Full paper

Introduction

The engineering education sector is currently in the process of undertaking a large shift in how to teach complex engineering theory, moving away from taught content in lectures to more student-centred project based learning (Dym, Agogino, Eris, Frey, & Leifer, 2005). This shift comes as a response to industry feedback that engineering graduates lack the practical, and empathetic, skillsets required to perform effectively in an engineering environment (Newcomer, 1997).

The paradigm shift towards project based learning (PBL) has required students to engage not only with complex, real world problems but also with the real world end user. Studies have shown that by exposing students to real world problems, the learning of key engineering fundamentals is made easier, with the use of a project or a design problem (Frank, Lavy, & Elata, 2003). Although literature (Mills and Treagust, 2004) has shown the effectiveness of PBL, many university engineering programmes still only allow students project experience in the later years of the degree, such as the required capstone project in the final year of study.

With momentum building for the positive effects of PBL it is important to reassess the skillsets that each student will have at different stages throughout their undergraduate study and the way in which deficiencies may hinder their ability to effectively complete projects (Newcomer, 1997). While benefiting from many aspects of PBL, first year undergraduate students may not have the level of tacit knowledge, or empathic ability, to fully understand the end user and therefore produce high quality design solutions. This issue has not been highlighted in current literature as first year engineering programmes are only just beginning to involve real world project based learning.

At Massey University, PBL in multidisciplinary teams is strongly emphasised throughout all engineering majors and year-levels. Examining what causes students to become high achievers in project papers has therefore become a topic of interest. It is believed that introducing front end user research such as user needs analysis (NA) at an earlier stage of the degree helps enhance the students' knowledge of user centred design (UCD) and in turn improves the student's ability to solve complex design problems. In light of this, a study was conducted to assess the importance of introducing NA techniques to first year undergraduate engineering students.

Literature Review

The importance of introducing proper design practices at an earlier stage than the senior years has been recognised by many academic institutes and professional bodies (Atman, Chimka, Bursic, & Nachtmann, 1999). Capstone design courses have become well established in engineering programs, and their value has been realised by educators, students, and employers (Newcomer, 1997). However, they tend to be carried out in the final year of study meaning UCD techniques, which are essential tools in engineering practice, as

they encourage students to give attention to the needs and constraints of the end user, are only practiced near the end of the degree.

This skillset is increasingly important as in modern project contexts engineering designers are expected to widen their scope to include factors such as environmental and social impacts as well as traditional technical design (Dym et al., 2005; IEA, 2013).

Studies have shown that student engagement, self-regulated learning and a student's willingness to take the initiative are strongly linked to their success (Carini, Kuh, & Klein, 2006; Paris & Paris, 2001; Rocconi, 2011). While other research has demonstrated the importance of student interactions with faculty members and the wider community on the success of a project (Harper, 2008). More closely linked to the skillset promoted in this article is a study which looks at key factors needed to ensure lifelong learning in undergraduates (Kember, Leung, & Ma, 2007). This states, through the development of six key capabilities, that student autonomy, and engagement as well as strong interactions with faculty and community are imperative to students developing an effective range of graduate competencies. These studies further strengthen the view that PBL should be present throughout a student's education.

Although there is an obvious importance placed on the way in which undergraduate students learn and undertake projects, emphasis must also be placed on when supporting content is delivered to students. Multiple studies show a clear need for the right design tools to be taught at an early stage of an engineering course and continually practiced (Newcomer, 1997). By teaching first year students to approach problems with a broader perspective, and treat design as a blend of many issues of societal and environmental, as well as the technical and economic, students will develop an empathetic skillset and in turn produce more relevant project outputs (Dym et al., 2005).

The key purpose of this study was to examine the effectiveness of teaching NA techniques to first year engineering students and how their engagement with this area affected their project output quality, where quality is viewed as the effectiveness, and relevance, of a conceptual design to meet a user's requirements. This was achieved through investigating whether teaching NA techniques and instilling user-centred empathy into first year students led to more awareness of social and cultural aspects in their design. Formative information into how NA teaching implementation, early in engineering education, can improve the ability of an undergraduate to complete project based learning activities was also investigated. However, a full study into this area would require researching how a student interacts with multiple project based papers, throughout the degree, which was outside the scope of this study.

Humanitarian projects expose the challenges of user-centred-design as they are explicitly user focused, as many challenges centre on usability, maintainability and local societal and logistical constraints. They also inherently create an empathetic attachment, between the student and the project, as create a sense of purpose and satisfaction in the student.

Methodology

Firstly, an investigation of existing research in the area of design education and how it affects a student's ability to perform complex projects was undertaken. This involved looking

at engineering education, on a whole, and how it has developed towards a project-based learning model. Attention was placed on any research in the area of UCD education and the effectiveness of NA techniques when used by undergraduate students in a project context.

Once an understanding of this area had been gained, an empirical study was conducted. This allowed for a link between high quality student output and their use of the NA techniques presented to be investigated.

A first year undergraduate project paper was chosen for this study as this allowed for a link between high quality student output and the use of NA techniques to be investigated. The following are pints of interest about the chosen paper:

1. First year engineering undergraduate paper
2. Part of the project-based-learning curriculum
3. Involved a real world context and required a tangible solution
4. Involved a project for a community which students had little knowledge of

These criteria meant that the study could focus on how NA techniques were engaged with in both a PBL and first year environment. The project chosen was facilitated by the organisation Engineers Without Borders (EWB) New Zealand. The project involved first year engineering students undertaking their first design project at University and was chosen as it required students to design solutions for communities in a developing country. This was deemed an appropriate context as it encouraged students to think of the end user at an early stage of their project, as they inherently knew very little about their intended user or target market. This year the project focused on developing solutions to problems encountered by the Bambui community in Cameroon. As communicated through a project brief, students were tasked to identify problems faced by local communities, and design solutions in the area of Water Supply, Sanitation and Hygiene, Energy, Food Transformation, Transport, Infrastructure and Urban Planning, Waste Management, Climate Change or ICT.

Once a project was selected, appropriate NA and UCD techniques were researched and selected to be presented to the class. Information was gathered from three main sources to form the NA toolkit and the corresponding techniques were strongly emphasised to the students. The majority of the NA techniques were sourced from existing engineering design content at Massey University, as well as the Engineering Your Future textbook (Dowling, 2013)**.** The third source contained lecture slides and taught content presented at Coventry University in the United Kingdom (Abarquez & Murshed, 2004; Watson, 2014). From these sources a summarised NA toolkit, involving 4 techniques, was collated. These were:

1. User personas
2. An interview of a person with local knowledge
3. Key elements table (formative demographic and environmental information on Bambui community and Cameroon)
4. Photographic content of currently used solutions

User personas are a technique which is commonly used today by educators and in industry to communicate the context of a design project to stakeholders. In using this technique for the EWB context, students are given the opportunity to improve their understanding of the end user and environment without visiting Bambui. One example of a provided persona was Patrick, a 30 year old father of four who worked as a farmer, rode a motorcycle and suffered

from multiple health issues including diarrhoea due to consumption of non-potable water. Students were encouraged to create their own personas or profiles of characters based on their research to suit their chosen problem area and target users. In utilising this technique, students were given the chance to, to some extent, experientially learn about the lives of those who live in Bambui and encouraged them to find ideal solutions.

An interview with a Nigerian person, who now resides in NZ, and has visited Cameroon, was conducted to further add detail about the context of this project. As Nigeria is a neighbouring country to Cameroon with similar socio-economic and environmental factors (CIA, 2014) this knowledge was deemed important as the assumption was made that each student would have very little knowledge about the different cultures, traditions and general lifestyles of the locals. Through this study that assumption was proven correct. The questions asked focused on the nine areas of possible development as well as insights into the everyday life of African local communities. This was recorded and uploaded to Massey University's online learning management system (i.e. STREAM), where students were able to access and listen to it.

For many first year students, a lack of experience in researching and finding reliable sources meant that credible information and insights into their project context was difficult to attain. To assist with this deficiency students were provided with a key elements document which contained basic research about the project context. The key elements document contained a table of topics, and links to resources such as statistics, videos and articles which were expected to be used as a starting point for detailed research. By providing students with example research content and a list of important topics to investigate it was thought that students would be more efficient and more likely to complete in-depth research about the end user.

Finally, providing the students with pictures and diagrams of existing solutions was important as it gave the students visual information about the context, available local materials and the technicality of the solutions which locals were currently using. As this information was very hard to gather through commonly available means, such as the internet or university library, it was provided as part of the NA toolkit. This visual content not only provided the students with valuable insight into how the current solutions operated but it also helped to create an empathetic link to the end user (i.e. to encourage the students to be mindful of the societal and environmental impacts of their projects).

Student-Student Mentoring

It was decided that the NA toolkit was to be introduced and promoted using a Student-Student mentoring scheme. This scheme was used as a way of introducing the importance of needs analysis and the corresponding techniques to the class with individual groups taken aside for detailed explanation if required. Mentoring was done weekly, one group at a time, throughout the duration of the project, which was one semester. Two third-year engineering students with a detailed understanding of the content were chosen to be involved in both the design of the NA toolkit and the Student-Student Mentoring scheme.

Interview protocol: A list of questions was developed based on the EWB criteria and the nine criteria developed for the study. These questions were piloted with a number of students who had completed a similar project but were not involved in the study and small adjustments were made to ensure understanding and clarity. Students were then interviewed

in their groups with the question order randomized to ensure no bias due to question order. Each interview was recorded and important notes were taken by a second interviewer during each session.

Recording the Data

It was decided that differences in student engagement and project output, in terms of UCD practices and paper grade, would be measured in two ways. The first was using marking criteria, based on the EWB criteria, a Massey University marking schedule and authors' knowledge, to judge the quality of each selected teams project report and individual log books. Across these documents all evidence of development and final solutions was expected to be present. The criteria covered nine areas, with a rating out of five being given for each one. A detailed outline of what evidence was expected, for each criterion, was also developed to ensure clarity. An initial report was analysed by multiple researchers and moderated to ensure a fair, un-biased marking approach. The criteria included were:

1. Environmental benefits and impacts of the proposed solution
2. Economic benefits and impacts of the proposed solution
3. Social benefits and impacts of the proposed solution
4. Use of locally available materials for the design
5. Consideration for end-user consultation during development and after implementation
6. Considerations made for the difficulty of communication with local community
7. Needs analysis techniques utilised
8. Breadth of research topics investigated
9. Overall level of engagement

The second data collection technique chosen was to interview members from each of the teams selected. This was done after report analysis to allow for insight to be gathered on each team before the interviews. A script was developed, and piloted, and included questions centred on the nine areas mentioned above as well as probing for examples of application to explore the student's engagement with the content.

Sampling Method

A systematic sampling technique was chosen to ensure a full spectrum of project outputs was present. This was done by the project paper Coordinator by ranking the teams in order of paper grade and then randomly selecting two teams from the top, middle and lower third. The reason for this sampling decision was that a wide spread of project grades was important to better highlight any effects NA technique engagement may have on project output. This resulted in six teams being chosen out of a population of 16. All names and grades of students were removed from reports and journals before analysis to minimise bias during the interview stage.

During the interviews, any suspicion of exaggerated answers was recorded and cross-referenced with the teams report evidence. To minimise the chances of false answers all students were informed that the research would in no way affect their university grades and there would be no consequence if they chose to opt out of participation.

Discussion

As outlined in the Methodology section criteria involving societal, environmental, economic and logistical considerations was used to analyse group project work from a first year humanitarian project course at Massey University, New Zealand.

All observations and results from interviews and report analysis were collated into a score for each of the criteria, outlined in the previous section and graphed against the teams overall project grade. As this grade was decided upon based on the university paper marking schedule, with appropriate moderation, it was important to identify any areas in which this study's evaluation may differ from the original grading. It is also important to note that no staff members involved in the original coordination of the university paper were directly involved in this study.

Initial analysis compared each of the nine criteria scores with the grade ranking, received in the initial paper offering. This shows that each of the scores given for the study criteria have a positive relationship with original grade given (i.e. teams who scored higher in each criteria also received a better overall grade). As all 9 of the criteria used showed a similar relationship this helped moderate the study and show that the marking criteria, and outline for each criteria, was reflective of the original marking schedule used and therefore deemed to be un-biased and credible.

One important relationship to note is that teams who received a low project grade also scored poorly in terms of NA techniques utilised. Whether there is a correlation or causation between the two is unknown but this does show that although NA technique engagement was not part of the original project paper marking schedule it may well have an impact on the quality of the project output. However, a low achieving team may also be less engaged in all aspects of learning and therefore score poorly across a number of areas. One team, ranked 5^{th} in this study of 6 teams stated in their interview that they did not use the NA toolkit provided and instead "did own research". While this may be indicative of a lowly engaged team it may also highlight that the effectiveness of the NA tool kit was not fully communicated to all teams.

Through comparing how teams scored in corresponding criteria it can be seen that teams who placed a large importance on including environmental considerations in their project were also better at utilising locally available materials. This may be a relatively obvious link, however through interviewing each team and explicitly asking about how environmental considerations impacted their designs a number of the high scoring teams had shown consideration for specific locations of materials, logistical constraints, potential local business opportunities and tradeoffs between local and imported materials. With most of this information provided, or at least guided, through the key elements table (see Methodology) it can be inferred that students who took the time to actively engage with the NA tool kit demonstrated a much more detailed consideration.

To support the statement that detailed environmental considerations (criteria 1) were closely linked to NA technique engagement and utilisation (criteria 7) the relationship between the two criteria was investigated. Again, a positive relationship can be observed strengthening the idea that NA techniques help in the development of environmentally conscious student projects. Whether this is purely due to the physical information and resources provided or because engagement with NA techniques begins to foster an empathetic skillset are not

obvious. One argument is that as a student interacts with the resources in the NA toolkit they begin to develop a professional empathetic skillset which in turn encourages them to put more effort into the environmental and social implications of their projects, as opposed to traditional technical and economic considerations. An example of this, from the top ranked group showed explicit consideration for locally available materials and the environmental impact of the project.

"The grinder is almost entirely composed of locally available natural resources which will have little to no negative impact on the environment. Bambui is close to a forest where wood and materials for rope can be sourced in small amounts; a granite quarry exists to the south-west of Cameroon and mud bricks are readily available almost anywhere in the country".

This was in contrast to a lower ranked group's assumptions and oversights in the areas of environmental impact and end-user expertise. This group relied on the end-user not applying too much heat in the process of melting plastic bottles over an open fire to avoid toxic gases being released.

"For example, the plastic brick melter must only melt and not burn the plastic as this could result in toxic plastic fumes damaging the ozone layer and people's health if breathed in".

Criteria 5, "Consideration for end-user consultation during the development and implementation process" showed a wide spread of data, however, when paired with criteria 7 (NA techniques utilised) no relationship was obvious. This may have been due to the lack of access or communication to the end user, Bambui locals in Cameroon, resulting in misguided assumptions negatively effecting project outputs. Students were not marked against what assumptions they made but instead how well they justified the need for each assumption and how associated risks could be mitigated if a humanitarian organisation was to actually implement their project solutions.

The way, and effectiveness, in which the content was delivered to the class was also investigated during the team interview phase with the majority of the teams satisfied with the amount of content provided in the NA toolkit and the appropriateness of the content to the project. However, the delivery style of having two 3rd year engineering student mentors introduce the NA tool kit in a tutorial/informal setting to a large class was shown to be less engaging than originally thought. The importance of the content introduced may not have resonated with all groups and furthermore groups which initially showed an interest were likely to have received more help than others resulting in a slight bias in group knowledge and engagement. A suggestion which may be implemented in the 2016 first year project paper is to introduce the NA toolkit during a compulsory lecture ensuring all students receive the same explanation of its content, effectiveness and importance to their project outputs.

Conclusions

The first year EWB project, discussed throughout this paper, will continue to grow and develop as more is learnt about the effectiveness of teaching Needs Analysis techniques early in the first year of an undergraduate engineering degree. However, evidence provided from this study suggests engagement with the NA toolkit provided shows an increase in student empathy and in turn a heightened awareness for environmental and local logistical issues. This research shows promising trends that more development should be put into

including NA content as lecture material early in a first year project paper. The skillset promoted throughout this study will become increasingly important to an engineer's role in society as social and environmental issues become important drivers in projects. This is supported by the Washington Accord Graduate Competencies stating an engineer must possess "appropriate consideration for public health and safety, cultural, societal, and environmental considerations"(IEA, 2013). Although a larger study would need to be undertaken to understand how these first year learning activities effect an undergraduate students project work and graduate attributes, throughout the degree positive signs can be noted that introducing NA content to first year students improves their contextual and empathetic engineering skillsets.

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