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Embedding Sustainability in Product Design Engineering Curriculum: A comparison of needs on an international level

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Abstract
Product Design Engineering is a relatively new engineering discipline that combines Mechanical Engineering studies with Industrial Design. The emergence and credibility of this field has created graduates who can successfully combine the creative thinking of design with the analytical thinking of engineering. A Product Design Engineer forms a vital role in a product development team making it even more necessary to ensure graduates from this field have sustainability embedded into their skill-set.

Product Design Engineers are at the forefront of product development; this in turn puts them at the forefront of unsustainable patterns of production and consumption that currently plague the manufacturing industry. Due to this, it is imperative to ensure all Product Design Engineering outcomes have implemented sustainable practices to develop quality products with environmental concerns in mind. Sustainable design has become more prevalent and is no longer perceived to be purely organic design, or associated with single actions such as recycling. It now also involves concepts of Product Stewardship and Life Cycle Management, including how these concepts translate into current best practice within leading global manufacturing companies. Knowledge of sustainable design has developed through necessity and a better understanding in this area has helped create successful, competitive products with less impact on the environment. The range of theoretical or conceptual knowledge and tools available across the environmental design spectrum are then practiced by the students as applied design methods within studio projects.

This paper shows how sustainability is now embedded in Product Design Engineering disciplines and does not only discuss the relevance of the content, but moreover addresses this issue from of student perspective. Three cohorts of undergraduate Product Design Engineering students have been surveyed to respond to individual comprehension of this topic — and how effective this is — on their knowledge base. Two cohorts from Swinburne University of Technology, Melbourne, Australia, and the other from EAFIT University, Medellin, Colombia. By doing this, an international perspective of educational experiences in sustainability for Product Design Engineering can be obtained and is discussed in depth within this paper.

Keywords: product design engineering, sustainability, curriculum

Introduction

This paper represents the findings of 112 undergraduate student surveys containing 13 detailed questions relating to sustainability for Product Design Engineers. Previous publications relating to this issue tend to consist of qualitative descriptions of the development of courses (Koen, 1994) (Dym et. al., 2005) (Diehl et. al., 2005) (Lamancusa et. al., 1997) (Dieter and Schmidt, 2009) (de Vere et. al., 2010). This paper provides an insight into student opinion about the way in which sustainability in this field has impacted their learning experience. It also brings to the discussion two geographical areas that are so far lacking in the literature.

The process of surveying students was conducted to eliminate any bias towards this study in favour of the two universities represented. It is always difficult to analyse the issue in question from a university in which the author's are employed in a non-bias manner, hence justifying the reasoning behind using surveys to gather qualitative and quantitative data. The main intention of this study is to understand from a student perspective what is working and perhaps what is not working in the embedment of sustainability into the pedagogy of Product Design Engineering. This provides an accurate understanding into this topic, which aims to inform the reader on how to successfully embed sustainability into Product Design Engineering degrees.

This study recognises — and to some extend validates — work done by Boks (2006) where he explains the Industrial Design Engineering curriculum at TU Delft in the Netherlands. This study gives methods of integration of sustainability into the curriculum, however there is no mention of embedding this. There is a difference. The difference between integration and embedment is that by embedding sustainability into the curriculum we ensure that this issue is a key consideration into all activities taught throughout the Product Design Engineering degree. This study is not to underestimate the successful work being done at other institutions; the aim is to educate others on the positive aspects that have been evidenced in the surveys. It should be noted that Boks' research in this area is also nearly six years old, giving credit for developing this when sustainability was not as prominent as what it is now. The areas within the surveys that were not perhaps favourable are also highlighted to ensure other institutions learn from this research, as well as the universities involved in this paper.

Product Design Engineering forms a crucial link between traditional Industrial Design and Mechanical Engineering. It is a key component of all new product development teams to ensure a cohesive translation between the creative 'design' teams and the analytical 'engineering' teams. This is visually represented in Figures 1 and 2.
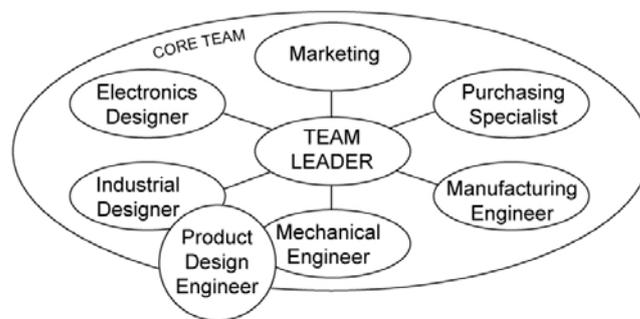

Figure 1.   Where Product Design Engineering fits within a standard product development team of an electromechanical product of modest complexity. Diagram adapted from Ulrich and Eppinger (2004). p 4.
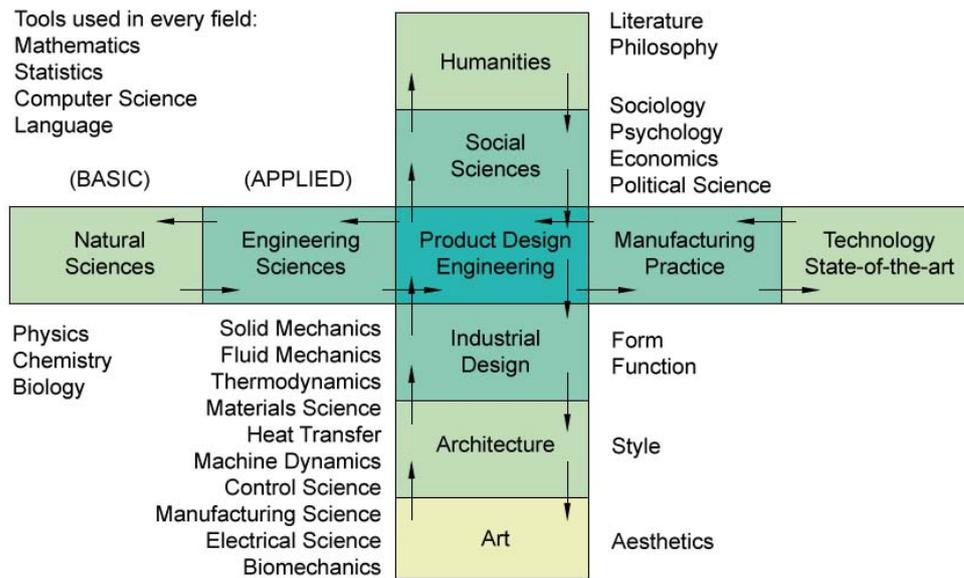
Figure 2. The place of Product Design Engineering in the technological and cultural world. (Adapted from Dixon, 1966, in Hundal 1997, p. 38).

In order to gain an insight into the two universities involved in this study a description of the current educational structure for each Product Design Engineering degree is as follows:

Figure 3.   The geographic location of the two universities involved in this study.

Product Design Engineering at EAFIT has a duration of five years. It includes a number of mandatory courses, electives and complementary courses. Students at EAFIT University, more specifically Product Design Engineering in the last stages of their course, have the opportunity to select a group of subjects in a specific topic in which they would prefer to focus on. Since the beginning of the program, courses focused in 'Design for Sustainability' were offered as a response to a need of integrating the sustainability competence required for a Product Design Engineering student. These courses offered are: Eco design, Green Marketing, Product Life Cycle and Cleaner Production and Manufacturing.

In addition, the crux of the Product Design Engineering program is the 'Design Projects', which involve a series of practical sessions and workshops including the involvement of three different domain-specific teaching staff. These tutors are responsible for providing students with the necessary knowledge needed to comprehend the product design process. As such, they are in charge of giving students the knowledge of sustainability issues such as methodologies, methods and tools dedicated to address these into the design process itself.

Product Design Engineering at Swinburne University of Technology (SUT) has a duration of four years with an optional 5th year if students complete a 4th year of industry-based learning. Students have a mandatory set of 28 units (subjects) with four specialist units. In order for full accreditation from Engineers Australia each student must also complete a minimum of 12 full-time weeks of approved relevant engineering practical experience at any stage of their course. Within this curriculum there is a strong focus on sustainability highlighted within the following core units: Product Design Engineering 2: Sustainability, Product Design Engineering 4: Social responsibility and Product Design Engineering 5: Innovative Methodologies. During every semester throughout the duration of the course there is a Product Design Engineering studio, which ensures sustainability is at the forefront of all project work.

While sustainability becomes an important design consideration across all studios, students are able to experience a specific sustainability studio for product design at second year level which equips them with an overview of concepts and theory of sustainable production and the range of strategies, methods and tools they can draw upon to problem solve and innovate towards greater efficiencies. Students apply concepts such as Dematerialisation, Decarbonisation, Extended Producer Responsibility, Product Service Systems, Closed System Cycles, Life Cycle Thinking and Life Cycle Management into a practical design project. It gives students the chance to experience how the above concepts change the priorities or considerations of the design and production process.

When dealing with a discipline that is responsible for the way in which products are produced and in-turn, responsible for the waste this practice generates, it is essential to educate future leaders of this industry with a strong focus on sustainability. Agenda 21 from the Rio Earth Summit Strategy to Save Our Planet (1992), states:

> *The world is presently on a path of energy production and consumption which cannot be sustained (Agenda 21, Rio Earth Summit Strategy, 1992).*

This shows that the challenge of creating a sustainable world has moved from the realm of idealism to that of necessity. The understanding of sustainability as an essential value results from a coming to consciousness in the field of engineering and design (Margolin 1998, Papanek 1972).

Margolin (1998), who wrote a seminal article published in Design Issues, *Design for a Sustainable World*, argues for change:

> *Design will change through a coming to consciousness of its individual practitioners. Broad proposals and visions are a stimulus to this process, but cannot replace the hard sustained work of rethinking one's identity as a professional. What makes this process so essential right now is the clear evidence that older models of practice are not working (Margolin 1998).*

This statement reflects the aims of this research, showing that a singular research study will/can create change, and an understanding of current practice in Australia and Colombia validates the reasoning for change. The result of this activity aims to create

new power for Product Design Engineering showing that alternative/sustainable ways of creating consumer products are possible. All actions that improve on current practice are important both inside and outside the market economy and by ensuring all students studying this degree graduate with a sound knowledge of sustainability – both in theory and practice.

Sustainability can be defined as:

> "Meeting the needs of the present without compromising the ability of future generations to meet their own needs (UNCED, Bruntland Commission Report, 1987)."

The above statement clarifies the most important aspects of sustainability education within Product Design Engineering. A strong focus is given towards efficient manufacturing processes and appropriate material selection while not jeopardising the product's function and aesthetic appearance. This somewhat simple statement lies at the heart of this issue and although extremely complex to satisfy, there is no excuse for graduates not attempting to apply their knowledge of sustainability into everything they create – providing they were educated correctly on this topic which this research suggests.

Method

At present, the credibility of survey research findings is largely a function of response rate. Low return rates are presumed to suggest biases in data (de Leeuw, 2005). To prevent any form of bias a relatively large cohort of students were surveyed from two similar courses from two vastly different countries. Swinburne University of Technology in Melbourne, Australia and EAFIT University in Medellin, Colombia have partnered to provide a greater understanding of similarities and differences of this topic on a global scale.

The methods of surveying were split between paper-based and web-based. Web-based — or Internet-based — surveying is very cost and time efficient (Dillman 2000; Couper 2000), and this together with the novelty value have made them very popular in a short time. They have a great potential, but they also still have limitations (e.g., non-coverage, nonresponse). These limitations are the reasons why the survey method was split to also include paper-based surveys. The biggest problem with web-based surveys was the poor response rate from certain cohorts whereas a 100 per cent response rate was recorded for the paper-based surveys.

Combinations of web and paper-based surveys are now more common, especially at universities and in official statistics (Couper 2000, Dillman 2000). Mixed-mode surveys are presently attracting much interest and were made a main topic at the data collection conferences of the Council of American Survey Research Organisations (CASRO) in 2003 and 2004. According to Biemer and Lyberg (2003), mixed-mode surveys are the norm these days in the U.S.A., Australia and parts of Western Europe. An optimal data collection method is defined as the best method, given the research question and given certain restrictions (Biemer and Lyberg, 2003).

The survey results used in this study provide an accurate understanding of the competence levels students from both universities have when designing for a more sustainable environment. This research is preliminary — albeit comprehensive — and the authors aim to expand this study to provide sustained research using future cohorts studying Product Design Engineering. The results shown in this paper provide an insight

into how students currently think about sustainability in Product Design Engineering, which provides the reader with useful information regarding Product Design Engineering curriculum. Surveys of this nature help comprehend the relevance of this topic and most importantly questions if the students are absorbing this relevant information.

The quantitative and qualitative data generated from the student surveys are used to identify the understanding each cohort has on eco design principles and sustainability, with an emphasis on the impact of manufacturing processes and materials on global ecosystems and the world's diminishing resources from a design and manufacturing perspective.

There are only around 30 Product Design Engineering courses in the world (de Vere et. al., 2010) that concentrate on the combination of Mechanic Engineering and Industrial Design intertwined with one another. Due to this small number a niche has been created and more courses of this nature are commencing to better link with expectations from industry (de Vere et. al., 2010). Also because of this, it is important to learn best practices from similar courses around the world – giving good reasoning behind the collaborative work between EAFIT University and Swinburne University of Technology. A global awareness of similar activities will aim to ensure research of this nature will stay at the forefront of global activity.

Findings

The followings findings are broken into four categories to best represent the survey outcomes. As previously mentioned three cohorts of undergraduate Product Design Engineering students were surveyed representing a total response of 112 completed surveys. The first results shown are from EAFIT University (Medellin, Colombia) and the second two are from Swinburne University of Technology (SUT) (Melbourne, Australia). Represented as EAFIT, SUT_ONE and SUT_TWO respectively. The final results presented are the combined outcomes of all three cohorts. This method of analysis gives a clear dissemination between Colombian results versus Australian results, as well as differences in semesters completed by each cohort (Figure 3), and also gives clarity to the final outcome with the combined results.

A mixture of qualitative and quantitative data was obtained forming a total of 13 questions relating specifically to student opinions of sustainability within Product Design Engineering curriculum. These results have been graphed to elucidate the quantitative responses and are followed by a sample of qualitative examples that underpin the general trend within responses. Following this, a summary of the findings for each question sets out to inform the reader of the major findings. It is important to note that all figures represented in these graphs are percentage values according to the number of responses from each cohort.
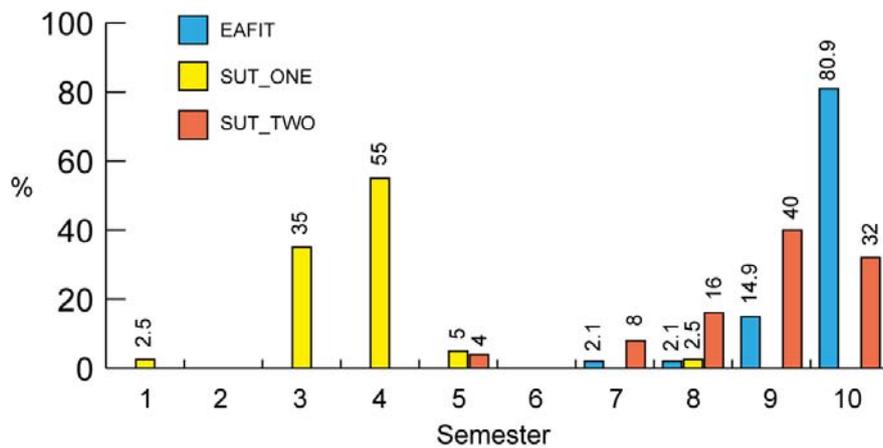
Figure 4.　　　Question one. Semesters completed for survey respondents within their Product Design Engineering degree.

Figure 4 shows the level of educational experience from all three cohorts that should be referred to when reflecting on some of the following results. When engaging in a study such as this it is preferable to survey students in the latter part of their course, which has been done by the majority, however it is also interesting to see the opinions of students in earlier years to understand differences in experience (seen in SUT_ONE).

Figure 5 shows the combined data for all three cohorts giving a clearer picture of the average semesters completed for the survey respondents. This graph shows 66.2 per cent of respondents have completed between 7–10 semesters (4–5 years), leaving 33.8 per cent having completed between 1 and 5 semesters (0.5–2.5 years).
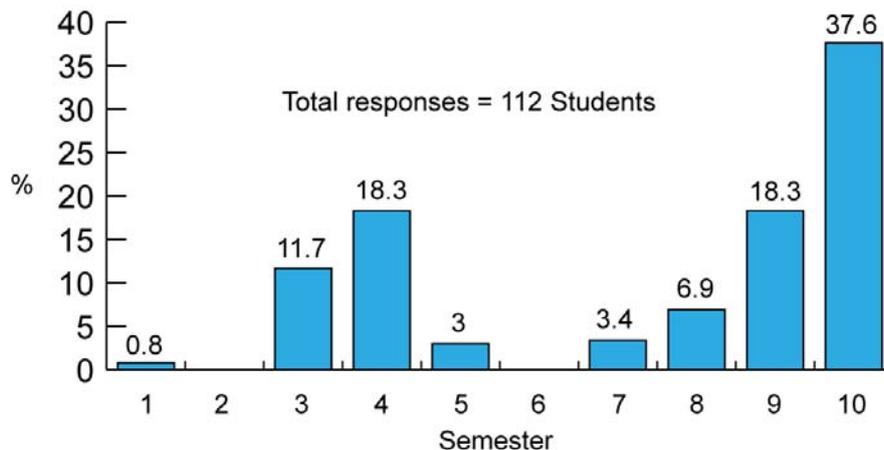

Figure 5.　　　Combined semesters completed for survey respondents within their Product Design Engineering degree.

The first question was used to understand the majority of opinions as to what was seen as the most appropriate definition that best describes the students understanding of sustainable design. Results are as follows:
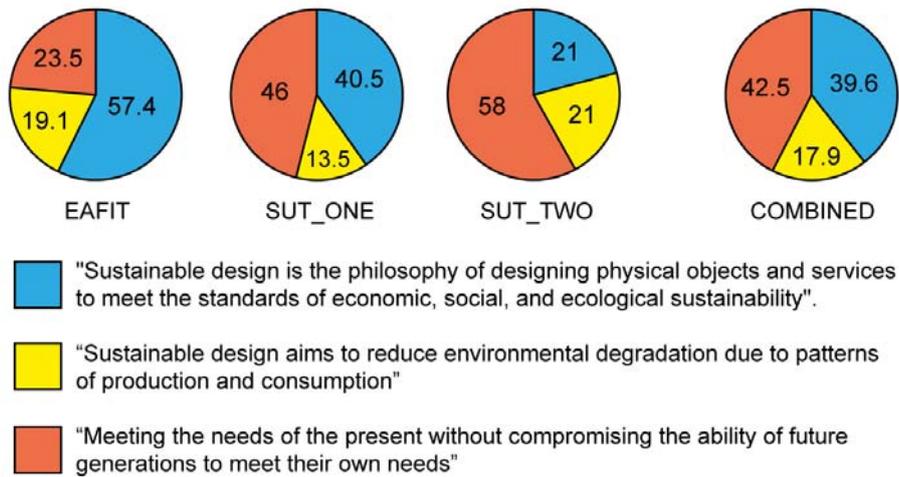
Figure 6.   Question two. Which of the following definitions best describes your understanding of sustainable-design?

All answers within this question have merit in their own right and there is certainly no wrong — or least desirable — outcome. This question merely gave a good introduction to the survey and the combined responses show that the first (blue) and last (red) definitions were the most favoured.

The third question was intended to gauge the knowledge level of each student before entering his or her Product Design Engineering degree. This is an important question that is used to compare the level of competence/knowledge students have gained during their degree. Initial thoughts suggested that knowledge levels would be low which was validated within the results (Figure 7).
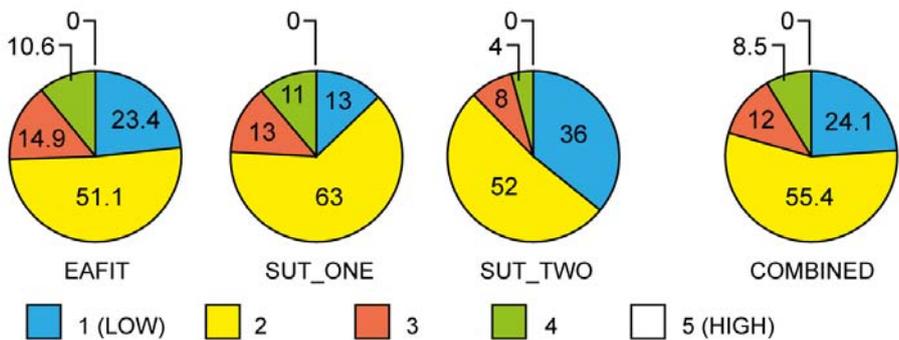

Figure 7.   Question three. What was your knowledge of sustainability before entering your course (Product Design Engineering)?

This question validates the importance of embedding sustainability into the Product Design Engineering curriculum as the majority of respondents (79.5 %) have shown that they had low (between 1–2) knowledge of sustainability before entering their degree. This result was expected but nonetheless validates the intentions of this study with no bias. This result also highlights the importance of ensuring sustainability must be embedded throughout the curriculum as the majority of students entering the course have very little knowledge.

To understand how effective the embedment of sustainability has been within the Product Design Engineering discipline the next question determined the level of increase in knowledge of sustainability for each cohort. The results are as follows:
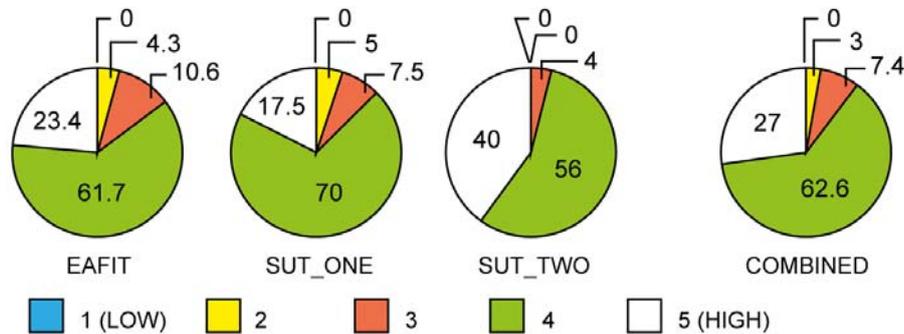

Figure 8.   Question four. How do you rate your knowledge of sustainability now?

It is satisfying to note that a majority of respondents (89.6 %) answered between 4–5 indicating that most students have gained significant knowledge in sustainability throughout their degree so far. To better understand the reasons behind this question students were asked to explain their response. It is obviously difficult to list every written response so in order to streamline this process the results were analysed by the authors of this study and the most common themes are as follows:

- Product Design Engineering has provided a good base knowledge of sustainability, although I feel as though there is still more to learn.
- There are still many things to do. Processes to develop, materials to improve. We won't know everything about sustainability because it is something that never ends.
- I have a much better understanding of sustainable manufacturing and lifecycle analysis. Although my knowledge has increased, there is still much I need to learn.

The general consensus confirms a competent understanding of sustainability with some uncertainty of how effective this will be, as all students surveyed have not had the industry experience to practice this knowledge. It is clear that students have increased their knowledge by comparing Figure 7 with Figure 8, however the underlying theme is that students understand that sustainability is a complex issue that requires constant attention and feel there is always more to learn. This is a positive response as this topic will always evolve and professionals within this field should always stay abreast with new developments in sustainability.

The following question refers to the importance of sustainability within Product Design Engineering to determine whether or not the students see this as a relevant topic. Results are as follows:
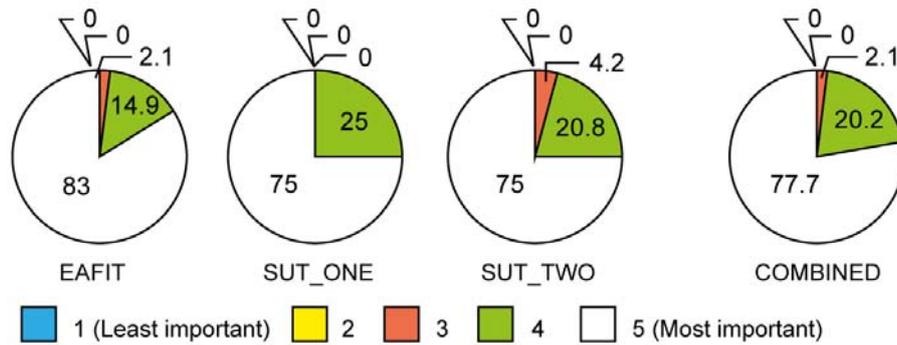
Figure 9. Question five. Please rate the importance of sustainability in Product Design Engineering.

Results for this question were also anticipated and it reinforces the intentions of this study, as it shows that a large majority (97.9 %) of students see sustainability as highly relevant and a necessary part of the Product Design Engineering curriculum. Although results were anticipated it is still very pleasing to see such a large percentage of positive responses, and most pleasing to note is no responses indicating that sustainability has little importance. Extended answers formed the second part of this question and the main themes conferring to the above quantitative data are as follows:

- Sustainability is highly important but the product still needs to function and be aesthetically pleasing.
- Product Design Engineering is an industry that can change consumerism towards sustainability.
- As designers we have the power to curb excessive consumption of unsustainable materials and processes as well as the responsibility to meet the increasing awareness and need for sustainability.
- Anything less would be selfish of our generation.
- I think that sustainability must be a lifestyle and everybody should be in it, even unconsciously.

A lot of the qualitative responses for this question discuss the important role Product Design Engineers play when dealing with sustainability. A positive theme identified is the ability for a Product Design Engineer to guide the way in which this industry currently operates. It is clear within the responses that these future leaders of this field are aware of the impact new product development makes on the environment and it is up to these individuals to try and influence change.

To expand upon the previous question students were then asked more specifically if sustainability should be considered in all of their project work. The responses are as follows:
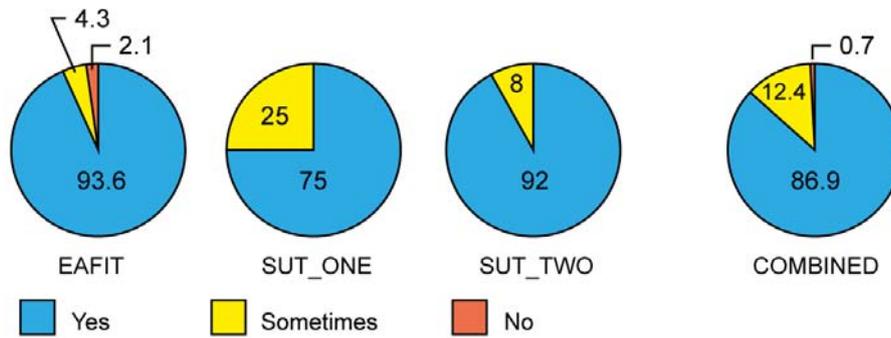
Figure 10.   Question six. Do you believe sustainability should be considered in all of your project work?

Again, the majority of responses (86.9 %) reinforce the comprehension levels the three different cohorts have regarding sustainability within Product Design Engineering. One response out of 112 suggests that sustainability should not be considered in all project work, leaving 99.3 per cent of respondents thinking it should be considered sometimes or all the time. When asked to describe their answer the following themes were observed:

- Sustainability should be considered in most designed products, however some products will not be able to implement this due to various reasons such as cost, quality, function etc.
- Not doing so in 'real' products is negligent and irresponsible – habits must be set now.
- We have to become more conscious about how we affect the environment and how we can be a factor of change. Every single thing we do now will affect our future, the products we develop today will have a huge impact tomorrow if we don't care about sustainability.

Although the majority of quantitative data suggest that sustainability should be considered in all project work, this is somewhat contradicted within the qualitative responses. The overall theme of these responses stresses the importance of sustainability for product development, however the majority of written responses position themselves more towards 'most' project work, not 'all'. The underlying theme clarifies the importance but there is emphasis given to the barriers that would prevent sustainability being considered in all project work. Barriers such as cost, time, availability of materials and jeopardising the products function have all been identified. This however is misconstrued, as there is a difference between consideration and implementation, which seems to be the thought patterns of many respondents.

Question seven was purely qualitative responses and referred to what are the key obstacles to incorporating environmental issues into a new product development process. The main findings are as follows:

- The issue is costs associated with using better materials, extra design time etc. Also 'green' products that end up being less 'green' than what they replace.
- Sustainability is very time consuming and the lack of resources and suppliers adds to the difficulty. Finding reliable and comprehensive data is difficult.
- Almost everything can be solved, the only thing that is difficult to change are the individual interests of many people that don't care about the environment and only care about the money in their pockets.

Time and costs are definitely the underlying theme throughout the qualitative responses for this question. However, an optimistic view on the way in which sustainability is becoming more prominent in industry and society shows that students are willing to understand this topic in more detail, rather than look at it as too complex to deal with.

To better understand the way in which a university can help students to better access sustainability information the following question asked what sources of information are used to support sustainable design. Due to more than one answer being possible to select, the percentage value shows the amount of respondents who selected that particular answer out of the 112 students surveys. Answers are also ranked to show the most popular to the least popular sources of information (Table 1).

Table 1.   Sources of information used to support sustainable design.

Rank	Source	Responses	Overall %
1	Internet	95	84.9
2	Data from specific companies	63	56.3
3	Professors at university	61	54.5
4	Books	48	42.9
5	Software	37	33
6	Databases	36	32.1
7	Informal meetings with experts	34	30.4
7	Government	34	30.4
7	Magazines	34	30.4
10	Journals	32	28.6
11	Networking	26	23.2
12	Engineering consultants	24	21.4
13	Design consultants	19	17
14	Environmental groups	18	16.1
15	Environmental consultants	17	15.2
16	Conferences	16	14.3
17	Sustainability consultants	15	13.4
18	Design contests	11	9.8
19	Fairs	4	3.6

Table 1 shows that the most widely used source for obtaining information about sustainability is the Internet. This is obviously the easiest and quickest way of gathering information, however not all information on the Internet is correct and could lead to falsification of data. Over half (54.5 %) of respondents rely on professors at university for accurate information, which shows the important role teaching staff play within the Product Design Engineering discipline. It is pleasing to see a large percentage of students (56.3 %) obtaining information from companies, as existing product specifications will be more accurate — and perhaps more comprehensive — than that found on the Internet. Clearly more work needs to be done in engaging students with professional engineering (21.4 %), design (17 %), environmental (15.2 %) and sustainability (13.4 %) consultants, as these groups provide accurate information that would benefit the students knowledge of this topic. Organised visits, guest lectures or planned meetings with such consultants could improve the interaction and learning experiences for the students.

The following question is set out to determine the practicality of the learning experience by asking students to respond to their ability to implement their sustainability knowledge into the development of a new product. The responses are as follows:
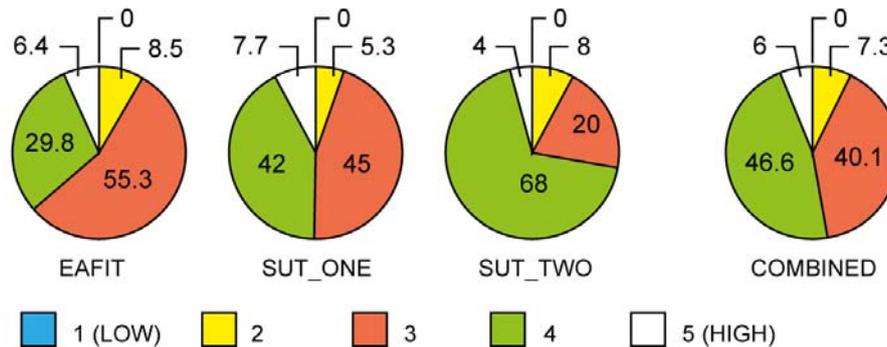

Figure 11.   Question nine. Please rate your current ability to successfully use sustainable materials and manufacturing processes in the development of a commercial product?

It was hoped as educators in this field that responses would be focused between 4–5 but this was not the case. There was some uncertainty around the individual's ability for successful development of a commercial product using sustainable materials and manufacturing processes. The reasoning for this is expanded in the qualitative responses but the main conclusion sways towards the lack of professional industry experience the respondents have had. It is one thing to comprehend sustainable practices but another to be able to implement them. This highlights an opportunity to build more industry-linked projects into the curriculum that will force students to work closer with 'real-world' product development teams with the intentions of educating students about sustainability in practice, not just sustainability in theory. The main themes observed throughout the extended answers are as follows:

- I have a good idea (about the implementation of sustainability into commercial products) but hands-on experience will help.
- There are so many limitations when alternative materials and manufacturing processes are expensive and hard to find.
- Engineering data that is reliable is hard to find for new materials and manufacturing processes.
- I feel as though my ability to implement sustainable materials and manufacturing practices into products is advanced but I would still require further advancement.
- It is still difficult to find companies that are trained or know how to work with sustainable materials. Colombia still has a lack of technology to manufacture and develop sustainable products.

Although Colombia and Australia are vastly different countries there were similarities within responses from these two different cohorts. Students are of the opinion that current industries do not have the ability to implement sustainability into new product development. This stresses the importance of this topic in undergraduate education, as these students can be drivers of change. By reinforcing the importance of sustainability in Product Design Engineering it is anticipated that these future leaders of this industry can pioneer improved 'sustainable' practices in this field. The ability to apply their knowledge is currently lacking, however this learning experience aims to ensure graduates of this course can start influencing others and one day hopefully revolutionise the way in which commercial products are currently being developed. It is probable that graduates with a good knowledge of sustainability will become an essential part of every product development team because the way in which manufacturing currently exists will be forced

to change. One such example of this 'forced' driver of change is the introduction of a Carbon Tax by the Australian Government.

Australia currently produces about 500 million tonnes of carbon pollution each year, ranked within the top 20 polluting countries in the world (Australian government, 2012). A carbon price changes this by putting a price tag on pollution. Instead of being able to pollute for free, big polluters must pay a price for every tonne of carbon pollution they release into the atmosphere.

The introduction of a carbon price will have two impacts:

- First, it will create a financial incentive to reduce carbon pollution in the cheapest possible ways. This will encourage businesses across the whole economy to reduce their pollution. Economists and independent institutions like the Productivity Commission have demonstrated that market mechanisms like a carbon price are the cheapest ways of reducing pollution.
- Second, it will also provide incentives to invest in clean energy, and will change Australia's electricity generation by encouraging investment in renewable energy like wind and solar power and the use of cleaner fuels like natural gas. In this way, introducing a price on carbon will make lower-polluting technologies more competitive and will trigger the transformation of the economy towards a clean energy future.

New government regulations such as this make Product Design Engineering graduates with a thorough knowledge of sustainability invaluable within the design and manufacturing industries. It is vitally important to ensure what is being taught at university is relevant to current industry standards and the embedment of sustainability throughout all subjects ensures this.

Question 10 investigates in detail what area(s) of the product development process are the most important to embed sustainability. The areas determined as essential parts within a product development process where derived from Dorst and Cross (2001), Ulrich and Eppinger (2002) and Zimmerman (2002), which all validate the vital steps required to develop a new product. These steps were then used to form this question.

Multiple areas could be chosen for this question and the results are shown in Table 2:

Table 2.   The most important areas to embed sustainability in the product development process.

Range	Responses	Overall %	Rank
Research	44	39.3	2
Idea/concept generation	38	33.9	4
Refinement	19	17	6
Prototyping	8	7.1	8
Test marketing (user validation)	11	9.8	7
Production	31	27.7	5
End of life	40	35.7	3
All stages	60	53.6	1

The 'easy' (most common) answer for this question is 'All stages' which does rank number 1 with over half of the students surveyed selecting this option (53.6 %). While many respondents would strongly believe all stages of the product development process should embed sustainability, it is positive to see large percentages in other, more specific areas also. By analysing the overall percentage of each area a bell curve is formed giving higher importance to the earlier and latter stages within the product development process.

To better understand the value of sustainability within Product Design Engineering the following two questions were asked:

- Question 11. What aspect of your Product Design Engineering program do you feel is the most significant when referring to sustainability?

- Question 12. What areas of your Product Design Engineering program do you think were/are lacking in sustainability?

The major findings for Question 11 are as follows:

- The Product Design Engineering subjects.

- The design aspects show more awareness of sustainability.

- Actually applying the sustainability theory in a project.

- Building our understanding of materials, processes and lifecycles.

- Understanding the entire life cycle of products.

The main focus for these responses centered on the design studio subjects. Perhaps the reasoning for this is the opportunity for students to use their knowledge effectively in their project outcomes, whereas in the engineering subjects the theoretical side of Product Design Engineering dominates. This has been somewhat validated in the majority of responses for Question 12, which show a heavy trend towards the engineering subjects lacking in sustainability. A selection of the most common responses is as follows:

- Engineering subjects.

- Materials other than plastics.

- Early stages of the course.

- Production and prototyping.

There was quite a significant difference in responses between EAFIT and SUT for this question. A large percentage from EAFIT suggests that the prototyping and material selection phase were lacking, whereas SUT weighed heavily towards the engineering subjects lacking information. This is something that can now be addressed where possible. Some barriers that would prevent this from happening are areas such as the specific engineering topics and teaching methods, such as Human Factors as an example. Sustainability is encouraged throughout the entire degree program, however certain first year subjects are building skills that will be used throughout the course. Skills such as CAD, sketching and mathematics are challenging — and perhaps not necessary — to build sustainability into. Nevertheless it is a good insight into student opinion and something that can be used as a positive advancement of the current course structures.

The final question was concerned with the student's ability to think beyond their current undergraduate degree and determine whether they believe the knowledge gained in sustainability will be used when they commence employment. Results are as follows:
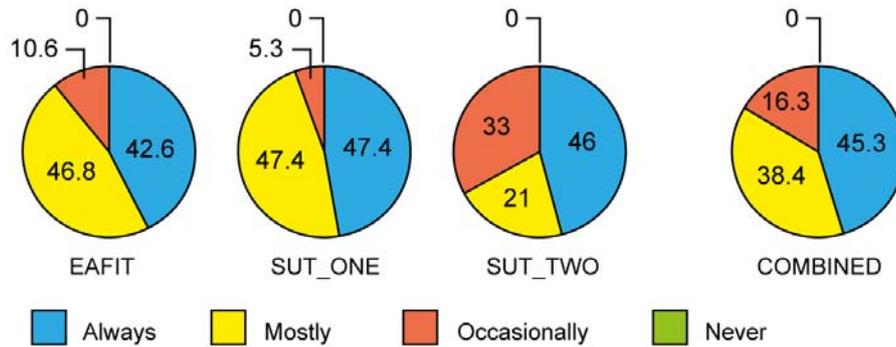
Figure 12.   Question 13. Do you believe the knowledge gained in sustainability will be used in a graduate position?

Over three quarters (83.7 %) of the 112 students surveyed believe that they will be able to implement sustainable practices when they join the workforce. This is a positive response highlighting the successful work being done to prioritise sustainability in the Product Design Engineering discipline. The most pleasing result from this final question is no students saying they will never use sustainability in a graduate position. Qualitative responses were also given for this question, which clarify why over half (54.7 %) of respondents answered between 'Mostly' and 'Occasionally'. The most consistent responses are as follows:

- I will do what I'm told in a graduate position. I can make better choices in a senior position.

- Even if not used directly, knowledge of sustainability helps you see through marketing 'green wash' or eco-trendy jargon, which helps make better decisions.

- It is limited by the company's willingness to adopt sustainable techniques.

- More companies are implementing voluntarily sustainable strategies. Hopefully this becomes standard and I can apply what I have learnt.

- Sustainability is an issue that is increasingly important making companies realise the need for better sustainable practices.

Overall there is a general sense of optimism regarding the way in which industry is responding to sustainability. While a lot of work is still required at least these heavy polluters are aware of the issue. A majority of responses understand that in a graduate position they may not have the freedom to explore sustainability but the overriding trend shows that if given the chance, the graduates will certainly be capable of designing more sustainable products.

Summary

The result of this study aims to create new power for Product Design Engineering by educating future leaders within this field of necessary sustainable practices. By doing this it shows that alternative/sustainable ways of creating consumer products are possible. All actions that improve on current practice — as this research shows — are important in improving the knowledge base of graduates in this field who would now have the ability to put sustainable practices into action.

There has been limited fundamental reinvention of design practice in order to play an active role in the culture of sustainability, highlighting no clear paths to new forms of practice (Margolin 1998). Although Diehl (2005) — along with others (Boks, 2006) — are improving this, a lot of work is still required.

This study is not about informing the reader about new curriculum development. It has been conducted to show the opinions of Product Design Engineering students and the effectiveness of sustainability throughout their course. It is intended that this study can now be used by educators and industry to appreciate the positive aspects, and hopefully work to implement them into their own structures. By increasingly promoting the benefits of sustainability, the way in which products will be designed and manufactured will improve.

An appreciation of variances from two vastly difference environments (Australia and Colombia) also adds value in better understanding the global nature of sustainable design within this discipline. This is clearly displayed within the separation of results for the quantitative responses, and in most parts the findings are very similar. This shows that sustainability is a global topic and it should be prioritised in all industries that currently contribute to an unsustainable world.

It is anticipated for this study to continue. The nature of this industry is always evolving, giving greater importance for continually assessing and implementing best practice from around the world. It has been highlighted within the results that sustainability is well understood in the later years of the Product Design Engineering programs in this study. The issue is the ability for graduates to successfully apply this knowledge in future product development teams. This is an area that requires fundamental change within existing manufacturing structures, but in order for this change to be possible, the people working in this industry require the necessary knowledge to make this change – underpinning the value of this study.

The result will create new power for Product Design Engineering, showing that alternative/sustainable ways of creating consumer products are possible. All actions that improve on current practice and current educational methods are important in improving the knowledge base of graduates in this field who would now have the ability to put sustainable practices into action.

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