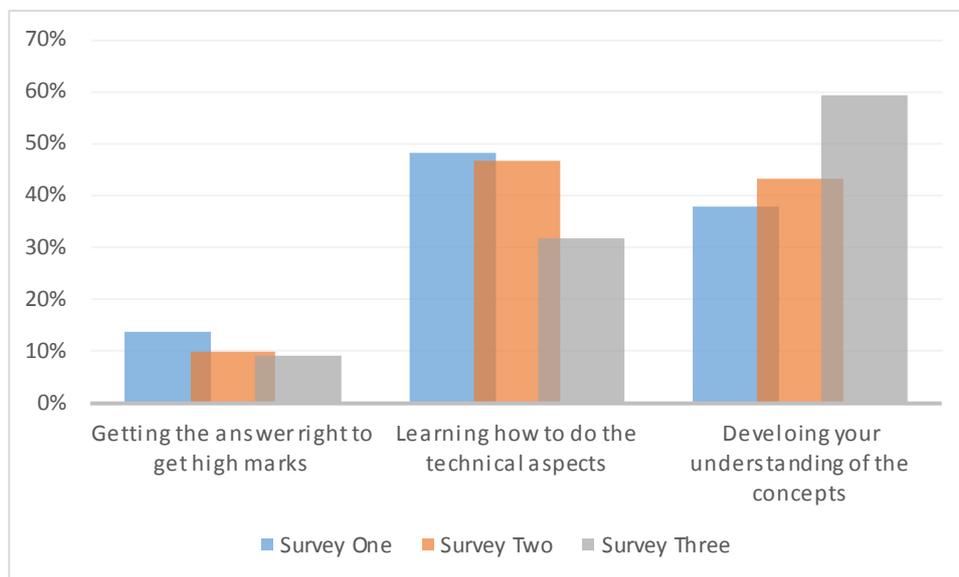
The third survey assessed what had been learnt from both lessons and if there was a change in answers in relation to conceptual understanding and learning motivations. Some questions were repeated from the initial survey to assess understanding gained by the two lessons in relation to the topic areas covered and to developing conceptual understanding of the topics covered and the engineering profession.

## **Results**

The results are mapped over the three surveys and they indicate that the approach taken had a positive effect on students' holistic conceptual understanding. This trend in results was consistent across the three areas, namely (i) holistic topic based content delivered in the lesson, (ii) understanding of the requirements of professional engineers and (iii) attitudes and motivations to studying. Details of the results can be viewed in Table 2 and Figure 2 and they are discussed in the following section.

**Table 2: Survey results indicating an increase in students' conceptual holistic understanding of topic content and their motivations to study.**

Topic		Results			
Topic	Sub Topic	Survey 1 (Lesson 1)	Survey 2 (Lesson 2)	Survey 3 (Lesson 3)	Increase in Conceptual Holistic Understanding
<b>Conceptual Understanding</b>					
	What Is Mechanics?	71%	76%	90%	19%
	Holistic Mechanics	57%	81%	-	24%
	Mechanics in the body	48%	100%	-	52%
	Mechanics in nature	62%	100%	-	52%
	Equilibrium	30%	-	100%	70%
	Approach to assignments	38%	43%	59%	21%
	Approach to concepts	17%	18%	59%	42%
<b>Motivations</b>					
	Holistic importance	71%	86%	90%	29%
	Understanding Engineers role	18%	43%	81%	63%



**Figure 2: When answering assignment questions what is the most important?**

## Discussion

As can be seen from the results in Table 2, and Figures 1 and 2, the research method has resulted in an increase in the knowledge of and the need for conceptual understanding of the topics covered.

One of the aims of the approach to the delivered lessons was to enable student connection to the science of mechanics in their own body. This involved empowering students with an ongoing learning mechanism that can be connected to at any time for reflection and continued learning. For deep conceptual ongoing learning and holistic understanding of a topic to be achieved, there needs to be an understanding of application to a variety of situations. The lessons and surveys were aimed at fostering knowledge building through elaborative rehearsal learning and meaningful learning. The results indicate that 100% of the class now have mechanics knowledge and awareness that they can call upon and use at any time. This includes relating the science of mechanics to life around them in comparison to 48% at the start of the class. Whether they do use that awareness to assist their understanding and knowledge development is beyond the scope of this research.

The results also indicated an increase in students' conceptual understanding of technical phenomena through making connections to personal and worldly based scenarios. Students gained a more accurate understanding of the role of engineers in the twenty-first century (Figure 1). Initially student answers indicated a perception that an engineer's main achievement and abilities were technical/mathematical. This is a common misconception in undergraduate engineers. Lesson material and survey questions were therefore aimed at broadening understanding of what a day in the life of a professional engineer is like. Including the broad range of skills and capabilities that are needed of professional engineers today. This content was included to help build understanding of why they are studying engineering and what their role in the study is. This encouraged students to think about their attitudinal approach and motivations. Answers indicated a shift in understanding of the demands of engineers towards a broad understanding of the profession. Answers also indicated a change in approach to studies and an understanding of engineering's role in society, and therefore their place within it as first year students and future engineers.

This study has been applied to the subject Applied Mechanics, a technical based subject. It could however be applied to other technical subjects within engineering degrees.

## Limitations

The research method was structured around two one-hour lessons within the subject lecture time which is rather limited to reinforce long-term behavioural changes. This research topic would be well suited to long-range studies that map learning developments over the course of a full subject or degree.

## Conclusions

The results of this study indicate that through providing holistic topic content of technically based subjects, students can be more aware of what will be required of them in the engineering industry of the twenty-first century. The results indicate an increase in holistic conceptual understanding of the mechanics topics covered, and the role of engineers in the workforce. It also included motivation to learning and therefore student ability to better develop engineering sense through their undergraduate engineering study.

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