CREATING THE HOLISTIC ENGINEER
ACKNOWLEDGEMENTS

The conference organizers gratefully thank all those who have endeavored to make the EESD 2018 a successful conference. We appreciate the hard work and dedication of those who contributed to the preparation, organization, and the follow-up activities. Of particular note, are the Local Organizing Committee, the Steering Committee, and the International Scientific Committee.

We appreciate the co-sponsorship of the American Society for Engineering Education (ASEE), whose mission advances innovation, excellence, and access at all levels of education for the engineering profession.

EESD 2018 would not have been possible without the support, both in-kind and financial, of Rowan University’s Office of the Provost, the Henry M. Rowan College of Engineering, the Rowan University Department of Chemical Engineering, and the FMC Corporation.

We appreciate the efforts of the conference session chairs, workshop organizers, key note speakers, and especially the presenters of the papers at EESD 2018. Their names can be found in the next section of the Proceedings in the appropriate session.

Special thanks to Rowan undergraduate and graduate students who have provided their time as conference aides for various functions. We also thank Mr. Matt Mammarelli and online staff from Rowan Global Learning and Partnerships for their assistance with web-related and information resources. Staff from the Rowan Office of Conference Event Services were quite helpful to us.

Conference Coordinator and Administrator

The leadership of Dr. Mariano J. Savelski, Conference Coordinator, whose insight into shaping this conference, was crucial to making this event a reality.

We are in debt to Ms. Kim Johnston, Conference Administrator, for the endless hours of time spent on every minute detail, and for her diligence to make this a successful endeavor.

Steering Committee

As we walk in the foot-steps of those who went before us, we gain wisdom from their organizational acumen. We appreciate the valuable insights provided by previous conference organizers, and thank those who are no longer with us.

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<td>The Hague University of Applied Science, TU Delft &amp; IDO vzw</td>
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<td>Chalmers University of Technology</td>
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<td>UBC Vancouver</td>
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<td>Luk Van Langenhove</td>
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<td>Rietje Van Dam – Mieras</td>
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<td></td>
<td>Bernard Mazijn</td>
<td>IDO vzw</td>
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<tr>
<td>9th EESD-conference (Glassboro)</td>
<td>Joseph F. Stanzione, III</td>
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<td></td>
<td>Mariano J. Savelski</td>
<td>Rowan University</td>
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**International Scientific Committee**

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<th>Title</th>
<th>Organization/University</th>
<th>Country</th>
</tr>
</thead>
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<tr>
<td>Bernard Mazijn</td>
<td>Managing Director &amp; Professor</td>
<td>Institute for Sustainable Development &amp; Ghent University</td>
<td>Belgium</td>
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<tr>
<td>Olga Kordas</td>
<td>Senior Researcher</td>
<td>KTH Royal Institute of Technology</td>
<td>Sweden</td>
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<td>Angelique Leonard</td>
<td>Professor</td>
<td>University of Liege</td>
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<tr>
<td>Amanda Graham</td>
<td>Executive Director, Environmental Solutions Initiative</td>
<td>Massachusetts Institute of Technology</td>
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<td>Karel Mulder</td>
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<td>Netherlands</td>
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<tr>
<td>Iris De Graeve</td>
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<td>Vrije Universiteit Brussel</td>
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<td>Jordi Segalas Coral</td>
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<td>Aurore Degre</td>
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<td>University of Malaya</td>
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<td>Conchita Jimenez-Gonzalez</td>
<td>Program Lead – Global Manufacturing and Supply</td>
<td>GlaxoSmithKline (GSK)</td>
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<tr>
<td>Edmond Byrne</td>
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<td>University of College Cork</td>
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<tr>
<td>Cheryl Desha</td>
<td>Associate Professor</td>
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<td>Raymond Smith</td>
<td>Chemical Engineer – National Risk Management Research Laboratory</td>
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*Colorado State University (United States of America)*

‘Is there a role for interprofessional education (IPE) in the future of engineering education for sustainable development?’
PREFACE

Creating the Holistic Engineer grounded in technical excellence, ethics, social responsibility and inclusivity was the theme of EESD 2018. The need for engineers who can see the opportunities in global challenges has not been more exigent. Problems facing the global community can and will be overcome by strategic and compassionate approaches which are the essence of a holistic engineer.

It is especially noteworthy for EESD 2018 to have been held for the first time in the United States, where sustainability education is recently facing significant and growing challenges. Together, we explored the implications in engineering education of building the holistic engineers for the future. As educators, we have a tacit contract with society to develop the next generation of engineers, and sustainability is an essential element of engineering education.

These proceedings are a compilation of the stimulating presentations and discussions at EESD 2018. In the most civil and collaborative manner, EESD 2018 participants consider key questions related to the development of holistic global engineers: How do we help transfer knowledge into action on the global challenges by appropriate stakeholders? What are the essential skills (technical and societal) of the holistic engineer? What are best practices to integrate sustainability throughout the curriculum and assist faculty in efforts to bring sustainability design and application into the classroom?

Quality of life throughout the world depends on making the sustainability knowledge base and pedagogy translational to the actions of world leaders and members of our global community. It has been my privilege to coordinate EESD 2018, a forum where essential sustainability ideals become design, development and applications for a hopeful future for humankind.
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   (Abstract only included)
16 years of EESD. A review of the evolution of the EESD conference and its future challenges.

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Abstract

Since the first Engineering Education in Sustainable Development (EESD) conference in 2002 in Delft, EESD has provided a platform for the exchange of concepts, policies, and strategies to enhance a sustainable education in engineering that train future engineering professionals with the appropriate competences to deal with sustainability challenges. During these 16 years (8 EESD conferences), engineering education has evolved and so has the EESD conference. This article aims to analyze the evolution of the EESD conferences and the future challenges of EESD through the characterization of all the papers (600) published and semi structured interviews to the coordinators of previous conferences.

Authors from The Netherlands, Catalonia and Sweden were responsible for publishing the largest number of articles (46%) and they have played key roles in the collaboration networks among the ten countries, whose authors published the majority of JCLP’s articles. At the institutional level, the Universities TUDelft and UPC-Barcelona Tech were the universities with the largest number of articles (27%) and were central to the EESD’s collaborative networking processes.

By investigating the co-occurrences of keywords, some topic clusters were identified. The categories that have most declined relevance during the EESD conferences are: Environmental Design, LCA and Management and policy; while Transdisciplinarity, Circular Economy, Ethics and philosophy have increased their relevance.

The interviews to EESD conference organizers analysis shows that most argue that transdisciplinarity is crucial to improve EESD, that real EESD is not happening at the pace it should at universities; moreover, new topics and networking activities for conference organization are highlighted.

1 Introduction

In 2002, Delft University of Technology organized the first EESD conference in Delft. It was initially organized as an isolated event, but due to its success, in 2004 Universitat Politecnica de Catalunya Barcelona Tech took over and organized the second EESD conference in Barcelona. Since then EESD conferences have been organized (Table 1). EESD has provided a platform for the exchange of concepts, policies, and strategies to enhance a sustainable education in engineering that train future engineering professionals with the appropriate competences to deal with sustainability challenges. During these 16 years (8 EESD conferences), engineering education has evolved and so has the EESD conference.
The knowledge that is gathered by the EESD through the years can be very essential for changing the education systems in the future and can help the general knowledge of society regarding sustainability. To get a clear view of the evolution that the EESD made through the years and which connections are made between different authors, organizations and countries inside it is important to analyze the steps that have been made by the organization since its start in 2002 in Delft until the last conference in Bruges in 2016. This article aims to analyze the evolution of the EESD conferences and the future challenges of EESD through the characterization of all the papers published and semi structured interviews to the coordinators of previous conferences.

2 Methodology

The methodology used is the mix concurrent nested where the qualitative research is nested in the quantitative one. The quantitative analysis consist in applying bibliometric techniques using QDAminer software analysis of discourses and networks. The qualitative analysis consist of semi-structured interviews to past EESD conference coordinators.

2.1 Quantitative analysis.

Bibliometric techniques can provide a way to analyze quantitatively the development of academic literature (Tsay, 2008). In that context, the authors developed this review paper based upon bibliometric analysis techniques. The subjects of the analyses included countries, research institutions, keywords and Networks during the EESD history.

2.1.1 Categories and content analysis.

To investigate the contributions of the EESD papers and the possible future content trends, this research team analyzed the topical clusters. The keywords and titles of articles and abstracts were used as the basis
for the analyses. The word frequency was calculated to identify the topical clusters of research in the different dimensions of EESD.

2.1.2 The social network.

The social network analysis is a method of social science, which can be used to visualize networks based upon statistical and mathematical analyses (Ye et al., 2012). Social networks consist of two parts. The first is comprised of multiple points, which represent the social actors. The second was focused upon the collaborative interconnections between and among the researchers. (Jeong-Yeon et al., 2014). In this article, this method was also employed to investigate the collaborative relationships among countries and institutes.

2.2 Qualitative analysis.

Based in the qualitative results a semi structured interview was design. Coordinators (those coordinators has been involved in the scientific committee in most of the conferences) of EESD conferences where contacted to be interviewed by skype. All interviews took place between 25 June to 5 July 2017.

Table 2: EESD chairs interviewed data

<table>
<thead>
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<th>Interviewed</th>
<th>Organization</th>
<th>Conference</th>
<th>Role</th>
<th>Response</th>
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<td>Karel Mulder</td>
<td>The Hague University of Applied Sciences</td>
<td>EESD 2002</td>
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<td>Didac Ferrer</td>
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<td>EESD 2016</td>
<td>Chair</td>
<td>Interview</td>
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</tbody>
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The semi structured interview was organized around the next questions.

- Are you satisfied with the progress the EESD made through the years?
- Do you feel that there has been an evolution in the topics that are discussed over the years? Which one?
- Do you feel that the evolution, regarding the education of the ‘future engineer’ is developing quickly enough?
- How do you think the EESD will develop in the (near) future and what will the major topics be? Why?
- How do you think that the organization can be improved?
- What kind of activities can be used to stimulate the collaboration between authors and/or organizations during the conferences?

Moreover interviewed have the possibility to build new discourse during the interview.
3 Results and Conclusion

To investigate the publication characteristics of the EESD, 600 papers presented between 2002 and 2016 have been evaluated. The information analyzed from these articles included titles, keywords (when possible) and year of EESD conference.

3.1 Evolution of the numbers of papers in EESD since 2002 and 2016

600 papers has been presented in the history of EESD conferences. There is not a trend in terms on number of papers or authors (Figure 1 and table 3).

Table 3: The characteristics of papers presented in EESD conferences between 2002 and 2016.

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<th>AU/TP</th>
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<td>746</td>
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<td>Barcelona 2004</td>
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<td>Cambridge 2013</td>
<td>89</td>
<td>235</td>
<td>2,64</td>
<td>762</td>
<td>8,56</td>
</tr>
<tr>
<td>Vancouver 2015</td>
<td>73</td>
<td>199</td>
<td>2,73</td>
<td>584</td>
<td>8,00</td>
</tr>
<tr>
<td>Bruges 2016</td>
<td>63</td>
<td>172</td>
<td>2,73</td>
<td>449</td>
<td>7,13</td>
</tr>
</tbody>
</table>

*TP: The number of total papers presented per year; AU: The number of authors; PG: The number of pages*

Figure 1: The number of papers per EESD Conference

The average of papers per conference of 75 papers and 182 authors. The number of authors per paper is also quite similar in all conferences with an average of 2.4 authors per paper but showing an increase of authors per paper in recent conferences.

3.2 The EESD paper distribution per country and academic institution

The contributions of authors from different countries/territories and academic institutions were evaluated by means of the addresses and affiliations of at least one author of each journal article. During the EESD conferences authors from 39 countries contributed to the conferences.
Figure 2: The number of paper presented in EESD Conferences by authors of the ten top countries.

Figure 3: The number of papers in each EESD conference by authors from each of the top five countries.

The analysis shows that in terms of quantity of papers there is a considerable concentration in few universities and countries (Figure 2, 3 and 4). The most active universities are TUDelft and UPC, 80 papers each, from Holland and Catalonia respectively, which actually are the two initial organizers of the conference. An expected trend shows that the participation of “local” authors increases in each conference.
The cooperative relationships among the countries contributing to the EESD conferences have been documented, as presented by the cooperation network diagram in Figure 5. The share of one country regarding published papers for the EESD is shown in the size of each circle. The thickness of each line between two countries resembles the amount of times these two countries worked together on a paper. It's been found that Balkan countries show a strong network of collaboration. Sweden, The Netherlands and Spain appear as the most collaborative countries.

3.3 Keyword network analysis: distribution and trend.

The most discussed key-topics in EESD 2002 have been taken as a reference. Over time, some key-topics disappear and new ones were added. Some key-topics appeared in the papers under slightly different names while handling more or less the same matter. An example of this is environmental design. This key-topic
appeared in the papers under numerous slightly different names being, sustainable design, ecological design and eco-design. Every time one these key-topics was discussed in a paper it was coded under the name ‘environmental design’. The same principle goes for the key-topic management and policy. This key-topic is a collective term for the search terms, sustainable management, environmental management and policy and management. Chemical engineering is a collective name for the search terms, chemical, mechanical, - and civil engineering. The key-topic integration, deals with both the integration as implementation of environmental practices in engineering studies.

The difference with between the key-topics renewing curriculum and integration is the fact that, renewing curriculum captures the papers that are about changing the curriculum of engineering curriculum that already deal with environmental and sustainable subjects.

Figure 8: Network of countries that collaborated in one or more EESD-conference(s)

There are also clusters of key-topics based on terms that relate to each other. An example of this is, transition and backcasting. Both these key-topics discuss how to create a future image and how to influence it. Management and policy both discuss, making a change in a judicial sense. The terms, social dimension and ethics are merged in one key-topic because they both deal with changing the mind-set of nowadays society and making changes in the way of thinking of people to create a more holistic perception of their view of the world and to make them understand why this is necessary. E-learning captures all the papers that involve learning and education programs set up on the World Wide Web. The final set of key-topics that have been distinguished are: Competences; curriculum changing; triple P; integration; social dimension and ethics; multi-, inter- and transdisciplinary; paradigm; pedagogical; e-learning; gamification; circular economy; development/cooperation; transition and back-casting; social dimension; ethics and philosophy. Figure 8 shows the results in the first, intermediate and last EESD conference. The three most discussed key-topics in the last conference are multi-, inter- and transdisciplinary, integration and renewing curriculum are
omnipresent from the first EESD-conference in Delft until the last one in Bruges. However multi-, inter- and transdisciplinary was at the first conferences merely a topic that was discussed in other papers, it grew out to be a central theme in lots of papers in later editions. Key-topics in which the interest grew later on is learning through games. Although triple p was already discussed in Delft the interest in the topic really took a lift since Gothenburg and the later conferences, before falling into oblivion again during the conference in Bruges.

3.4 Interviews to EESD conferences’ organizers.

Six out of eight organizers of EESD conferences has been interviewed (Table 2). Results of the interviews match the results of the key-topic analysis and most interviewed highlight transdisciplinarity as crucial to improve EESD, that real EESD is not happening at the pace it should at universities; The interview also show that the EESD made some progress regarding the education of the ‘future engineer’, but it is not enough. It is hard to convince universities and their teachers to change their way of education Interviewed claim that the social dimension of the sustainable education should play a bigger part during the conferences. The EESD should also take a more advising role towards universities. Another important topic that should be discussed in the future is how to organize a conference with new topics and networking activities like workshops and unconference methods.

4 Future view

The future view is based on both the quantitative and qualitative analysis. It seems that the European growth regarding participants of the EESD is stagnating; the core group is not growing nor changing in its composition. Therefore it is very likely a good step to expand the reach of the EESD and have more conferences outside of Europe. The first conference that took place in another continent was the conference in Vancouver in 2015. That conference formed the introduction for a lot of new members and it would a positive step if the same could happen in the U.S.A. When the conferences are every three years in Europe and alternately in the U.S.A., this would release the pressure on the core-group of the EESD who now have to (partly) organize a new conference approximately every two years. A negative side effect that European members only visit the conferences in Europe and the American members only the one on their continent.

Another future step of the EESD is to invite more students to the conferences. This could be stimulated by financing students for actively participating at the future conferences. Another option is to let students (partly) organize the conference itself. Students will bring innovating ideas, and get a better insight on the EESD itself. This will give the organization new impulses and a better dynamic between the different generations that are trying to achieve the same goals. It will also help to stimulate collaborations between organizations, universities and third parties.

References

Widening Engineering Education, scientification of engineering and increased specialisation.

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Introduction

Since the publication of the Our Common Future, 31 years ago, sustainability problems have not vanished, on the contrary. The ‘ozone hole’ has more or less been healed, but regarding climate change, resource depletion, and declining bioproductivity and biodiversity no signs of a transition to a new equilibrium can be observed. However, there is increasing political support for taking action to solve these problems.

In the past three decades, it has been repeatedly claimed that engineering plays a key role in solving these problems. EESD has been based on this conviction, and emphasized the importance of strategic competencies in defining action for SD. However, in the midst of a growing societal recognition of these problems, progress of EESD in engineering seems to be stalking.

Ever since its inception as an institutionalised profession, engineering branched out in an ever increasing number of specialisations: Mechanical-, Geological-, Agricultural-, Industrial-, Chemical-, Electrical-, Physical-, Architectural-, Maritime- and Aerospace- and Design-engineering followed. Moreover, by the general scientification of education, the educational programmes of engineering became narrower, more theory-, and less practice oriented.

The Bologna process created a strong divide between BSc and MSc programmes. This created options for another wave of new specialisations, this time at the MSc level. Only few MSc programmes were created that broadened the scope of engineering by adding new perspectives to engineering (e.g. Industrial Ecology, Sustainable Energy, or Innovation Studies) This new engineering programs, bridging various fields, were embraced by SD seeking students and managers, that aimed at combining model based analysis with practice oriented action.

The general branching out of engineering into more specialised engineering degrees was accompanied by the large scale introduction of ‘minor programmes’ and ‘exchange semesters’ in the bachelor phase that created options for specialisation in the BSc programmes, often as a pre-selection for the MSc phase.

This development of at one hand increasing specialisation and at the other hand new programmes that aim at bridging various fields of engineering might be worrying for traditional engineering:
- A narrow specialisation can only be legitimised by emphasising the unique knowledge value of the program, i.e. negating the value of general knowledge
- The existence of MSc programs that bridge knowledge fields, can act as an ‘alibi’: students might opt for that program, so the subjects do not need to be included generally
- The existence of new MSc programs that bridge knowledge fields might draw staff attention to that program, instead of drawing attention to implement general change in engineering

This might be an explanation for the stalking progress in Engineering Education for Sustainable Development.

The paper will illustrate these points by analysing trends in recent engineering education. The paper is intended as a start for a discussion how we could boost progress in EESD.

**Engineering Education until the 1980s**

Traditionally the key to becoming a respected engineer was to gain experience. Until the 19th century, engineers learned the craft by apprenticeships. Although a university mathematics course could be helpful, the craft of engineering was learned in practice [1]. The foundation of engineering schools in the 19th century implied a revolution for engineering. Engineering education became based on rationality and science, instead of being based on tradition and experience. Many of the new 19th century engineering societies demanded that their members should be trained ‘scientifically’, to underline the break with the past [2].

However, there were many problems that could not be calculated: engineering designs were in practice often not based on exact calculations, but calculations with additional safety factors that emerged from practice. In this way fatigue and wear factors had to be dealt with, etc. But quantification became an important feature of the engineering paradigm. Especially designers that were dealing with features that were hardly quantifiable (beauty, user friendly, etc.) often met disdain from their colleagues. For example ‘Psychology’ was considered unscientific, and should be kept out of engineering education [3]. However, the soft features made their way into engineering, mainly as this was a key factor in turning engineering design into reality. It is fascinating to see how many bright engineering ideas failed in the Soviet Union, due to the inability to adapt engineering designs to 'soft' demands [4].

**Engineering by the end of the 20th Century**

Massive and cheap computing removed several of the barriers for improved engineering design: design features could be computed, and maintenance and user experiences could be registered in data bases and evaluated. ‘Modelling’ replaced the craft of experimenting and full ‘mock-ups’ were hardly needed for design evaluation. Tradition and experiences of the past were hardly needed anymore for good engineering design, and so ‘apprentice’ elements in the engineering curriculum were diminished.

However, the controversy regarding nuclear power, that emerged in most industrialised countries, showed that engineering design based on this ‘scientific rationality’ was not unproblematic; in fact scientific
rationality’ often coincided with predominant values in society [Cf. e.g. 5]. New values could come into play in engineering designs and old ones could be contested. Engineering became far more part of societal force fields, and various controversies emerged on engineering designs (airports, motorways, acceptability of food additives, agricultural chemicals, fluoridation of drinking water, etc. etc.) [6-10]

The increased flexibility that computers and science created for engineering design, as it was no longer bound to forces of tradition implied that engineering designs became the centrepiece of societal controversy. Instead of being perceived as the great force of progress, engineers were often portrayed as irresponsible nerds.

**Our Common Future and its reactions**

After the Brundtland committee presented ‘Our Common Future’, the engineering community reactions were not very positive: ‘another report bashing technical-industrial progress…’. However, also soon other reactions showed up. Contrary to the wave op environmentalism of the 1970s, the analysis underlying ‘Brundtland’ was not one of ‘environmental protection’ but one of being able to provide for mankind in the long term future¹. Such a long term planning perspective fitted to the mathematical model based planning perspective of engineering.

Backcasting was embraced as a strategic decision making method to take the (future) limits of planet earth as a starting point for planning[11, 12]. The method created an interesting controversy between what could be determined as

- a planning approach, taking Sustainability principles as leading principles in order to derive a sequence of planning actions [13],

- and a decision-making approach aiming at bridging the divides between engineers and societal stakeholders, aiming at sketching long term options in order to trigger productive interaction [14, 15].

The first approach to backcasting could be determined as ‘engineering planning with Sustainable Development as a core value set’ while the second approach could be determined as ‘Strategic and interactive decision making on technology for SD’

The first approach is therefore a traditional expert based approach that is in line with the role that engineers have long played in society. It takes SD a given external goal. In the second approach, engineers take a new role, aimed at informing stakeholders on technological options and, creating interaction in order to reach consensus regarding socio technical development pathways. This involves a new role for engineers; a role that does not only involve expertise but also democratic leadership.

In other words, the difference is between ‘Engineering the future from Sustainable Development values’ versus ‘Jointly engineering the future, based on Sustainable Development and other values’. It is a

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¹ Of course one might argue that ultimately, providing for mankind is only possible if the environment is well protected, and the environment can only be well protected, if the number of people is limited and people are provided for.
difference between focussing on outcome and focussing on process; a difference between a traditional expert promoting inescapable solutions and the new expert, providing expertise as input for dialogue…. 

In highly educated societies, dialogue and interaction are important values. However, a scientific discipline has its own social mechanisms that keep the discipline together, the paradigm [16]. This also applies to engineering. Upon entering engineering schools, engineering students are increasingly inclined to give up their societal orientation, and define themselves, and their engineering designs, as neutral tools. Engineering education is in fact not just learning theories, facts, and design but also the initiation in a disciplinary paradigm [17, 18].

**Changes in engineering education**

Academic education has experienced various debates in recent decades. At the one hand, access to higher education has been curbed by deteriorating support schemes. At the other hand academic education has been promoted as a key factor in international competition. As a result, academic educating became more geared to demands of the labour market.

The diminishing freedom for students was compensated by the introduction of ‘minor’ programs. The intention was that students could develop an additional qualification. In practice however, such minor options were often used for being admitted to specialisations that were in high demand, i.e. as increased specialisation options.

The result of these developments was that engineering students were, during their studies, increasingly focussing on their professional qualification. Education became less a matter of personal development and far more an issue of obtaining a ticket for a career as an (engineering) specialist.

**Stalking Progress to EESD?**

In many engineering schools modernising engineering seems to be stalking. For Sustainable Development no hard numbers are available. However, the landscape does not appear to be very flourishing. Initiatives do not grow and every now and then there is a setback. Moreover, related initiatives to strengthen linkages between engineering and societal developments are not thriving: For example, despite many efforts, the number of female engineering students hardly increases in the last decade [19-21]. New interdisciplinary MSc programs like Sustainable Development, Industrial Ecology, Sustainable Energy Technology, Sustainable Engineering, Environmental Engineering, etc., have established themselves in the academic landscape.

However, the establishment of such programs might turn out to be negative for SD in the established engineering programs. In principle, competition for students might lead to increasing the SD content of established engineering programs. However, the opposite might also occur, as SD minded students might be referred to electives from the other MSc program, instead of implementing SD in the own program.
Given the strong tendency to focus programs on technological content[17], such a reaction might even be far more obvious.

Moreover, an expansion of the efforts thus far is required. Academic engineering education has taken the lead in education for SD, but given the transition to renewable energy, and circular economy initiatives, vocational education should now rapidly sustainabilise. Installers play a crucial role in a transition[22]. Installers of heating and cooling equipment for example hardly know of fossil free heating and cooling alternatives.

**The Future of Engineering**

Nowadays designing engineers should design ‘value sensitive’, i.e. designers should perceive their designs not as neutral solutions for a given problem, but as an intervention in society, that can be assessed according to various different value systems[23, 24]. These consequences affect human values. But what are these values, and who weighs them? The engineer him/herself? Of course it would be an advantage if engineers would make such value analyses to evaluate their designs. But would it make much difference? Even if it could be shown convincingly that assessing values involved in the design, would lead to improvements, it is doubtful if the engineers would be able to convince the stakeholders involved:

The key is not to involve all relevant values in an engineering design and present that to stakeholders, as it cannot be established beyond any doubt how these values have played a role, the key is trust: to show transparently how different values affect the outcome of the design process, i.e. interaction with stakeholders. Engineers should have the ability to work with stakeholders, who put forward their own values.

The designing engineer is also a gatekeeper that has to take the responsibility if the design ‘works’. In that respect, the engineer bears a specific responsibility, a responsibility that should be based on design expertise, and not on ‘alternative facts’.

In debates on Science & Society, scientists have been assigned the role of being honest brokers. In parallel, engineers should be able to play a similar role in regard to the public: being able to show the alternatives that are available and their impacts[25].

Expert communities have been ‘deconstructed’ as being not just sharing expertise, but also sharing specific values and as being susceptible for specific interests. This has sometimes contributed to a conviction that the expertise reasoning is equally valid as all other types of reasoning as it is just ‘a representation of interests’. If such distrusts to experts would be widespread among the citizens, it could lead to terrible accidents.

**Conclusion**

Engineering for Sustainable Development dies not just require an engineer to have knowledge of sustainability issues, it does not just require new values, it requires foremost a new identity as an
engineer: an identity as an expert, who is an honest broker in technological design, and serves the pathway that our communities decide to take towards Sustainable Development.

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4.1.1 Abstract

Educating new generations of engineers requires a curriculum that will equip our students with necessary skills and competencies that will enable them to be more effective in the global context of the engineering practice. Thus, we need to include in the engineering education programs the current global considerations to conserve natural energy resources, convert to more sustainable methods of power generation, and smart and eco-inspired manufacturing. Drexel University’s Engineering Technology program curriculum evolved during the recent years towards integrating topics based on new and emerging technologies, combined with learning-by-discovery and project-based learning. As a consequence of enhancing our curriculum, more than 80% of our capstone projects topics chosen were related to sustainable solutions in energy, health care or manufacturing. The projects are also interdisciplinary and even used as learning modules enhancing current experiential activities. The two-prong approach of ET program, and the course enhancements based on new topics combined with incorporating term projects related to these topics and culminating with student-led capstone projects shaped a new curricula, better tuned to global industrial demands and to sustainable development (SD).

5 1 Introduction

The modern engineering is more global in character and practice and also increasingly concerned about sustainable use of resources and to convert to more sustainable industrial processes across all industries, from energy generation to smart manufacturing.

5.1 1.1 Energy Considerations

Renewable energy industry is growing at fast pace as a result of green and clean energy efforts to avert the effects of climate change and fossil fuel depletion. Sustainability is closely related to energy resources conservation and the increased use of renewable energy. Many national governments around the world implemented programs to support the use of sustainable energy systems. According to 2018 Annual Energy Outlook, the energy consumption for 2017 is 96.8 quads BTU with a projected increase to 109 quads BTU until 2050, while the total production of energy in 2017 was of 88.37quads BTU, increasing to 115.4 quads BTU by 2050. Projections consider a dramatic increase in the generation and use of biomass, nuclear and hydroelectric energy, and other renewable energy sources (almost two-fold increase in the next three decades). Accordingly, the demand for clean energy solutions and for new technologies for reducing the use of fossil fuel for energy generation is also increasing, with energy efficiency being a top priority (Clean Energy Solutions, 2011). As a result of the need of professionals in emerging technologies related to energy conversion, energy security and clean energy industries (Kandpal et al., 2014), (Hinrichs-Rahlwes, 2012),
there is a growing demand for training at all levels in energy education, from enhancing basic knowledge and competency based education to new and innovative curricula regarding sustainable design of renewable energy systems (Shi et al., 2011).

5.2 1.2 Smart Manufacturing Considerations

As presented in the Manufacturing Annual Report for FY 2016, “American manufacturers contributed $2.18 trillion to the U.S. economy in 2016”. However, the deficit in advanced manufacturing is about $90 billion. This calls for an increased pace of job creation on American soil, in manufacturing industry allowing us to continue to research and invent. Educational institutions have a mission to develop game-changing technology and the skills needed to equip our future U.S. manufacturing workforce (Manufacturing USA Annual Report FY2016, 2017).

Manufacturing plays a critical role in the American economy, underpins U.S. innovation, and is essential to national security. Smart manufacturing, the use of real-time data and technology that are needed to meet the changing demands in manufacturing industries, is predicted to be the next industrial revolution. (Lu et al., 2016) With emerging trends opening up new areas of innovation to optimize the manufacturing fields, there is an ever increased need of future skilled workforce that adheres to emerging manufacturing technologies. These skills need to be developed and applied in engineering and engineering technology education (Smart Manufacturing, Davis et al., 2012), as it is predicted that it will be a skilled workforce deficit of about 2 million jobs during the next decade.

5.3 1.3 Educational and Curricular Context

Sustainable energy generation and use and green and sustainable manufacturing are hallmarks of today’s industrial world. In US and around the world, the advanced manufacturing and energy manufacturing industry are experiencing a growing talent gap. Many factors are in play for this shortage, some of them being the retirement of existing skilled workforce, the technical complexity of the work in these areas, a science, technology, engineering, and math (STEM) skills deficit among students, and persistent negative perceptions make it difficult for companies to fill critical roles in a timely manner. Hence, the need of a well-rounded and skilled workforce able to serve a global sustainable industry leads inevitably to new trends and strategic areas in engineering education fields. As presented in (Vargas et al, 2015), sustainability concepts and issues have been introduced in engineering curricula in universities and educational institutions around the world over the last decade, students being challenged to include these concepts in their projects and research as well as being a required part of their curriculum, including capstone design projects (The Barcelona Declaration, 2004).

Drexel University’s Engineering Technology program offers a combined electrical and mechanical engineering technology major, filling in the gap between the industry demand and the current educational offerings in the area and nationwide. Our curricula have been enhanced in two directions: manufacturing and renewable energy and clean/green energy conversion. It may seem that the two concentrations are independent of each other; however, as part of a DOED awarded funding in Green Energy Manufacturing, the two directions converged, leading to a more unified approach of the curricular changes, generating an engineering curriculum rooted in sustainable development (Chandu et al, 2012). The paper is a review and an assessment of the developments of Engineering Technology (ET) program curriculum during
recent years towards incorporating emerging topics such as green and sustainable manufacturing, energy conversion, harvesting and generation.

6 Course Design and Developments

During the past five years, new topics were introduced in our ET courses related to manufacturing processes and mechanical design to equip students with advanced tools that will guide design decisions that minimize or eliminate adverse ecological impact. Embodied energy and carbon footprint, recycle fraction and toxicity have obvious concerns that require careful considerations for Product Lifecycle Assessment combined with mechanical, thermal, and electrical properties that have the greatest role in design to minimize eco-impact (Malkki et al., 2017). This approach combines competencies necessary to succeed in today’s engineering and engineering technology world: application of fundamental engineering concepts with a sustainable focus, team skills and multi-attribute decision making skills. In the area of traditional lecture-based thermal-fluid courses we introduced lecture-integrated experiential activities combined with project-based learning oriented towards sustainable energy applications in manufacturing environment. As a consequence, students were required to explore all facets of sustainable systems, including environmental and societal impact of an engineering system or technology, looking mainly at the “big picture”, rather than subsystems and components.

6.1 Renewable Energy Curriculum

Our ET curricular improvements were made to meet the needs and objectives of engineering education in renewable energy and sustainability (Belu et al., 2012), (Husanu et al., 2017), (Kandpal et al., 2014). Starting with AY 2008-2009 we introduced our very first Renewable Energy course, with a focus on energy conversion, clean energies such as wind and solar, providing students an overall view of the renewable energy. The course evolved towards a more complex integration of renewable energy sources. The main topics studied include the study of solar and wind energy and power systems, and energy storage, culminating with the study of relationship between energy, sustainability and the industry, and system integration, thermal imaging, industrial energy efficiency, and energy audit. The learning experience is enhanced by project-based learning using “GaBi LCA Simulation” regarding Green Energy Manufacturing, and laboratory activities for each topic in the lecture, enhancing teamwork and the ability of developing larger scope projects, stimulating critical analysis of industrial systems energy audit and energy efficiency. This will enrich students’ knowledge in the area of Industrial Sustainability.

We developed short courses on fuel cells and solar and photovoltaic cells as pilot courses at ET and full course implementation at University of Texas at El Paso (UTEP) as a part of a DOED funded project. This led to a new course in Applications of Fuel Cells and Photovoltaic Technology, which introduces the students to industrial applications of fuel cell and photovoltaic technologies, providing students with a working knowledge of the science, technology, applications, and economics of PEM fuel cells and fuel cell stack, and photovoltaic energy sources.

Another new course is providing students with an understanding of the fundamentals of industrial energy systems, components and their characteristics, operation and analysis; to help them develop an understanding of the technical and some economic aspects of a wide range of current and future technologies for energy generation, inter-conversion, storage, and end usage, including electrical, thermal
and mechanical energy systems. Energy Conversion and Power Electronics courses have increased the renewable energy content, being enhanced with hands-on design and experimental work and project-based learning (Belu et al., 2012), where students explore aspects of SD such as green and clean energy conversion, generation, storage and recycling.

With these new curricular enhancements, students will develop the ability to critically evaluate integrated energy systems in industrial context, developing competencies in critical evaluation of energy content of product and technology development, and sustainable energy generation and management. Students will be working with current and new energy technologies in current global sustainable energy approach. A new **Minor in Green Energy and Sustainability** has been developed and implemented as of fall 2017, these above mentioned courses being the backbone of this minor.

### 6.2 2.2 Enhancements of Traditional Engineering Courses - Thermal-Fluid Courses

The energy management of industrial heating and cooling systems is very complex, many of them being currently operated using fossil fuels but on their way to transition towards new clean energy sources. Most of the modern industry will soon move towards utilization of novel thermal management systems either in heating and cooling industry or in manufacturing, with an emphasis on additive manufacturing, all of them oriented towards reducing the carbon footprint. Therefore, the traditional courses seen as mostly lecture-based in the area of thermal-fluid science must adapt to enable students acquiring the skills needed for these engineering career paths. We enhanced the traditional courses with a wealth of investigative activities, including using thermal imaging for comparative thermal analysis, internet-based remotely operated laboratory activities that simulated modern industry-like heating and cooling systems, and system and process simulations and virtual system analysis (Husanu et al., 2017). During the past five years, the student-led term projects chosen for these courses were by far in the area of renewable energy and energy management. Topics approached were ranging from theoretical and experimental study of chimney effect, and phase change materials in industrial heating and cooling to microfluidic heat exchanger and to development of sustainable and green cooling systems of CNC tools in motion, just to name some of them. Our integrated approach, that combines experiments with theoretical preparation and project based learning allow students familiarize themselves with the various energy conversion systems from a variety of industrial applications. As can be seen from this description, sustainable design is an integrated part of these courses as reflected in the student-led projects.

### 6.3 2.3 Sustainability in Manufacturing Courses

Manufacturing industries are adapting to sustainable processes and products while enhancing the use of green energy alternatives. The educational counterpart should keep the pace with the demand of trained professionals in these areas. In its efforts to meet the industry demands, our curricula encompassed courses that exposed students to the latest emerging technologies such as Microfluidics and Microfabrication, and Nanotechnologies Conversion. Drexel University’s ET undergraduate program incorporated several courses related to sustainable manufacturing and green manufacturing.

In addition to familiarity with a number of manufacturing processes and CAD/CAM techniques, various process simulation tools are increasingly becoming an essential tool in the design and manufacturing of complex systems. Students can quickly evaluate manufacturability during design process, to eliminate costly mold rework, improve part quality, and accelerate time to market. The course Manufacturing
Processes has been redeveloped since 2010 and offered in every winter term by the authors at Drexel University. This course provides a requisite understanding of manufacturing processes as it relates to the quality of parts produced for students to progress to the advanced level in the course and the ET curriculum. The course also serves as a means for students to gain exposure to advanced manufacturing concepts before students take senior design project.

As we teach engineering materials and manufacturing process courses prior to capstone senior design projects, it is imperative to introduce ET students with advanced tools to impart skills that will guide design decisions that minimize or eliminate adverse ecological adverse effects. We developed course materials and modules using modern software such as CES EduPack™ software, Autodesk's Moldflow and CAD systems that help bridge the gap between the Industrial and Mechanical Engineering Technology curriculum, introducing collaborative decision-making and sustainability, life-cycle assessment and product-embedded energy; all necessities in today’s engineering education. The main focus of the course improvements was to embed and integrate sustainability concept, in the beginning using representative courses such as Mechanical Design and Manufacturing Processes. We are infusing sustainability and eco design teaching materials and projects into Mechanical Engineering Technology courses.

Our interdisciplinary minor in Engineering Product Development consists of a series of courses from ET major and Product Design major in Drexel's Westphal College of Media Arts & Design. These courses would provide students with a greater understanding of sustainable engineering product development. The newly developed and adopted courses cover emerging product development fields and applications such as CAD, 3D printing, Embedded Systems Design (microcontroller programming and interfacing) and Toy Design.

7 3 Capstone Design

As our courses geared towards incorporating new technological trends in green energy and sustainability, the capstone senior design project topics in this area increased as well. The main aspects presented are related to the integrative approach in green energy harvesting, manufacturing and sustainability, serving as models of energy efficiency and sustainable energy power transmission, with a clear assessment of student-led projects developed during past AYs and how they contributed directly to development of leadership skills along with untamed creativity. A brief technical description of the projects along with clear connections between projects and curriculum development are described, underlining the interdisciplinary nature that simulates real-world situations and integrate sustainability with creativity and innovation (Taleghani et al., 2010).

Capstone projects developed in the past five years by our students are the corollary of their educational journey and also an excellent assessment of their level of skills and competencies acquired during this journey. As it can be seen from the figure below, manufacturing and energy and sustainability capture more than 65% of the capstone topics chosen by our students.

Students are approaching a project that has the potential of serving several communities, in an affordable and
sustainable way has technical merit and presents innovative nature of the system. As the long term approach: students studied the viability of the system on a long term basis. This practical, real-world approach is essential for educating and training future “iEngineers” or “Global Engineers”. Their generation as well as future generations are more and more connected to real world needs and issues.

Our ET senior design project is a 3-courses sequence quarter based and has the following Student Learning Outcomes: students gain experience and expertise in solving real-world problems, significantly improving their skills in system analysis and design, technical writing, public speaking, teamwork, project and time management.

Several courses above mentioned in conjunction with core curriculum courses serve as project-based learning courses that feed directly into our senior design projects, by requiring students to design a system, a component or a subsystem of an engineering system in the area of emerging technologies. Following the first introduction of renewable energy courses and topics, several capstone design projects addressed either wind or solar energy generation combined with smart grid integration such as “Indoor Solar Harvesting for Sensor Nodes”, “Design of Maximum Point Power Tracker for PV Systems”, “A Digitally Controlled and Portable Photovoltaic Power Source”, and “Design and Implementation of a Micro-Wind Turbine”. The teams are multidisciplinary and they are tasked to design, assembly and test the prototype in order to validate their simulated results. The students have the opportunity to apply the classroom lessons on renewable energy systems combined with manufacturing techniques, and knowledge of sensors and instrumentation and computer programming for data acquisition and data reduction and analysis. As our curricula evolved, and many more learning modules related to energy and sustainable manufacturing have been added to our existing courses, more complex projects have been developed by our students: “Integrated Wind and Solar Powered Outdoor Area Lighting Kit”, “Smart DC Power Grid”, “Automated Probing and Testing of Solar Cells”, “Portable Power Source using Micro Direct Methanol Fuel Cell”, “Automated Green Energy Solar Heating”, “PHiLTER - A Pico Hydroelectric Generator and Water Filtration System”, “Combined Algae Bioreactor/Solar Cell Array for Biofuels and Photovoltaic Electricity”, “Camouflaged/Aesthetic Hybridized Energy Harvesting Installation: Project Green Tree”, “Dragon 3D Adding and Subtracting Machine”, “Injection Molding Learning Module”, “Dr. Filex:Desktop-3D Filament Manufacturing Device” (see figures 2 and 3 below for some examples).

Figure 3: Senior design projects from left to right: Microfluidic Fuel Cell; PHiLTER, Green Tree
Figure 4 Left: Thermal Imaging of Microfluidic System as model for Microfabrication and investigation of energy efficiency; Right: Senior design Project Combined Algae Bioreactor for Biofuels

During the development of the senior design projects students are addressing several important issues, such as Life Cycle Assessment of each component as well as the system, environmental and societal impact, regarding their product/process from a global perspective. The quality and complexity of the projects increased significantly as we included more emerging technologies in our ET curricula, with students being more confident in proposing and solving engineering problems that are in tune with today’s needs and challenges in terms of engineered systems. Students incorporate knowledge from manufacturing, energy, thermal-fluids, electrical and mechanical engineering into their capstone project, being environmentally and societal conscious while developing an integrated system.

8 Assessment and Conclusions

During the assessment of each course, we evaluated the strengths and weaknesses as well as the level of achievement of each learning outcome, using relevant performance indicators. Courses are subjected to Course Improvement analysis (CQI annual cycle). Renewable energy and thermal-fluid sciences related courses strengths were in the area of systems integration and project development of green energy related topics, while manufacturing courses showed strengths in incorporating environmentally conscious manufacturing technologies in the curriculum. Students scored higher on critical thinking abilities, in identifying and applying realistic solutions that meets requirements in terms of technical, environmental, economic and societal criteria. Another criterion that students’ scores were up-trending during the past decade was related to identifying potential and adverse impacts of engineered systems on society or the environment. This trend was accelerated as students were offered more courses related sustainable development: scores for these performance criteria varied in average 3.1 to 3.4 out of 5 on a LIKERT scale during AYs 2008-2012, with a higher marks (4.4 to 4.9 in average) as we started incorporating more interdisciplinary learning modules related to clean energy, energy management, life-cycle analysis and product-stored energy. As weaknesses, we identified students’ ability to apply knowledge of mathematics and science to engineering problems, as well as to successfully integrate the theoretical approach with practical application. While enhancing their theoretical understanding was the primary remedial action, we also enhanced the project-based-learning, focusing on practical application of theoretical knowledge.

The capstone projects are a hallmark for demonstrated understanding of sustainable development as was incorporated in various curricular courses and later applied as they developed their system. All our capstone projects are assessed at the end of each of the 3 quarters using performance indicators stemmed and mapped to the a-k ABET-ETAC criteria, on a LIKERT scale from 1 to 5. The performance indicators assess student knowledge regarding application of science and engineering principles to engineering systems, as well as their abilities to produce practical, realistic and optimal engineering solutions, meeting technical and economic requirements as well as solutions that meet societal and environmental criteria. Students ‘strengths were highlighted by their scores in each performance criteria related to applying engineering knowledge in developing engineering systems. Also, an upward score trend was noticed for criteria related to identifying novel solutions that impact society and environment with scores’ range of 3.9 to 5.0. As our course offerings in areas such as renewable energy, sustainability and advanced manufacturing increased,
our students were more and more involved in developing capstone design projects stemmed from real engineering challenges, integrating energy with manufacturing. We crafted an entire curricula that incorporates all the required “ingredients” to educate a “global and holistic engineer”. Students demonstrated competencies in areas such as design and analysis of sustainable energy systems, technology assessment, technology economics, and applied quality control and assurance. As it can be inferred, there is a direct correlation between skills and competencies developed in the area described and the type and complexity of capstone projects developed by the students.

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9 References


Can education lead to behavioural change? Effects of sustainable consumption projects in an engineering programme

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Abstract

It is claimed that for behaviour to change, it is not enough for someone to realize what needs to change; the person also needs both motivation and support in changing habits. In the first year of a chemical engineering programme in Sweden, students have, since 2015, engaged in individual projects in which they make a sustainability motivated change in their every-day lives for one full week. They are asked to document their activities and compare to a reference week, reflect on their experiences and calculate some sustainability consequences, e.g. the climate impact. They hand in an individual report and they also discuss their findings in a seminar with other students. In this way, they identify potential sustainability solutions on a consumer level, carry them out, experience them, and calculate impacts of them, and they compare and contrast their experiences and findings to those of other students in order to understand, e.g., what types of changes, in general, provide considerable improvements and which do not, and what is easy to change and what is difficult. In 2018, a survey was made among all students that had participated in the three years that the course had been run in order to find out to what extent any of the changes they had tried out or heard about in the course had resulted in any behavioural change and if so, why.

This study evaluated by means of a survey whether participation in the student project resulted in behavioural change and if so, for what reason. Many students adopted changes they tried out in the course and the strongest correlation was seen with a perception of the project as meaningful in relation to the student’s role as a consumer and citizen. Implications for course development are discussed in the paper.

1 Introduction

1.1 Behavioural change and education

First, it is perhaps important to mention the elephant in the room - should behavioural change be a goal of education? To discuss this, it first needs to be established what behaviour that is considered. It is uncontroversial that we want students of engineering to adopt appropriate behaviour with regard to the profession and the different situations that may appear, for example to behave in a safe way in the laboratory and to behave towards collaborators and other people in an ethical manner. However, when it comes to the personal sphere, it might be considered controversial to aim for behavioural change, at least in higher education. Arguments against such approaches would be that they are normative and instrumental and that they therefore clash with ideals of ‘Bildung’ in university studies. However, it can also be argued, in particular from a normative sustainability perspective, that the need for change is urgent and that we need to address this by any means available. It may also be important how the education is carried out, e.g. if it
is done in a highly instrumental way or by more emancipatory approaches.

This study builds on a previous course development effort that focused on change agency and it was suggested that one aspect of change agency is whether students are able to implement lasting change in their every-day life (Svanström 2015). The student project itself as an educational element does not have as a primary goal to result in behavioural change but rather the learning around important factors behind behavioural change, and on which change that is needed in a sustainability context and how the sustainability consequences of changes can be assessed. However, it is of interest both for coming students in the course and for teachers in general or anyone intending to use education to change behaviour to study if the intervention in fact also leads to behavioural change and if so, why.

The behaviour that we are talking about in this context may be referred to as private-sphere environmentalism as different form activist or non-activist public behavior or behavior in organizations (Stern 2000). Many educational interventions aim at changes in such behavior, perhaps most evidently educational effort directed towards certain risk groups or groups that have been diagnosed with different diseases and that need to change their behavior. However, in engineering education interventions that explicitly aim for this are rare.

Stern (2000) summarises different theories on determinants of environmentalism, defined as ‘the propensity to take action with proenvironmental intent’. Some theories look upon behaviour as strongly connected to worldviews, such as in the New Ecological Paradigm (NEP) within social psychology, while others focus on values, e.g., postmaterialist or religious values (see Stern, 2000). Stern and colleagues developed a value-belief-norm (VBN) theory of environmentalism that builds on earlier theories and can help explain a variety of behavioural indicators of non-activist environmentalism, such as private-sphere environmentalism (Stern et al. 1999). The VBN theory links value theory, norm-activation theory, and the NEP perspective through a causal chain leading to behaviour, from personal values (especially altruistic values), via beliefs covered by NEP as well as related to adverse consequences for valued objects and perceived ability to reduce threat and to pro-environmental personal norms manifested in a sense of obligation to take pro-environmental action. Kaiser et al. (2005) used the VBN theory and the competing theory of planned behaviour (PB) in explaining conservation behaviour among university students and found that both had a remarkably high explanatory power. In PB theory (Ajzen 1991), intention to perform the behaviour as a function of perceived control, attitude towards performing the action (seen as a rational-choice-based evaluation of consequences and likelihood of these outcomes) and subjective norms (strength of normative beliefs - perceived expectations of relevant others – combined with motivation to comply). In the present study, important factors were selected from both these theories.

1.2 The student project context

The student project that is in focus in this study is part of an introductory course on chemical engineering towards the end of the first year of a five-year chemical engineering programme. The main purpose of the course is to introduce chemical engineering and to do that in a sustainability context. Systems aspects and concepts such as life cycle perspective, biorefineries and industrial symbiosis are in focus and tools such as mass balances and sustainability assessment are practiced. The course is part of a compulsory series of educational elements in the programme on ‘environment and sustainability’\(^1\). The course has earlier been described in more detail in this conference context (Svanström 2015). Apart from some lectures, exercises, assignments and a written exam, the course contains two larger projects, one focusing on students’ future
role as engineers and one on their role as consumers or citizens. This is not only to highlight those different roles but also to provide a deeper understanding of how to assess and address sustainability aspects in both the production and use stages of the life cycle of products (often called production respectively consumption perspectives in e.g. accounting of emissions).

This study explores the project that is related to the use stage. The course learning outcome that connects the strongest to the study described here is that the students should be able to demonstrate an ability to describe the challenges involved in changing their own or other people's behaviour. The task that the students work with in the project is to select a sustainability motivated change that they can do in their life during one week, plan for the change and for assessing the consequences, do the change, monitor and calculate consequences compared to a normal week and reflect on challenges in both performing the change and in assessing the consequences. In the start of the course, they hand in an idea for the change they are considering, which needs to be approved, and after a lecture/exercise that prepares them for the work, they hand in a rough plan on how they will go about, that also needs approval. They then carry out the work and write the report. The report must contain a description of the change including a motivation to the selected change and to how it is assessed, as well as the calculated consequences and a reflection on the outcomes. Calculations and the log they fill in during the work should be attached. After handing in the report, all students meet for a seminar in which their findings are compared and discussed. Assessment of learning is made primarily through the written report but handing in the idea and the plan and participating in the seminar are also compulsory activities.

The present study aimed at exploring if the student project also leads to lasting change in the daily life of students, both in terms of the own project and of what they heard about from other students, and if so, why.

2 Method and data

The student project has been performed by three student groups over three consecutive years (2015-2017). The number of students that have finalised the project are: 45 (2015), 49 (2016) and 48 (2017), respectively. About half of the students have selected changes related to their diet (e.g. from meat-containing to meat-free or from vegetarian to vegan), and other common themes are related to transports (e.g. from car to bus or from bus to bike), showering (reducing the time and/or reducing the temperature) and waste (e.g. from no source separation to full source separation). Most students have calculated consequences for the climate (from 2017, this is a requirement to allow for comparisons) and have reflected on whether time requirements for the activity or their own costs have changed. Many other aspects have also been covered, depending on topics. Only a few projects were primarily motivated by other concerns than environmental, for example a change to buying fair-trade-labelled groceries as much as possible.

In February 2018, a survey was sent out to all students that had done the project, asking them about whether they had continued to do the change they tried out in the course or whether they had implemented any

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* All programmes at bachelor level at Chalmers University of Technology must contain at least 7.5 ECTS – 5 weeks of fulltime studies – on ‘environment and sustainability’
drivers behind adoption of pro-environmental behaviour, e.g., as suggested by earlier mentioned theories of VBN or planned behaviour. The questions in the survey (translated and shortened from Swedish) along with an explanation of what they each represent in terms of behavioural outcomes as well as important factors behind such outcomes are provided in Table 1. All the survey questions discussed here were in the form of multiple choices.

Table 1: Survey questions and their role in the analysis of behavioural outcomes. V=variable; O= (behavioural change) outcome.

<table>
<thead>
<tr>
<th>Question</th>
<th>Short term</th>
<th>Theoretical argument</th>
</tr>
</thead>
<tbody>
<tr>
<td>Which year did you take the course…</td>
<td>Year</td>
<td>To allow for analysis of differences between student groups and the time dependence</td>
</tr>
<tr>
<td>In which area did you do your personal change project…</td>
<td>Theme</td>
<td>To allow for analysis of differences between themes</td>
</tr>
<tr>
<td>Did the change result in a decreased environmental impact?</td>
<td>V: Environmental impact</td>
<td>Variable related to Adverse Consequences in the VBN theory and part of the Attitude category in the PB theory. However, we do not know whether the student actually sees these consequences as severe</td>
</tr>
<tr>
<td>Did the change result in increased costs for you?</td>
<td>V: Cost</td>
<td>See V: Environmental impact, but here, the outcome is not directly related to environmental conservation/protection.</td>
</tr>
<tr>
<td>Did the time requirements for the activity increase with the change?</td>
<td>V: Time</td>
<td>See V: Environmental impact, but here, the outcome is not directly related to environmental conservation/protection</td>
</tr>
<tr>
<td>Did you perceive the project as meaningful in relation to your role as a consumer and citizen?</td>
<td>V: Meaning, citizen</td>
<td>The variable was included because students tend to appreciate educational elements that are perceived as meaningful to them, and we hypothesize that a positive attitude towards the activity could increase the likelihood of a changed behaviour. Could be connected to Motivation to comply, part of the Subjective norm category in the PB theory</td>
</tr>
<tr>
<td>Did you perceive the project as meaningful in relation to your future role as engineer?</td>
<td>V: Meaning, engineer</td>
<td>See V: Meaning, citizen</td>
</tr>
<tr>
<td>Did you continue with the change after the course ended?</td>
<td>O: Own</td>
<td>One of the targeted outcomes in the analysis</td>
</tr>
<tr>
<td>Did you implement changes you heard about from other students?</td>
<td>O: Other</td>
<td>One of the targeted outcomes in the analysis</td>
</tr>
<tr>
<td>Do you think you have sufficient knowledge to understand environmental/sustainability consequences of your choices?</td>
<td>V: Knowledge</td>
<td>Connected to the perceived ability to reduce threat in the VBN theory and the Perceived behavioural control category in the PB theory</td>
</tr>
<tr>
<td>Would you say that you make an effort to find out environmental/sustainability consequences of your choices?</td>
<td>V: Effort</td>
<td>Connected to the Sense of obligation variable in the VBN theory and close to the Behavioural intention category in the PB theory</td>
</tr>
<tr>
<td>How strongly do you feel that it is your own personal responsibility alternatively society’s responsibility that environmental impacts related to your consumption decrease?</td>
<td>V: Responsibility</td>
<td>Connected to Sense of obligation in the VBN theory, and part of the Subjective norm category in the PB theory</td>
</tr>
</tbody>
</table>

For variables and outcomes, there were three to five different possible answers in the multiple choice
survey that reflected different levels. Before the analysis, these levels were translated into numerical values from 0 to 1, with 1 representing the strongest pro-environmental behaviour respectively the strongest driver according to our hypotheses, see Table 2.

3 Results and discussion

53 students responded to the survey: 21 from the 2015 course, 8 from 2016 and 24 from 2017 (assuming that all students received the email with the link to the survey, this is a response rate of 47%, 16% and 50%, respectively, or overall 37%). In total, 30 students had made a diet-related change in the project, 7 related to waste, 6 related to water, 5 related to transport and the rest, 5 students, had made other changes. For students that had continued more than single days with a change they had tried themselves, 18 were related to diet, 5 were related to waste, 3 to transport and 2 to other things. For students that had adopted changes tried out by other students, 5 were related to water, 4 to several areas, 3 to waste and 3 to other changes. The percentage distribution of all other results are reported in Table 2.

According to the survey results, many of the changes led to environmental improvements, which was the targeted outcome of the change in most cases. In terms of costs, perhaps surprisingly, they were mostly either unchanged or reduced. However, the time spent by the student on doing this daily-life activity changed in both directions but mostly towards an increase (the students were asked in the survey to consider only the time that involved the activity itself and not the reflection and assessment activities done in the project).

In terms of how meaningful the project was perceived to be, a higher result was, not surprisingly, seen in relation to the role as a consumer and citizen than to their future role as an engineer. There could in fact be more done in the project to help the students connect the project to chemical engineering activities. However, their future role as engineers in this first-year introductory course is still likely quite vague to them.

Surprisingly many students continued after the course with the changed activity in some form – more than half of the students continued more than only single days, counting also the ones that claim that they do this for other reasons than the project itself. This could mean that the course created an openness for such change but that student did not have motivation to comply in this specific context and therefore want to claim other reasons, or something else.

When it comes to the student’s perception of their own knowledge level, they seem confident that they have sufficient knowledge to understand the consequences of their choices. This could be an expression of youthful omnipotence but also a realisation that they are already among the best educated people in the world in this field and therefore, should have sufficient knowledge and anything else would be highly disturbing. It does not reflect their teacher’s much more humble attitude. In terms of the effort they claim to put into understanding consequences, many students state that they do make an effort. This could very well be a result of the current pro-environmental culture among young people in Sweden, especially for young people that choose to study chemical engineering. In fact, many of the students that tried out dietary changes went from a normal vegetarian diet to vegan, which indicates that pro-environmental (or pro-animal-well-being) behaviour is already widespread in this group. Finally, half of the students think that individual’s do have a large responsibility for the environmental impact of consumption choices and most
of the rest that the responsibility is equally shared with ‘society’.

Table 2: Survey scale and responses. V= variable; O= (behavioural change) outcome.

<table>
<thead>
<tr>
<th>Variable or outcome</th>
<th>Response</th>
<th>Assigned value in analysis</th>
<th>Response distribution (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>V: Environmental impact</td>
<td>Large reduction</td>
<td>1</td>
<td>32.1</td>
</tr>
<tr>
<td></td>
<td>Small reduction</td>
<td>0.67</td>
<td>54.7</td>
</tr>
<tr>
<td></td>
<td>Neutral</td>
<td>0.33</td>
<td>9.5</td>
</tr>
<tr>
<td></td>
<td>Increase</td>
<td>0</td>
<td>1.9</td>
</tr>
<tr>
<td>V: Cost</td>
<td>Reduction</td>
<td>1</td>
<td>37.7</td>
</tr>
<tr>
<td></td>
<td>Neutral</td>
<td>0.67</td>
<td>41.5</td>
</tr>
<tr>
<td></td>
<td>Small increase</td>
<td>0.33</td>
<td>17.0</td>
</tr>
<tr>
<td></td>
<td>Large increase</td>
<td>0</td>
<td>1.9</td>
</tr>
<tr>
<td>V: Time</td>
<td>Reduction</td>
<td>1</td>
<td>15.1</td>
</tr>
<tr>
<td></td>
<td>Neutral</td>
<td>0.67</td>
<td>34.0</td>
</tr>
<tr>
<td></td>
<td>Small increase</td>
<td>0.33</td>
<td>43.3</td>
</tr>
<tr>
<td></td>
<td>Large increase</td>
<td>0</td>
<td>7.5</td>
</tr>
<tr>
<td>V: Meaning, citizen</td>
<td>High</td>
<td>1</td>
<td>17.0</td>
</tr>
<tr>
<td></td>
<td>Pretty high</td>
<td>0.75</td>
<td>43.4</td>
</tr>
<tr>
<td></td>
<td>Fair</td>
<td>0.5</td>
<td>17.0</td>
</tr>
<tr>
<td></td>
<td>Low</td>
<td>0.25</td>
<td>17.0</td>
</tr>
<tr>
<td></td>
<td>No</td>
<td>0</td>
<td>5.7</td>
</tr>
<tr>
<td>V: Meaning, engineer</td>
<td>High</td>
<td>1</td>
<td>5.7</td>
</tr>
<tr>
<td></td>
<td>Pretty high</td>
<td>0.75</td>
<td>17.0</td>
</tr>
<tr>
<td></td>
<td>Fair</td>
<td>0.5</td>
<td>22.6</td>
</tr>
<tr>
<td></td>
<td>Low</td>
<td>0.25</td>
<td>17.0</td>
</tr>
<tr>
<td></td>
<td>No</td>
<td>0</td>
<td>37.7</td>
</tr>
<tr>
<td>O: Own*</td>
<td>All the time</td>
<td>1</td>
<td>5.7</td>
</tr>
<tr>
<td></td>
<td>Most of the time</td>
<td>0.75</td>
<td>11.3 (+11.3)*</td>
</tr>
<tr>
<td></td>
<td>For some periods</td>
<td>0.5</td>
<td>24.5</td>
</tr>
<tr>
<td></td>
<td>For single days</td>
<td>0.25</td>
<td>24.5</td>
</tr>
<tr>
<td></td>
<td>No</td>
<td>0</td>
<td>22.6</td>
</tr>
<tr>
<td>O: Other*</td>
<td>In several areas</td>
<td>1</td>
<td>7.5</td>
</tr>
<tr>
<td></td>
<td>In one area</td>
<td>0.5</td>
<td>20.8 (+11.3)*</td>
</tr>
<tr>
<td></td>
<td>No</td>
<td>0</td>
<td>60.4</td>
</tr>
<tr>
<td>V: Knowledge</td>
<td>Highly sufficient</td>
<td>1</td>
<td>47.2</td>
</tr>
<tr>
<td></td>
<td>Fairly sufficient</td>
<td>0.75</td>
<td>49.1</td>
</tr>
<tr>
<td></td>
<td>So so</td>
<td>0.5</td>
<td>3.8</td>
</tr>
<tr>
<td></td>
<td>Not sufficient</td>
<td>0.25</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>Highly insufficient</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>V: Effort</td>
<td>High</td>
<td>1</td>
<td>11.3</td>
</tr>
<tr>
<td></td>
<td>Pretty high</td>
<td>0.75</td>
<td>26.4</td>
</tr>
<tr>
<td></td>
<td>Fair</td>
<td>0.5</td>
<td>52.8</td>
</tr>
<tr>
<td></td>
<td>Low</td>
<td>0.25</td>
<td>5.7</td>
</tr>
<tr>
<td></td>
<td>No</td>
<td>0</td>
<td>3.8</td>
</tr>
<tr>
<td>V: Responsibility</td>
<td>Individual’s high</td>
<td>1</td>
<td>17.0</td>
</tr>
<tr>
<td></td>
<td>Ind.’s pretty high</td>
<td>0.75</td>
<td>32.1</td>
</tr>
<tr>
<td></td>
<td>Shared</td>
<td>0.5</td>
<td>41.5</td>
</tr>
<tr>
<td></td>
<td>Mostly society’s</td>
<td>0.25</td>
<td>7.5</td>
</tr>
<tr>
<td></td>
<td>Fully society’s</td>
<td>0</td>
<td>1.9</td>
</tr>
</tbody>
</table>

*For O: Own and O: Other, students could also respond that they have done a change but for different reasons than the project. The number in parenthesis provides these responses.
All in all, the behaviour of many students seems to have been influenced by activities carried out in the course. Based on different theories, different factors may contribute to behavioural change, as earlier discussed. The questions in the survey were intentionally phrased to capture some of these factors and the survey results were analysed with respect to the explanatory power of any of the variables (V; independent variables, predictors) to the achieved outcomes (O; dependent variables). Results were analysed both with and without the students that expressed that their adoption of a change had a connection to the course. Simple linear curve fitting was done to the data points, see Table 3.

Table 3: Results from simple regression analysis, assuming linear dependence between dependent variable (O) and independent variables (V); k=slope, i=intercept and $R^2$=data fit. Very low or negative slope or extremely low fit is shown in italics and relatively high slope or fit is shown in bold.

<table>
<thead>
<tr>
<th></th>
<th>O: Own (only course)</th>
<th>O: Own (all)</th>
<th>O: Other (only course)</th>
<th>O: Other (all)</th>
</tr>
</thead>
<tbody>
<tr>
<td>V: Environmental impact</td>
<td>k=0.27</td>
<td>k=0.18</td>
<td>*</td>
<td>*</td>
</tr>
<tr>
<td></td>
<td>i=0.17</td>
<td>i=0.28</td>
<td>R^2=0.04</td>
<td>R^2=0.02</td>
</tr>
<tr>
<td>V: Cost</td>
<td>k=0.25</td>
<td>k=0.18</td>
<td>*</td>
<td>*</td>
</tr>
<tr>
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</tr>
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<td>k=-0.15</td>
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<td>*</td>
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<td>R^2=0.02</td>
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</tbody>
</table>

*These variables relate to the own project and are therefore not expected to predict outcomes with regard to other changes.

It is clear that the correlation between variables is generally low and that some expected dependencies cannot be seen based on this data and this analysis – some slopes are even negative (see e.g. for Time and Knowledge). It is also clear that the predictive power typically decreases when including data for students that claim that they have done changes in their daily life but not due to the activities in the course (compare ‘only course’ columns to ‘all’ columns in Table 3). The strongest dependencies are seen for the variables representing whether the project was seen as meaningful for their role as a citizen but also for their future role as engineers.

Comparing results for the first three variables in Table 3, low costs and reduced environmental impact seem to be stronger drivers than an increase in time spent is prohibitive. The first three variables were linked to
the students’ own projects and were therefore not analysed in terms of adoption of other students’ changes. If, however, the first three variables are low and this leads to that the own change is not continued, this might lead to the adoption of other changes if the sense of responsibility is high enough. This was, however, not checked. The Knowledge variable does not provide very useful results as almost all students felt they had a high knowledge level. However, the relatively strongly negative correlation for this variable when looking at how students adopted other student’s changes should be noted. It also seems that students with a larger sense of individual responsibility have a higher propensity to adopt changes they hear about.

A limitation is that the survey was not set up to be perfectly aligned to the subsequent statistical analysis. One could, with support in theories, look into correlations between some of the independent variables. This was not done in this study. Many other ways of treating the data material statistically are possible. However, with the fairly low number of respondents, the typical high variability of human data and the purpose of the study to provide input to educational development and to general understanding of the connection between education and behavioural change, this analysis sufficiently provided the most obvious conclusions.

So, what can we bring into the further development of the student project? The connection between the project to the students’ individual and future professional lives could be emphasized more strongly, for example by having the students reflect in their reports on how chemical engineering industry is involved in the life cycles of the products involved and how they may influence the life cycle in a way that affects the impacts of consumption or even the behaviour of consumers. Responsibilities of various actors could also be discussed more.

4 Conclusions

Many students continued after the course with the changed activity in some form. The strongest dependency to the investigated variables was seen for when the project was perceived as meaningful in relation to the student’s role as a consumer and citizen. Adoption of changes presented by other students had a relatively strong correlation to a sense of individual responsibility for the consequences of consumption.

5 References


Global Engineering and the Social Context: A Cross-Disciplinary Course for Undergraduates

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Abstract

Because of an increasingly complex global economy and challenges that span countries and cultures, it is imperative that today’s engineering graduates have the skills and attitudes necessary to communicate and develop engineering solutions that consider cultural and social differences. The forward-looking Vision for Civil Engineering in 2025 by ASCE (2006) states that “greater education and training of engineers in ethics and a greater emphasis on ethics in global engineering practice” is one of eight primary actions needed to achieve their vision “to create a sustainable world and enhance the global quality of life.” To help accomplish this goal, a cross-discipline team at Rose-Hulman Institute of Technology has developed a course entitled “Global Engineering and the Social Context.” The team consists of faculty from four engineering disciplines, as well as humanities and social science faculty. The course, offered for the first time in the spring and summer of 2018, will consist of an on-campus component and an international travel component that will include design experiences with students in the host country. The course will be available to students of all levels, but will primarily be marketed to freshman and sophomores so that the skills learned can be transferred to technical courses throughout the curriculum. This paper will present background information demonstrating need for the course, course development activities, including a summary of input from alumni/industry stakeholders, and lessons learned from the first iteration of the course.

1 Introduction

1.1 Background

The complexity of our global society requires that engineers, across all disciplines, consider the broader impacts of their work. In addition, successful engineers must be able to navigate culture differences to provide context appropriate designs and effectively communicate design solutions. Learned skills and attitudes are necessary to complete these two important functions. In 2009, the Newport Declaration
(Grandin and Hirleman, 2009) provided a call to action for engineering programs to equip students with the necessary skills and attitudes for global engineering. More specifically, the American Society of Civil Engineers’ Body of Knowledge document states that graduating civil engineering students should demonstrate competency up to the fourth level of Bloom’s taxonomy (analysis) to “analyze engineering works and services in order to function at a basic level in a global context” (ASCE, 2008). The concept of skill development for global engineering in undergraduate engineering programs has become important enough that it is also now included in the student outcomes for the ABET criteria for accrediting engineering programs (ABET, 2017).

Because of the recent emphasis on global engineering, undergraduate programs in the United States have added new courses, new content in existing courses, or even entirely new majors, minors, and certificate programs. Extracurricular activities, such as Engineers Without Borders, have also provided students with a global perspective that they do not otherwise obtain through traditional coursework (Litchfield et. al., 2016). These program and curriculum additions have had varying results, and anecdotal evidence suggests that many students are not prepared for working in a complex global environment upon graduation (Walther et. al., 2011). One major challenge to adding a global engineering course to an existing program is that a course may need to be removed to make room in a student’s plan of study. To remedy this issue, global engineering content can be added to a technical course, providing valuable context to engineering problems. This approach has been shown to provide better context to the students (Gilleard and Gilleard, 2002; Kilgore et. al., 2007). However, simply adding a globally-focused project to a technical course without additional instruction of the necessary professional skills is often not sufficient and may even result in negative perceptions of global engineering issues (Soibelman et. al., 2011). To further reinforce the concepts of global engineering, some courses include or primarily consist of a travel component. While it is clear that the travel component helps shape the attitudes of the students, results have been mixed with attempts to meet specific student learning growth goals (Bland, 2010).

In addition to the obvious benefits of fostering a global and cultural context for engineers, global engineering coursework and experiences provide additional benefits for students, regardless of whether they will ever work internationally or on global projects. Students are able to better identify and deal with complexity on projects and work better in multidisciplinary teams (Grigg, 2014). Communication and team management skills are also enhanced, better preparing engineers for future leadership roles (Downey et. al., 2006). Participation in international projects, particularly if they have a humanitarian component, may also help attract and retain students, especially women and minorities (Litchfield and Javernick-Will, 2014; Bielefeldt, 2014).

1.2 Institute Need

The current strategic plan of Rose-Hulman Institute of Technology includes a goal that the Institution “will be a diverse, globally-connected, sought-after community in which to live, learn, and work.” To meet the global portion of this goal, groups including the Office of Global Programs have been working to provide better access for students to have a meaningful international experience. Table 1 shows the number of students that participated in international experiences in the last six academic years, reported by category for the type of experience. The undergraduate enrollment for the time periods shown in the table was approximately 2,200.

As shown in Table 1, the participation rate of undergraduate students in meaningful international experiences is still relatively low, despite the effort of campus groups to provide additional opportunities.
In addition, the vast majority of courses that include an international experience (shown in Table 1 as Faculty/Staff Led Programs, Class Component) are humanities and social sciences courses. These courses provide the students with a valuable global perspective and introduce them to new cultures, but they do not provide opportunities for honing skills needed for engineering–specific problems. Therefore, the need for a course that integrates instruction on cultural and global skills, technical engineering concepts, and international travel is apparent.

Table 1: Undergraduate international experience participation numbers.

<table>
<thead>
<tr>
<th></th>
<th>AY11-12</th>
<th>AY12-13</th>
<th>AY13-14</th>
<th>AY14-15</th>
<th>AY15-16</th>
<th>AY16-17</th>
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<tr>
<td>AY Study Abroad</td>
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<td>13</td>
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<td>27</td>
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<td>13</td>
<td>16</td>
<td>24</td>
<td>25</td>
<td>15</td>
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</tr>
<tr>
<td>Class Component</td>
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<td>23</td>
<td>35</td>
<td>34</td>
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<td>8</td>
<td>-</td>
<td>6</td>
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<tr>
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<td>10</td>
<td>3</td>
<td>13</td>
</tr>
<tr>
<td>Volunteer Service</td>
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<td>12</td>
<td>5</td>
<td>6</td>
<td>12</td>
<td>8</td>
</tr>
<tr>
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<td>5</td>
<td>9</td>
<td>3</td>
<td>1</td>
<td>1</td>
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<tr>
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<td></td>
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<tr>
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<tr>
<td>Spring Break Trip</td>
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<td></td>
<td></td>
<td></td>
<td>35</td>
<td>18</td>
</tr>
</tbody>
</table>

Note: AY = Academic Year

2 Course Development

2.1 Alumni and Stakeholder Input

The initial draft of the program was developed by a team of faculty representing various engineering disciplines, humanities, and the Office of Global Programs. The group also received support from the office of Cross-Cutting Programs and Emerging Opportunities. In reviewing the literature on global engineering competencies (Lucia and Lepsinger, 1999), it was decided that one of the avenues of determining the appropriate student outcomes for the program would be to interview alumni about existing work situations and associated behavioral requirements faced in the practice of global engineering. The alumni were selected based on their interest in the Institute, size of industry they work for and personal experiences either working globally or working with global partners. They represented both small (less than 100 employees) and large (greater than 40,000 employees) pharmaceutical and medical device companies. For the large company that was represented, about 50% of the employees work outside the USA. The smaller company works with distributors in Canada, Israel, Australia and New Zealand and is looking to grow this reach. These representatives met with the development team during a one-day workshop in June 2017 to develop the framework for the program. The industry representatives were each asked to address the following questions:
I. What global engineering knowledge and skills are needed in industry currently?

II. What global engineering knowledge and skills are going to be needed 5 to 10 years from now?

III. Where are the gaps? How are these gaps being filled currently?

IV. What is industry looking for from graduate engineers?

Some of the highlights from the discussions included the following:

Globalization is important in almost every industry and for all sizes of industries.

There are country/regional differences in laws (e.g. intellectual property), regulations (e.g. registration process), standards (e.g. units of measure), and culture (e.g. business practices).

Strong and adaptable problem solving skills are needed.

2.2 Multi-Disciplinary Aspects

Engineering Design for a global economy requires a broad range of skills which are met by professionals in science, engineering, and the humanities. Therefore, a multi-disciplinary course was designed at Rose-Hulman. The characteristic of a STEM education that is most translatable to any field of study and any post-education vocation is the ability to develop critical thinking processes resembling those of an expert, scientist, or engineer. This course prepares students to develop engineering skills using a world-view by applying basic knowledge of engineering principles combined with the social awareness of the impact their work has on the people. The enrollment for AY1718 includes students majors from chemical engineering, mechanical engineering, biomedical engineering, and engineering management.

As faculty we must model the traits that we expect our students to adopt. The course instructors also are representative from mechanical engineering, civil & environmental engineering, electrical engineering, chemical engineering, and humanities. This program will create opportunities for faculty to learn more about global engineering needs and how to work together to meet them. Participation will remind us that we learn and teach these subjects, not just to pass on knowledge, but to make the world a safer, healthier, better place to live.

This course includes project-based learning as a tool to introduce the multi-disciplinary nature of the material and build relevance. It has been shown that undergraduate student teams that collaboratively address multidisciplinary research topics associated with grand challenges in engineering agree that a course like this can expand their knowledge, skills, and abilities beyond just completing required assignments and recognize their own growth in understanding what engineering can contribute to the society.

2.3 Integrating Technical Skills and Socio-Cultural Knowledge

Similar to other academic disciplines, engineering fields are diversifying and globalizing at a rapid pace. As such, engineering departments must adapt their pedagogical approaches to meet the needs of a new generation of engineers who are expected to become global citizens. Therefore, new approaches to engineering education must be as practical as they are epistemological. Indeed, employers expect recent STEM graduates to be globally competent, yet many report that institutions are not adequately preparing students for these expectations (Warnick 2011).
Engineers are expected to engage the social. According to Dark et. al. (2013), young engineers must understand the economic, political and social contexts (i.e. the “social environment”) that inform, influence, or exasperate engineering problems. Social interaction is key to develop this understanding (Dark, et. al. 2013). As such, this course requires students to acquire basic knowledge about the many “social environments” of China. To this end, students will be required to interrogate theories on culture, familiarize themselves with China’s recent history, political changes, and cultural make-up, and develop ethnographic research skills. These tools will enhance the student’s abilities to view engineering problems distinct to China from a local perspective.

2.4 On-Campus Course Format and Objectives

For the on-campus portion of the course, we generated a series of learning objectives based the brainstorming session from industry partners and input from the course development team (Table 2).

Table 2: Course learning objectives for Global Engineering and the Social Context I.

<table>
<thead>
<tr>
<th>After successful completion of this course, students will be able to:</th>
</tr>
</thead>
<tbody>
<tr>
<td>a. Develop an understanding of different consumer needs and requirements between different world regions.</td>
</tr>
<tr>
<td>b. Recognize different regulatory structures and standards that exist worldwide.</td>
</tr>
<tr>
<td>c. Discuss engineering design method as applied to global projects.</td>
</tr>
<tr>
<td>d. Discuss how the pillars of sustainable design can be applied to global engineering projects.</td>
</tr>
<tr>
<td>e. Identify important cultural and political structures in specific local contexts.</td>
</tr>
<tr>
<td>f. Discuss the role of cultural/political influences in global engineering design.</td>
</tr>
<tr>
<td>g. Explain how designs are influenced by local cultural and political norms.</td>
</tr>
<tr>
<td>h. Integrate these norms into a current or new design.</td>
</tr>
<tr>
<td>i. Apply curiosity and open-mindedness to learn something new.</td>
</tr>
<tr>
<td>j. Solve problems in a flexible and adaptable way.</td>
</tr>
<tr>
<td>k. Explain the basic principles of engineering ethics and empathy.</td>
</tr>
<tr>
<td>l. Communicate and work effectively in a multi-disciplinary team.</td>
</tr>
</tbody>
</table>

Some of the learning objectives targeted specific technical or engineering outcomes (a, b, c, d, l), while others were aimed at broadening students’ awareness of cultural context and ethics (e, f, g, h, k). We also included two learning objectives related to enhancing students’ ability to approach problems in an open-minded, flexible manner (i, j). Both faculty members and industry representatives agreed that mindset plays a key role in determining success of global projects, and we wanted to integrate activities designed to encourage an open mindset explicitly into the course.

With those learning objectives in mind, we developed an on-campus course for introduction in spring 2018, which met twice weekly (two hours per course session) for 10 weeks. The course was divided into a number of modules, with faculty members from different disciplines leading various sessions (Table 3). Cultural context and technical skills modules are interspersed through the initial seven weeks of the course, with the final three weeks devoted to problem solving modules. For this interdisciplinary, global course, we focused on developing course modules that would be applicable across engineering disciplines and across regions.

Table 3: On-campus course modules and organization.
The cultural context modules, rather than focusing on a single region, are designed to encourage students to observe and ask questions about cultural norms. Specific examples are drawn from the region for the travel course (China), but the material is designed to be generally applied in future versions of the course with different travel destinations. Strategies for intercultural communication are also addressed.

Technical modules focus on broadly applicable concepts across disciplines, including engineering ethics, identifying stakeholders in design, applying principles of sustainability in design, and understanding codes and standards across regions.

Finally, in the flexible and adaptable problem solving modules, the students are asked to undertake a team design project applicable to the region of the travel course. Some additional technical content is introduced to aid in design (open-ended problem solving approaches, systems engineering approaches), and students are asked to use their understanding of cultural context as they work through identifying project requirements and stakeholders.

2.5  Travel Component Format and Objectives

Global Engineering and the Social Context II is a travel abroad experience that puts into practice and builds upon the content of the on campus course. The first offering of Global Engineering and the Social Context II is scheduled to take place during the summer of 2018 and will include three weeks of travel to China. The long-term goal for this course is to expand the number of destinations available each summer so that students can choose from several destination or participate a second time in a different country. During the visit to China that will constitute the first offering of this course, students will experience cultural immersion, go on plant visits, tour the Three Gorges Dam, and work on engineering design projects at Huazhong University of Science and Technology in Wuhan. The learning outcomes established for the travel course (Table 4) reiterate and expand upon many of the learning outcomes identified for the on-campus course (Table 3).
Table 4: Course learning objectives for Global Engineering and the Social Context II.

After successful completion of this course, students will be able to:

a. Demonstrate how their understanding of culture impacted their approach to an intercultural interaction.

b. Work with local engineering students, professionals and other stakeholders to complete an engineering project in the travel country.

c. Recognize different regulatory structures and standards that exist between the USA and the travel country.

d. Discuss the engineering design method as applied to projects in the travel country (what information do you need to gather, how is it culturally different?).

e. Discuss how the pillars of sustainable design are applied to engineering projects in the travel country.

f. Identify important cultural and political structures in the travel country’s local context.

g. Discuss the role of the travel country’s cultural/political influences in engineering design.

h. In the context of the travel country, explain how designs are influenced by local cultural and political norms.

i. In the context of the travel country, apply curiosity and open-mindedness to learn something new.

j. Demonstrate flexibility and adaptability in solving problems in the travel country.

k. Demonstrate the basic principles of engineering ethics and empathy.

l. Communicate and work effectively in a multi-disciplinary team.

3 Assessment Plan

The course development team will utilize multiple assessment methods to better understand student experiences and perceptions. A primary focus is placed on those students traveling to China and how their learning gains differ from those who did not travel to China.

Students in both courses will complete pre- and post-surveys mapped to specific global and intercultural learning outcomes. Students traveling to China will complete a retrospective post-then-pre survey at the conclusion of their experience. This will allow the researchers to examine differences between the two groups and also within the group of students traveling to China.

Students traveling to China will complete online reflections as part of their attendance/active participation grade. Similar to the surveys, these reflective prompts will allow students to articulate their experience and perceptions. Some prompts will be mapped to global and intercultural learning outcomes.

Upon returning from China, a student focus group will be conducted. This focus group will provide students with an opportunity to reflect on their experience further. Additionally, researchers will gain further clarity on findings from surveys and online reflections.

In addition to our approaches to collecting data from students, data will also be provided by faculty and external stakeholders. Faculty will assess project presentations as part of the campus-level assessment plan using institute rubrics for Global and Intercultural Learning. Local students, professionals, and other stakeholders in China will provide feedback on student performance/artifacts mapped to specific course learning outcomes.
References


Holistic Engineering Ethics?

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Abstract

This paper focuses on the question of What kind of engineering ethics (EE) is needed to develop holistic engineers who can practice and promote the principles of sustainable development? It is argued that, given the existence of other models, an approach to EE, as argued for at EESD 2016, centred on “training engineers for handling ethical dilemmas in sustainability contexts” (Lundqvist and Svanstrom 2016) is inadequate to address the sustainability challenge facing engineers. It argues that while EE is now a diverse and fragmented field sociological tools can be used to understand this diversity. A framework is offered for understanding different approaches. This is used as the basis for arguing for a more extended and broad approach which allows us to focus on the relationship between social structure and human action and the need for “adequate social institutions and structures” (Becker 2012: 28) to enable ethical action. Thus engineers not should only understand the constraints and enablers emanating from the environments in which they work but can also strive for change in these environments.

1 Introduction

According to Grasso and Helble (2010) holistic engineers need to address social needs and be ethically grounded. In many countries engineering educators are mandated to provide ethics education including the principles of sustainable development. Despite these mandates, research suggests that provision of ethics education in engineering is inadequate, discussion of cases focused on ethics dilemmas is the most prevalent means of teaching, and that “the broad public purposes of engineering receives little attention” (Colby and Sullivan 2008: 330). Our research on the integration of sustainable development in a number of Irish engineering programmes found that “it was not evident how commitment to SD values is generated in the programmes. Modules that focus on ethics focus on micro ethical issues and professional responsibilities as set out on the code of ethics” (Nicoleau et al. 2018: 32).

In light of the dissatisfaction with the dominant approach, there is an increasing variety in approaches to EE (see Conlon and Zandvoort 2010). Therefore, it seems surprising that at EESD 2016 the only paper to deal substantially with EE should propose an approach based on “training engineers for handling ethical dilemmas in sustainability contexts” (Lundqvist and Svanstrom 2016). While the authors are aware of the problems associated with the use of an approach focused on ethical dilemmas we are not convinced that their approach overcomes the limitations associated with this dominant approach or addresses the demand for a refocusing of EE to address macro ethical issues and the broader ethical obligations of the profession, such as those embodied by sustainability.

This paper will proceed as follows. Firstly, the traditional approach, including the approach of Lundqvist and Svanstrom, and its limitations will be discussed. We then briefly identify a number of alternative approaches which can be found in the literature. This provides the basis for arguing for an integrated approach to sustainability ethics which pays attention to the institutional context in which engineers work.
2 Engineering Dilemmas

In previous work (Conlon and Zandvoort 2011, Martin, Conlon and Bowe 2017) we have identified some of the problems associated with the traditional and dominant “individualistic” approach to EE. This approach focuses narrowly on the ethical commitments of individuals, uses case studies to “train” students to be morally sensitive and resolve ethical dilemmas, and sees whistleblowing as a key device for ensuring that engineers can remain true to their ethical codes. Some key features of this approach are:

1. There is an almost exclusive focus on individuals who are facing a dilemma and from whom an ethical decision is expected involving a challenge to the interests of the organisation in which the engineer works. A key objective is to improve their ethical awareness and will power. A problem here is that “ethical awareness has not been demonstrated to translate into ethical behaviour” and “many ethical dilemmas engineers face are predominantly outside his or her control” (Bairaktarova and Woodcock 2017:1129,1143).

2. Codes of ethics, as standards of responsibility, are assumed to be the main source of rules that guide ethical decisions. It is implicitly assumed that these rules are sufficiently clear and free of conflicting elements to be applied to particular cases. If for some reason elaboration of the rules provided by the ethical codes is considered necessary, this approach falls back on traditional moral philosophy for help.

3. There is an assumption that “win-win” or “creative middle way” solutions, where one must choose among two or more conflicting morally important values, always exist and can be implemented by individual engineers. Key problems with this include the assumption that win-win solutions exist for ethical problems that engineers encounter and that individual engineers can implement their proposed solutions. The scenarios used do not faithfully reflect how engineers actually practice engineering. The focus is on small-scale human interactions, while ignoring the ethical problems of multi-actor situations that frequently arise within the context of engineering and technology.

4. Arising from the above there is a neglect of the macro-ethical problems of the profession (Herkert 2005). A problem here is that this approach is about providing students with an understanding of the nature of EE: “the value of engineering ethics rather than the values of an ethical engineer” (Shuman et al 2004). This is a call for value neutrality and is based on the contradiction that while we want engineers to practice engineering ethically we do not seem to want them to commit to any particular set of values. A shift to a focus on macro issues will require that engineers reflect on and commit to the goals of engineering which should be realised through engineering practice and public policy (Son 2008).

It can be argued that the commitment to value neutrality, the focus on the individual engineer and the bracketing out of the wider context are linked. This approach rarely calls on students to question the context from which dilemmas arise. The options provided to students rarely “entails permanently changing any social arrangements…and there are no analyses of how the social arrangements for making this decision could be changed in various ways” (Devon and Van De Poel 2004:463).

In their paper Lundqvist and Svanstrom (2016) acknowledge the difficulties for teachers in integrating ethics into the engineering classroom and seek to provide guidance on how ethics can be integrated into engineering education. Their approach is focused on the use of ethical dilemmas which, they say, “can be an effective tool in education to support students’ motivation and learning about ethics, since they give an opportunity for students to deal with issues they can face in their profession” (196). They are aware of some
the issues that have been raised about the use of case studies in EE and approvingly draw on Lynch and Kline (2000) to argue that cases should “be formulated to reflect the complex and open conditions that exist in engineering practice to make them the most effective in education” (197).

Yet in their focus on theory “in terms of what characterises an ethical dilemma, different ethical theories, and on how to apply ethical theories to manage ethical dilemmas” (199), their suggestion of using “stripped-down” ethical dilemmas and their focus on students making “informed evaluation of…potential ethical concerns, based on ethics theory, and construct arguments for how to act” (201) they seem to be advocating an approach to case studies which is the very focus of Lynch and Kline’s (2000) critique. Lynch and Kline are critical of approaches based on the simple application of moral theory. They suggest that what takes place in the ethics classroom is a mistaken attempt to embolden engineers against unethical employers: “A solid grounding in moral philosophy, a personal moral code, and a commitment to professional responsibility are assumed to inoculate us from the weakness of will” (Lynch and Kline 2000: 207). They argue for a move away from agency focused accounts of ethical failure and argue for cases (both large and small) to include more contextual detail; to “expand casuistry’s focus to include more actions, and more agents”(198-9); to provide a more realistic understanding of engineering practice; to encourage students to understand the need for persuasion and engage in role-playing so that they can understand the perspectives of others and the constrains in which they act. Large case studies should include topics related to activities beyond the technical such as contracting, regulation and technology transfer.

The “individualistic” approach can be useful for getting students to reflect on the nature of moral decision-making and highlighting the manner in which the operation of corporate decision-making can clash with the requirements of good engineering. But in focusing solely on an individual engineer’s possible courses of action, these case studies tend to be uninformative about the social, organisational and political complexities of engineering practice. For example, rather than looking for the causes of accidents in the moral failings of individuals, it is more productive to focus on the social and organisational properties of the overall sociotechnical system (Conlon 2015). Accidents have an historical background and an unfavourable organisational context in as much as a number of decisions and unfavourable circumstances progressively generate a pre-accident situation long before the triggering of the accident itself. We can identify recurrent features of organisational accidents all of these were present in the case which Lundqvist and Svanstrom want to strip back in order to teach students about moral theory. So, for example, in their analysis of the Pinto case Lee and Erdmann (1999) say that some engineers reported that those who had reservations about the safety of the Pinto “believed themselves powerless to challenge the prevailing “acceptable risk” definitions” (39). A key legal judgement in the case, the Appeal Court decision in Grimshaw v Ford, said “Ford’s institutional mentality was shown to be one of callous indifference to public safety.” Much is lost if students come to hold narrow views about how moral dilemmas can be resolved or if they believe that engineers are to meet their obligations to the public “regardless of any pressure they may encounter working in a corporate environment” (Lynch and Kline 2000: 197). By not taking adequate account of these pressures there is a danger of moralism as unrealistic expectations are placed on engineers.

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2 In an article in the New Yorker Malcolm Galdwell describes how the culture in Ford changed a young engineer, Denny Gioia, who worked in Ford during the Pinto controversy: “Gioia says he went to Ford with the idea that he would “fight them from the inside,” but sooner or later, inevitably, the world that surrounds us, all the working day, takes precedence. “Here’s the guy that went in with a strong value system, with intent and purpose, and got flipped within the space of two years,” he went on. “If it could happen to me, it could happen to anybody.”
In light of these problems with the “individualistic” approach a number of other paradigms have emerged. There have been calls to replace the dominant approach with a greater focus on macro ethical issues; to focus on the daily routines of engineering practice; to adopt approaches based on social ethics or aspirational ethics; and/or to engage with the philosophy of technology or with Science and Technology Studies (STS) (see Conlon and Zandvoort 2011). Given a divergence in approaches it is necessary to develop tools to understand these different approaches and how they might relate to each other.

3 Alternative Approaches

The emergence of alternative approaches are attempts to address different problematic aspects of the dominant approach by seeking to contextualise case studies better or by integrating macro issues more fully. Given the focus within the literature on the requirement for a macro focus we use a framework developed by George Ritzer (2001), for understanding different paradigms in social analysis, to analyse approaches to EE (Fig 1).

<table>
<thead>
<tr>
<th>Macroscopic</th>
</tr>
</thead>
<tbody>
<tr>
<td>O b j e c t i v e</td>
</tr>
<tr>
<td>i. Macro-Objective: Focus on social, economic and political structures and public policy</td>
</tr>
<tr>
<td>ii. Macro-subjective: Focus on goals and values of the profession</td>
</tr>
<tr>
<td>Microscopic</td>
</tr>
<tr>
<td>i. Micro-objective: Focus on engineering practice and role of organisational culture and processes</td>
</tr>
<tr>
<td>ii. Micro-subjective: Focus on consciousness of individual engineers: their ability to identify and solve ethical dilemmas and their ethical will power</td>
</tr>
</tbody>
</table>

Figure 1: Levels of analysis in engineering ethics

The framework is based on four levels of analysis which emerge from the interaction of two social continua: the macro/micro (the magnitude of phenomena) and the objective/subjective (whether a phenomenon has a material existence, or exists simply in the realm of ideas and knowledge). Given the variety of approaches to engineering ethics, Ritzer’s framework provides a useful tool for analysing current approaches. In using it, our focus is on capturing the fundamental image of the subject as presented by each paradigm. Space allows for only a cursory examination of the different approaches. The main elements of Paradigm iv have already been discussed so features of the other three approaches are discussed below.

3.1 Micro-objective

In order to address the context of engineering practice, some have argued that EE should be informed by STS. One focus in this approach is on why accidents happen in engineering projects. The explanation is usually sought within the prevailing organisational culture and processes with exemplary work being Vaughan’s (1996) analysis of the Challenger disaster. In explaining the disaster, she emphasises

\[\text{A more extended discussion of this framework can be found in Conlon (2011).}\]
institutional logics and the manner in which patterns of behaviour developed and became institutionalised within the organisations supporting the Shuttle programme. Vaughan discusses how risk came to be redefined, leading to a number of launches with a flawed design. This led to what Vaughan calls the “normalisation of deviance”.

In a significant contribution to the EE literature, Lynch and Kline (2000) draw on Vaughan’s analysis to argue for a focus in EE on the detail of engineering practice and the role of organisational culture and processes. Their aim is to explore how engineers can learn to identify features of their practice that potentially contribute to ethically problematic outcomes before clear-cut dilemmas emerge: engineers should exercise imagination to prevent these problematic characteristics from developing in their practice. While this approach can be welcomed as it moves us away from simplified case descriptions lacking their organisational and social context it is not without problems.

Firstly, although Vaughan pays attention to the wider economic and political environment, including budgetary pressures, in which NASA operated and the way it reinforced the normalisation of deviance, Lynch and Kline’s focus is mainly on the organisational culture. This is perhaps unsurprising. Although Vaughan is aware of the significances of wider macro questions of domestic and international political economy her analysis focuses mainly on the micro-processes of decision-making. By not problematizing this context, and exploring how it might be different she ends up accepting the social inevitability of mistakes. Further there are difficulties in the manner in which Vaughan understands the relationship between forces operating at different levels. She sees individual behaviour as shaped by overwhelming macro forces. Her emphasis is on the integrating role of the organisational culture leaving little room for change, protest and resistance (Conlon 2015a).

Secondly, Lynch and Kline fail to specify how engineers who become aware of the normalisation of deviance are to change the problematic aspects of organisational practices. It is perhaps ironic that in drawing on Vaughan, who has a structuralist bias, Lynch and Kline end up with an overly agency focused view. Their approach remains focused on the moral responsibility of engineers and less on the changing the institutional environment in which they work. Some (Swierstra and Jelsma 2006) have argued that the picture painted by Lynch and Kline is too rosy and call for “an institutional ethics”: a focus on the relationship between individual moral agency and the individual’s enabling and constraining environment.

3.2 Macro-Subjective Approach

Drawing from the philosophy of technology, Son (2008) has argued that a shift to a macro focus, should lead to a questioning of the goals of engineering or current forms of technological development: “…engineers will be obliged to reflect on what kind of society is desirable, to produce sound arguments for their ideas, and to conduct and justify their engineering practices accordingly” (413).

In this spirit, and drawing on the tradition of virtue ethics, Bowen (2009) calls for an “aspirational ethics”. He states that ethics may be seen as aims of a life that can be regarded as good, and morality as norms that provide articulation of these aims. Rather than focus on the resolution of moral quandaries “an essential antecedent approach is to adopt a positive way of being the very nature of which helps to minimise the occurrence of such difficult situations” (85). He argues that EE has focused, to date, on morality and suggests that engineers have, to a significant extent, forgotten that their primary objective is the promotion

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4 But see Lynch (2015) where he responds to this criticism.
of human well-being. What is needed is the development of a genuinely aspirational ethical ethos which prioritises human flourishing through contributing to human well-being. Bowen argues that engineers have not engaged sufficiently in any ethical analysis of their activities; he suggests that engineers themselves need to adopt a positive way of life and take responsibility for the outcomes of their activities. A person who “genuinely possesses a virtue would be expected to manifest it through the range of his or her activities” (p. 79). Two issues arise.

Firstly, the main emphasis, for Bowen, is on the culture of engineering and the development of an aspirational ethos which prioritises human flourishing. An issue then is what criteria are to be used to measure human flourishing. Secondly, there is a danger here of moralism. While engineers may be committed to ethical practices it is not always possible to behave ethically. To exercise moral agency, commitment to particular outcomes is necessary, but so is the power to achieve these outcomes. In later work Bowen (2014) pays some attention to this issue emphasizing the importance of a supportive social context. This highlights the need, in raising the level of analysis, to address both the goals of engineering and the capacity of engineers to practice engineering in a way that promotes human flourishing.

3.3 Macro-Objective Approach

As seen above Swierstra and Jelsma (2006) have argued for an institutional ethics. While not wanting to abandon a focus on the responsibilities of engineers they argue that an EE that takes responsibility to heart needs to reflect upon the conditions in which responsibility can be exercised. They argue that a sociologically informed way of studying engineering practice can help engineers to recognise the possibilities and obstacles for assuming social responsibility for their work. They believe it is both necessary and possible to influence the institutional environment of engineers so as to enable them to behave responsibly. The manner in which they can do this “should be part and parcel of engineering ethics” (2005: 225).

In a similar vein Zandvoort et al. (2000) have argued that engineers need to accept that they must play an active role in helping to reshape the context from which ethical problems arise. It is possible to identify two broad approaches to facilitating change in the environment in which engineers work. The first would seem to accept that the current organisation of production and consumption can be reformed through regulation to give support to engineers. Some approaches (Zandvoort 2005) have focused on specific changes in the structures of corporate and management accountability and proposed wide ranging changes to legal systems to enable socially responsible behaviour and the promotion of sustainability.

The second questions whether the goals of sustainability and social justice can be met within the confines of current relations of production and consumption. Some have argued that legal reforms are not enough, that we need a wider focus and that there are contradictions between the goals of engineering, such as sustainability, and current political and economic priorities (Petrella 2001, Weiler 2001). Further the promotion of overconsumption undermines efforts to promote more sustainable patterns of consumption (Woodhouse 2001). Thus sustainability requires that the profession influence change in “social, political, economic, and institutional paradigms” increasing our ability to move in sustainable directions (Donnelly and Boyle 2006: 153).

A Conclusion

This short review of approaches to EE has moved from an approach that emphasizes the capacity of
engineers to exercise social responsibility to one where the actions of engineers are significantly constrained by the contexts in which the work. The framework used allows us to see that a macro-focus should involve interrogating both the goals of the profession and the social context in which engineers work. This should allow us to avoid a moralism that may burden engineers with responsibilities they cannot meet, while allowing us to better identify those circumstances which would facilitate the attainment of broad goals such as enhancing human welfare and sustainable development.

This suggests that, analytically, the key focus should be on the relationship between the agency of engineers and the social structures in which they work, and the extent to which they constrain or enable a socially responsible engineering practice, rather than on the scale of the issues that EE addresses, which is the focus of the macro/micro debate. One good reason for saying this is that it is not always easy to distinguish the micro from the macro as they are intertwined and depend on each other. Herkert (2005) has, for example, identified the design of safe products as a micro issue. But the safety of engineering products and processes is affected by the attitudes, practices and organisation of engineers, organisational structures and culture, the regulatory regime, production pressures and public policy, which includes policy on product liability which Herkert identifies as a macro issue.

It would seem then that the key issue is not just the scale of the issues which EE addresses but how different mechanisms, operating at different levels, come together to produce particular effects in the practice of engineering. In this the commitments of engineers and the goals of the profession matter. But so does the context in which engineering takes place. Frameworks that attempt to link these issues can be found in work on sustainability ethics, drawing on the virtue ethics tradition, which rejects traditional approaches to moral philosophy, based on consequentialism or duty ethics, recognise that humans are embedded in many unchosen relations of unequal power and that a key challenge for sustainability ethics is to focus on “what structures and institutions govern these relations…and how we should design them to allow for an ideal organisation and realisation of the sustainability relations” (Becker 2012: 34).

In doing so we can draw on a key insight of STS which is that engineers do not just produce technology, but socio-technical systems which shape human activity (Johnson and Wetmore 2007). Thus engineers’ ethical responsibilities are wider than traditionally understood. Further, they must engage with other actors who are responsible for the development of socio-technical systems. Therefore, we need a wider focus which places engineering practice in its wider context but does not eliminate an active role for engineers in changing that context as necessary (Conlon 2015a). The focus in ethics education must be on generating commitment to larger systematic change to established practices over time rather than on heroic responses to management wrongdoing (Lynch 2015). This will require engineers to engage with public policy and the extent to which it enables an engineering practice committed to human welfare and sustainability. This takes us far from training engineers to deal with ethical dilemmas as a focus for EE.

References


A comprehensive design and analysis of a turbofan engine under sustainability consideration is presented in this paper. The components of jet engine have been analyzed based on green design concept. An attempt has been to select materials based on sustainability and green design considerations. The energy content (e) of the materials has been one of the parameter for material selection. The choice of material has a substantial impact on cost, manufacturing process, and the life cycle efficiency. All components nose cone, fan blade, inlet shaft, including compressor has been solid modeled using Siemens NX 11.0 CAD software. The finite element analysis of every component were performed and found safe. A tolerance analysis was performed before assembly of the turbofan engine. A numerical analysis was completed on blade and inlet geometries to determine a more efficient turbofan engine. Thermal analysis was executed on the cone and suitable corrections were made. Finally, the total energy to manufacture turbofan engine is estimated to show how much energy is needed to manufacture a turbofan jet engine.

1 Introduction

The research presented here explore in detail fundamental steps in designing and life cycle analysis of a turbofan engine. Jet engines are extremely advanced pieces of machinery that take teams of engineers [1] years of research and design to produce. Most modern airliners use turbofan engines because of their high thrust and good fuel efficiency. The hot exhaust passes through the core and fan turbines and then out the nozzle, as in a basic turbojet. The rest of the incoming air passes through the fan and bypasses, or goes around the engine, just like the air through a propeller. So, a turbofan gets some of its thrust from the core and some of its thrust from the fan. The fan and fan turbine are composed of many blades, like the core compressor and core turbine, and are connected to an additional shaft. As with the core compressor and turbine, some of the fan blades turn with the shaft and some blades remain stationary. The fan shaft passes through the core shaft. In fact, high bypass ratio turbofans are nearly as fuel efficient as turboprops. Because the fan is enclosed by the inlet and is composed of many blades, it can operate efficiently at higher speeds than a simple propeller. Therefore, the airplane inlet slows the air down from supersonic speeds an example of a Turbofan Engine can be seen below in Figure 1.

Figure 1: Schematic of Standard Turbofan Engine Figure 2: Nose Con Capture area

The design of turbofan engine follows a modular concept and each of the modules has its own identity. The main engine modules can be summarized as the following: Fan, Low Pressure Compressor (LPC), Cone Engine Module, Low Pressure Turbine (LPT), Generally, it is the core engine module that is subjected to the most adverse conditions in terms of temperature, pressure, and rotational velocity. It is this module that
suffers the fastest deterioration of performance. In addition to its main components the engine needs various systems to become operable. These include amongst others an air cooling and sealing system, a lubrication system, a fuel distribution system, an exhaust and thrust reverser system as well as an air inlet and a nozzle [1].

1.1 The mathematics describing the thrust of a turbofan engine is presented below. The capture area of the fan, required to achieve the desired mass flow rate, need to be determined. The total mass flow, \(\dot{m}_t\) is given by eq. (1) below

\[ \dot{m}_i = \dot{m}_{fan} + \dot{m}_{core} \] (1),

\[ R_b = \frac{\dot{m}_{fan}}{\dot{m}_{core}} \] (2),

\[ R_b = \frac{\dot{m}_{fan}}{\dot{m}_{core}} \] (3)

Where \(\dot{m}_{fan}\) is fan exhaust mass flow and \(\dot{m}_{core}\) is core mass flow rate. The bypass ratio, \(R_b\), is estimated as:

\[ m_{fan}=p^\infty ViAf an \] (mass flow rate) (4).

Where \(p^\infty\) the Pressure of the Free Steam Air is, \(Vi\) is the inlet air velocity, and \(Af an\) is the capture area of fan. Turbojet engine noise is predominately jet noise from the high exhaust velocity, therefore turbofan engines are significantly quieter than a pure-jet of the same thrust with jet noise no longer the predominant source. Since the efficiency of propulsion is a function of the relative airspeed of the exhaust to the surrounding air, propellers are most efficient for low speed, pure jets for high speeds, and ducted fans in the middle. Turbofans are thus the most efficient engines in the range of speeds from about 500 to 1,000 km/h (310 to 620 mph), the speed at which most commercial aircraft operate. Turbofans retain an efficiency edge over pure jets at low supersonic speeds up to roughly Mach 1.6. The core airflow needs to be large enough to give sufficient core power to drive the fan. Specific Thrust (net thrust/intake airflow) is an important parameter for turbofans and jet engines in general. The higher the Fan Pressure Ratio (fan discharge pressure/fan inlet pressure), the higher the jet velocity and the corresponding specific thrust. Although turbine blade (and vane) materials have improved over the years, much of the increase in high pressure turbine inlet temperatures is due to improvements in blade/vane cooling technology. The gas temperature can therefore be even higher than the melting temperature of the blade [3]. After picking up heat from the blade/vane, the cooling air is dumped into the main gas stream. It is desired to achieve the following goals;

- Design and model important components of a working Turbofan Jet Engine, Life Cycle Study of Standard Turbofan Engine, perform a Finite Element (FE) analysis on its problematic areas (discussed later), Test different blade and inlet geometries to see if a more efficient high speed Turbofan can be achieved, Energy requirement to manufacture a turbofan engine

2 Design Parameters: Engine Properties and Flight Characteristics
The methodology for design and analysis is presented for a set of data given below. These values are the standards for many commercial jets operating at cruise conditions. A summary of these basic operating conditions is listed as;

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thrust at cruise condition ((T_{cruise}))</td>
<td>42,000 lbs</td>
</tr>
<tr>
<td>Mach number at cruise ((M_{cruise}))</td>
<td>0.9</td>
</tr>
<tr>
<td>Cruising Altitude (Altruism)</td>
<td>37,000 ft</td>
</tr>
<tr>
<td>Turbofan Bypass Ratio ((R_b))</td>
<td>9.5</td>
</tr>
<tr>
<td>Maximum angular engine speed ((N_{max}))</td>
<td>2550 rpm</td>
</tr>
</tbody>
</table>

Once a cruise altitude, target thrust and an average bypass ratio is established, the atmospheric conditions could be determined. The atmospheric conditions at a cruise altitude of 37,000 feet are standard and adopted as they are.

2.1 Analysis and Design
2.1.1 Inlet Fan; Sizing the Fan
The fan draws in enormous quantities of air, producing the over 70% of the engines total thrust1. Due to the importance of this single part much of the engine is sized around the Inlet Fan’s dimensional
requirements. The inlet conditions are listed below.

Inlet velocity: \( V_i = 871.65 \text{ ft/s} \), Inlet Temperature: \( T_i = 390.6^\circ \text{R} \), Inlet Pressure: \( P_i = 3.13 \text{ psia} \), Inlet mass flow rate: \( m_i = 1378.2 \text{ lbm/s} \). The capture area of the fan, \( A_{fan} \) required to achieve the desired mass flow rate, \( m_f \), should be determined. By rearranging Equations 1, 2 and 3, shown above, \( A_{fan} \) and \( m_f \) can be calculated using Equation 4. The fan exhaust mass flow can be calculated from inlet mass flow as below

\[
m_f = m_i \left[ \frac{Rb}{Rb + 1} \right] = \frac{1246.94 lb}{s} \quad (4)
\]

<table>
<thead>
<tr>
<th>Materials</th>
<th>Density ((\rho)) (lbm/in(^3))</th>
<th>Young’s Modulus ((E)) (Mpsi)</th>
<th>Yield Strength, ((\sigma_y)), (kpsi)</th>
<th>Embodied Energy ((T_e)), (Btu)</th>
<th>(M_1 = \frac{\sigma_y}{\epsilon p})</th>
<th>(M_2 = \frac{E}{\epsilon p})</th>
<th>Performance Index</th>
<th>Detected</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ti alloys</td>
<td>0.6</td>
<td>16.5</td>
<td>143 - 750</td>
<td>66.36 (\times) 10(^3)</td>
<td>(1.89 - 3.59) (\times) 10(^{-3})</td>
<td>4.15 (\times) 10(^{-4})</td>
<td>(M_1')</td>
<td></td>
</tr>
<tr>
<td>Nickel-based super alloys</td>
<td>.2820</td>
<td>28.5 - 28.8</td>
<td>36.28 - 98.7</td>
<td>(15.168 - 17.04) (\times) 10(^3)</td>
<td>2.05 (\times) 10(^{-2}) - 8.48 (\times) 10(^{-3})</td>
<td>(5.93 - 6.73) (\times) 10(^{-3})</td>
<td>(M_1)</td>
<td></td>
</tr>
<tr>
<td>Magnesium Alloys</td>
<td>440</td>
<td>29.5</td>
<td>80</td>
<td>312 - 346</td>
<td>(5.25 - 5.83) (\times) 10(^{-4})</td>
<td>(1.94 - 2.15) (\times) 10(^{-4})</td>
<td>(M_2)</td>
<td></td>
</tr>
</tbody>
</table>

The capture area of fan as: \( A_{fan} = \left( \frac{m_f}{\rho_{osv}} \right) \), \( A_{fan} = 66.23 ft^2 \) This is the capture area necessary to achieve the desired mass flow rate and is located between the Inlet Fan Housing and the Nose Cone, shown in Figure 2.

**2.1.2 Green Material Selection for least Environmental Impact:** Strong, lightweight, corrosion-resistant, thermally stable components are essential to the viability of any aircraft design, and certain materials have been developed to provide these and other desirable traits. Titanium, first created in sufficiently pure form for commercial use during the 1970.

While it is very difficult to shape; its extreme hardness renders it strong when subjected to intense heat. To improve its malleability titanium is often alloyed with other metals such as nickel and aluminum. The intake fan at the front of the engine must be extremely strong so that it doesn’t fracture when large birds and other debris are sucked into its blades; it is thus made of a titanium alloy. The intermediate compressor is made from aluminum, while the high-pressure section nearer the intense heat of the combustor is made of nickel and titanium alloys better able to withstand extreme temperatures [4]. The combustion chamber is also made of nickel and titanium alloys, and the turbine blades, which must endure the most intense heat of the engine, consist of nickel-titanium-aluminum alloys. Often, both the combustion chamber and the turbine receive special ceramic coatings that better enable them to resist heat. The inner duct of the exhaust system is crafted from titanium, while the outer exhaust duct is made from composites—synthetic fibers held together with resins. Although fiberglass was used for years, it is now being supplanted by Kevlar, which is even lighter and stronger. The thrust reverser consists of titanium alloy. We have two constraints—shear stress and deflection—and for material selection, it is recommended that material related to dominant constraint should be selected. We can write as min-max optimization model. An analytical method is presented below We will use charts generated by Asby [5] between material index M1 and M2 to short list materials useful for fan blades and then use analytical method [5]. The short-listed for blade materials and calculations for TE1 and TE2 are presented below in the Table 2. If we rank the material starting with best choice to least choice, they are: Ti – alloys are best for cone & Nickel based super alloy is best for fan
blade.

2.1.3 The Manufacturing of Jet Components

Building and assembling the components of a jet engine takes about two years, after a design and testing period that can take up to five years for each model. The research and development phase is so protracted because the engines are so complex: a standard Boeing 747 engine, for example, contains almost 25,000 parts. In jet engine manufacture, the various parts are made individually as part of subassemblies; the subassemblies then come together to assemble the whole engine. One such part is the fan blade, situated at the front of the engine. Each fan blade consists of two blade skins produced by shaping molten titanium in a hot press. When removed, each blade skin is welded to a mate, with a hollow cavity in the center. To increase the strength of the final product, this cavity is filled with a titanium honeycomb.

Compressor disc; The disc, the solid core to which the blades of the compressor are attached resemble a notched wheel. It is manufactured by powder metallurgy process. It consists of pouring molten metal into a rapidly rotating turntable that breaks the metal onto millions of microscopic droplets that are flung back almost immediately. Turbine blades are made by forming wax copies of the blades and then immersing the copies in a ceramic slurry bath. After each copy is heated to harden the ceramic and melt the wax. Molten metal is poured into the hollow space left by the melted wax due to tables spinning. As they leave the table, the droplets' temperature suddenly plummets (by roughly 2,120 degrees Fahrenheit—1,000 degrees Celsius—in half a second), causing them to solidify and form a fine-grained metal powder. The resulting powder is very pure because it solidifies too quickly to pick up contaminants. Turbine blades are made by forming wax copies of the blades and then immersing the copies in a ceramic slurry bath. After each copy is heated to harden the ceramic and melt the wax, molten metal is poured into the hollow left by the melted wax. In the next step, the powder is packed into a forming case and put into a vacuum. Vibrated, the powder sifts down until it is tightly packed at the bottom of the case; the vacuum guarantees that no air pockets develop. The case is then sealed and heated under high pressure.

2.1.4 Design of the Inlet Fan

To determine the actual dimensions of the Inlet Fan is modified. The calculated is the area of an annulus, since the engine’s nose cone is located at the center of the inlet fan, indicated in Figure 1. Since the nose cone only redirects air and does not draw any in, this area is not accounted for in the calculated 66.23 ft². To account for the nose cones area, as well as obtain radii for both the inlet fan blades and the nose cone, a ratio needs to be established. For a typical Turbofan Engine, this ratio was found to be 3.54. Knowing this, the two radii are calculated by Equation 5. The nose cone is the forward most section of a Turbofan jet engine. Its primary purpose is to help slow down the flow of air before it enters the engine. It also allows for air to be redirected into the blades of the Turbofan and its profile shape is designed such that it minimizes air resistance and temperature gains from aerodynamic heating. The nose cone is in fact hollow in many cases and houses many rotating components used to transmit power, change the pitch of the propeller, and so forth. First; the general dimensions of the nose cone had to be established. These dimensions are; the radius of the nose cones base (R1), the overall length (Ltotal), the radius at any given point x(yx ) where varies from zero, at the nose cones base, to , at its tip. These dimensions can be seen below, in Figure 4, for a general parabolic shape profile. After analyzing the data presented in Figure 5 the x12/Power Series was chosen as the initial profile shape. This choice was based on the criteria of the extent of testing data available and the performance ratings in the transonic range, specifically between 0.8 and 1.2. The x²(1/2) Power Series profile was chosen since it provided testing data at seven different Mach Numbers and operated at the highest performance rating at Mach 0.9, 1.1 and 1.4. This series is generally characterized by its blunt tip and the fact that its base is not tangent to the body tube. Due to this, the base is usually smoothed out to rid the profile of this discontinuity.

2.1.5 Dimensioning the Nose Cone
Once it was established that the \( x^{(1/2)} \) Power Series would serve as the general nose cone profile shape determining the specific dimensions could be considered. Equation 7, shown below, is the governing equation for the shape and dimensions of the nose cone with the variable \( n \) defining the final shape [6].

2.1.6 Material Considerations of the Nose Cone
For the Nose Cone design two primary materials were being considered, Aluminum (Al) and Titanium (Ti). The reason for these specific two is because each material is extremely light when compared to heavier ones such as steel, are readily available, have high melting points and can handle significant stress. By nature, is far more expensive then since it offers a higher melting point, lighter weight and far exceeds the strength.

2.1.7 Analysis and Design of the Nose Cone
Nose Cone is designed so that it minimizes air resistance and temperature gains from aerodynamic heating. The primary load that the Nose Cone is subjected to is the resultant of the aerodynamic drag. The drag force \( (FD) \) is quite substantial due to the large frontal area and high speed air passing over it. The drag force on the Nose Cone is calculated as: \( 556.703 \text{ lbf} \).

2.1.8 Thermal Analysis of the Nose Cone
Due to the high-speed air traveling over the Nose Cone a temperature rise will inevitably occur, this is due to frictional forces. Where; \( Aannulus \) is equivalent to \( Afan \), \( A2 \) is the total area of the Inlet Fan and \( A1 \) is the area of the Nose Cone. By substituting the basic equation for a circle’s area into Equation 5, \( R1 \) and \( R2 \) are calculated; \( R1 = 16.227 \text{ in} \) and \( R2 = 57.443 \text{ in} \). The nose cone is the forward most section of a Turbofan jet engine. Its primary purpose is to help slow down the flow of air before it enters the engine. It also allows for air to be redirected into the blades of the Turbofan and its profile shape is designed such that it minimizes air resistance and temperature gains from aerodynamic heating.

The disc, the solid core to which the blades of the compressor are attached, resembles a big, notched wheel. It must be extremely strong and free of even minute imperfections, as these could easily develop into fractures under the tremendous stress of engine operation. For a long time, the most popular way to manufacture the disc entailed machine-cutting a metal blank into a rough approximation of the desired shape, then heating and stamping it to precise specifications (in addition to rendering the metal malleable, heat also helps to fuse hairline cracks). Today, however, a more sophisticated method of powder metallurgy is being used by more and more manufacturers. It consists of pouring molten metal onto a rapidly rotating turntable that breaks the metal into millions of microscopic droplets that are flung back up almost immediately. Turbine blades are made by forming wax copies of the blades and then immersing the copies in a ceramic slurry bath. After each copy is heated to harden the ceramic and melt the wax, molten metal is poured into the hollow left by the melted wax due to the table's spinning. As they leave the table, the droplets' temperature suddenly plummets (by roughly 2,120 degrees Fahrenheit—1,000 degrees Celsius—in half a second), causing them to solidify and form a fine-grained metal powder. The resulting powder is very pure because it solidifies too quickly to pick up contaminants.
is known as aerodynamic heating. The thermal load will be caused by the temperature difference the surface outer surface area will undergo. The mechanism of heat transfer are convection and conduction since the outer surface is exposed to a fluid and the inner area of the Nose Cone is a solid. First the temperature difference between the free stream air ($T_\infty$) and the Nose Cone’s surface ($T_s$) was analyzed. The cruise conditions it is assumed that its initial surface and body temperature are uniformly at $T_\infty$. It is calculated as: $T_\infty(1+M^2)$, $T_o=453.82^\circ R$. The thermal conductivity of Al is estimated as: $kAl=29.625\, lbs^{-1}^\circ R$

2.1.9 Fan Blade

With the basic geometry of the inlet fan the actual size of the fan blades can be found. This was done by first knowing the desired length of the blades. Since the maximum length, the blades can be in is predetermined to be 41.22 inches, due to geometric restraints, indicated in Figure 3, this will be used as the maximum allowable length. To calculate the necessary length needed to achieve the desired cruise conditions a basic power analysis needs to be performed on the turbofan engine and the fan blade in specific. The torque of the engine needed to be calculated as:

$$T = \frac{5252\, HP}{N}$$

and horse power, HP is estimated as HP = 66562.3 hp and [SHP]g=64565 hp. (15)

2.2 Shaft, Bearing, and Gearbox

Once the torque and [SHP] is calculated three more values are necessary to determine the speed and power of the fan blade, these being: the number of bearings between the gearbox output and the propeller, $Ng$, the gearbox reduction ratio, $Gr$ and the power loss due to the bearings, $Pb$. For this analysis $[PLB]$ and $Gr$ will be based on average propeller values and are assumed to be 3.70 and 6.00% respectively. To determine $Ng$, the number of objects that are fixed to the shaft need to be accounted for. An up-close view of the inlet assembly, shown in Figure 8, reveals that there is a total of five objects that are fixed to the shaft and thus can be treated as bearings. With these values known the shaft horsepower at the propeller, [SHP], the propellers rotation speed, $Np$, and the propellers torque, $Tp$, can be found using Eqs 19 and 21, shown below.
\[ [SHP]p = [SHP]g \left(\frac{100 - [pL]b}{100}\right), [SHP]p = 64527hp \text{ and } Np = \frac{N_{max}}{Gr} = 689rpm \] (19)

\[ Tp = \frac{5252[SHP]p}{Np} = 491807 \text{ ftlb} \]

and the diameter of blade Db = 114.871 in is also estimated.

The following design parameter are now defined;

The fan diameter is less than the maximum allowable diameter of 114.88 inches. The thickness of blade is estimated to be 0.5 in. The fan blade the width of each blade, \( wb \), is determined below [3].

\[ wb = \pi Cb/(b# + cb#) = 15.786in \]

2.2.1 Force Analysis of a Fan Blade

To accurately analyze the lift and drag force a propeller blade experiences the pressure distribution across the frontal surface needs to be defined. \( Aref = hw = 906.67 \text{ in}^2 \times 6.30 \text{ ft}^2 \). rectangular reference area will be used corresponding to the blades maximum height. This value for drag force is far larger then what the blade will experience during operation. The drag force, \( FD = 12\rho \infty V^2 ArCD \) =481.99 lbf.

2.2.2 Blade Rotor: Geometry of the Rotor

For the blade rotor, there are four primary dimensions of interest, these being; the length, \( l \), the thickness, \( tr \), the initial radius, \( R1 \), and the final radius, \( Rf \). These dimensions as well as the nose cone and blade rotors radii as in Figure 6. For analysis, the following assumptions are made; \( tr = 1.12 \text{ in}, trc = 0.77 \text{ in}, tb = 0.25 \text{ in}, drb = 0.024 \text{ in} \). Where \( drb \) corresponds to the appropriate clearance between the blade plate and the blade rotor Eqs. 24 and 25, we get: \( R1 = 15.575 \text{ in}, r1 = 14.807 \text{ in}, L = 14.427 \text{ in} \)
The Hollow Section

The Hollow Section, shaft’s dimensions $RH$ can be found using Equation shown below.

$$RH = Ds + Sbar = 10.15 \text{ in, Where; } Ds \text{ is the diameter of the shaft and } \delta \text{br is the clearance between the shaft and the blade rotor.}$$

2.2.3 The Spacing Ring and Primary Rotor

The spacing ring is used to support the electronic shaft at the point where it meets the primary rotor Using Des, the remaining thickness and diameters were determined using similar scaling factors used in the previous section, the values are estimated as: $H_{\text{max}} = 18.035 \text{ in, Des} = 0.987 \text{ in, tpr} = 1.776 \text{ in, and Dsr} = 1.479 \text{ in.}$. The radii for the multiple components of the blade pitch control are calculated below. Using equations, A (from before) and B (from before) as well as the scaling factors shown below as Equations 34 and 35 the geometry for the blade pitch control can be completely defined. Equation 30 is used to find $R_{pr}$.

The drawing of the blade pitch control can be seen in Figure 13. $Les = 0.140H_{\text{max}} = 2.525 \text{ in (34), Lsr = 0.199Les = 0.501 in, (35), Rpr= H_{\text{max}} – Les – Lsr = 15.009 \text{ in.}}$

3 Primary Inlet Shaft: Sizing Inlet Shaft

Initial Assumptions: The turbine shaft is subjected to constant bending and torsion only, The bending stress is completely reversible and the torsion is steady., The shaft operates in temperatures between 70°F - 100°F.

Design Parameters Given: Shaft length(L) = 32.3 in, Propeller power (P) = 64527 hp, Speed of shaft (Nmax) =2550 rpm, Bending moment (Ma) and Torque (Ta) =0, Factor of safety =1.6.

$$d = \left( \frac{8nA}{\pi Se} \left[ 1 + \frac{2BSe}{ASut} \right]^2 \right)^{\frac{1}{3}} \text{ (37), }$$

$$B = \sqrt{4(KfMm)^2 + 3(KfsTm)^2} \text{ (37b) }$$

Due to these considerations, a Carbon Steel was chosen to be the initial material, specifically AISI 1060 Q&T at 1000 °F. The mean mechanical properties of AISI 1060 Q&T and Sut=156 kpsi. The diameter of the inlet shaft is calculated as: $d =10 \text{ in.}$
3.2 Tolerance Analysis; Shaft Tolerance:
The tolerance is a measure of variation accumulate during manufacturing and assembly. In the design of aircraft engines tolerances are generally kept extremely low for parts critical to performance and reliability, a typical value is ±0.0001 inches. The results are displayed in Table 3. Similar analysis was performed on the outer diameters of each piece and the blade rotor, which houses all the mentioned components. Since the diameter of the rotor changes with respect to length the diameter must be specified for each part to keep the analysis accurate. \(wb=15.786\pm0.0001\), \(wb,\min=15.7859\) \(\text{in}\), \(wb,\max=15.7861\) \(\text{in}\), \(cb=0.27\pm0.0001\), \(cb,\max=0.2701\), \(cb,\min=0.2699\). \(Lb=47.24\pm0.0001\), \(Lb,\min=47.2399\)

4 Solid Modeling: Nose Cone
A step by step method for the solid model is presented below. Using the data obtained earlier, each point was input so that a general shape was established.

**Blade Rotor:** The drawing of the blade pitch control can be seen in Figure 7a. Once the solid model was created holes needed to be drilled from the rotor where the electronics shaft of the Blade Pitch Control part could fit into.

![Figure 7: Solid Model of Individual Fan](image1)

**Figure 7: Solid Model of Individual Fan**

![Figure 7a: Wireframe of the Blade Pitch Control](image2)

**Figure 7a: Wireframe of the Blade Pitch Control**

**Fan Blade**

**Blade Pitch Control:** First the basic profile needed to be created. Using the circle tool, two circles of radii 15.05 and 5.05 were created which represent the inner and outer diameter of the blade pitch control.

**Primary Inlet Shaft:** The final solid model of the shaft can be seen below in Figure 21.

**FINITE ELEMENT ANALYSIS**

**Nose Cone:** Now that the design process has been complete the finite element analysis for each component were performed. All parts are safe and factor of safety were calculated. The force acting on the Nose Cone is the calculated drag force of 582 lbf. And The results of the FE analysis can be seen in Figures 8 to 11. The heat flux was applied to the outer surface and the thermal conductivity of the material was gauged.

Fan Blade: It is seen in Figures 12 to 14, the stresses in the fan blade are relatively low although the maximum encounter stress is larger than that experienced by the nose cone. Overall the maximum stress that was experienced was 7.143 kpsi. Since the forces on this blade are only estimations this stress is quite considerable and close to the yield of many lighter materials. The factor of safety for the fan blade is calculated equal to 16.8.

**6. Inlet Shaft:** The shaft is used to transmit work and torque, and has six forces acting on it at different points, the forces due to the weight of the mounted components and the distributed force from its own weight. The FE analysis for the shaft was performed. The results of the FE analysis is in Figure 15 It is found safe.

7 The Final Assembly
Final assembly of the turbofan is presented below in Figs 16-19. Assembly begins with bolting the
high-pressure turbine (that closest to the combustor) to the low-pressure turbine (that furthest from the combustor). Next, the combustion chamber, fan and other components are assembled.

8. Cost Analysis

The overall cost a Turbofan Engine usually ranges on the order of millions. Due to such advanced technology, extensive testing, low tolerances and the multitude of staff working on such a project estimating a cost can be quite challenging. It is for this reason that most of the cost analysis will come from analyzing material and possibly labor costs. It was found that the largest of the material costs occur from the fan blade. Life. Life cycle cost need to be estimated.

9. Energy Estimation

9.1 Embodied Energy

| TABLE 5: Embodied Energy Estimation for Turbofan Engine |
|----------------------------------|--|--|
| Parts                        | Mass of Material (kg) | Embodied energy(MJ/kg) | Estimated Embodied Energy |
| Inlet shaft                  | 400 kg super alloy steel | 38 | 15,200 MJ |
| Nose Cone                    | 8, Al                   | 240 | 1928 MJ  |
| Blade                        | 687, Nickel based super alloy | 150 | 103050 MJ |
| Rotor Blade                  | 60 Low carbon CD steel | 35 | 2100 MJ  |
| Electronic Tube             | 1, Medium carbon steel | 38 | 38 MJ    |
| Spring Ring                  | 1, Medium carbon steel | 38 | 38 MJ    |
TABLE 6: Processing Energy estimation for Turbofan Engine

<table>
<thead>
<tr>
<th>Parts</th>
<th>Mass of Material (kg)</th>
<th>Processing energy (MJ/kg)</th>
<th>Processing Energy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inlet shaft</td>
<td>400, super alloy steel</td>
<td>4.6</td>
<td>1840 MJ</td>
</tr>
<tr>
<td>Nose Cone</td>
<td>8, Aluminum</td>
<td>2.9</td>
<td>60 MJ</td>
</tr>
<tr>
<td>Blade Rotor</td>
<td>687, Nickel based super alloy</td>
<td>4.06</td>
<td>2817 MJ</td>
</tr>
<tr>
<td>Blade Pitch</td>
<td>60 low carbon CD steel</td>
<td>5</td>
<td>300 MJ</td>
</tr>
<tr>
<td>Electronic Tube</td>
<td>1, Medium carbon steel</td>
<td>4</td>
<td>4 MJ</td>
</tr>
<tr>
<td>Spring Ring</td>
<td>1, Medium carbon steel</td>
<td>4</td>
<td>4 MJ</td>
</tr>
<tr>
<td>Fan Blade</td>
<td>205 Nickel based super alloy</td>
<td>5</td>
<td>1025 MJ</td>
</tr>
<tr>
<td>Total Processing Energy</td>
<td></td>
<td></td>
<td>6050 MJ</td>
</tr>
</tbody>
</table>

9.2 Processing Energy

This section focuses on primary shaping processes since they are generally the most energy-intensive steps of manufacture of indexing head. The process energy and CO2 per unit mass are retrieved from [5]. The processing and embodied energy per kg is retrieved from Ashby [5]. The total energy to manufacture an indexing head for milling operation is about 16335 MJ and CO2 released in atmosphere is about 800 kg. The total energy spent in manufacture of a turbofan engine is estimated here is 159154 MJ or close to 600000 kWhr.

10 Conclusion

An attempt has been to present complete design and analysis including FE analysis. The solid modeling of each components of the turbofan is based on the designed dimensions using NX 11.0. The assembly problem was mainly related to tolerances and it has to be modified again and again to get the final assembly. We have also attempted to estimate the total energy including embodied energy and processing energy. For sustainability considerations the energy estimation should be useful.

REFERENCES

Geometric Programming for Aircraft Design Optimization, Warren Hoburg, Pieter Abbeel
Integration of Sustainability into the Environmental and Civil Engineering Curriculum

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Abstract

Sustainability is a central component of Florida Gulf Coast University’s (FGCU) Vision, Mission, & Guiding Principles. FGCU prepares students, faculty, and staff to be engaged citizens and leaders of the green economy. The mission statement of FGCU promotes “innovative, student-centered teaching and learning”, “the practices of environmental sustainability”, and promotes “habits of lifelong learning and the discovery of new knowledge.” In keeping with ABET criteria, the College of Engineering has incorporated sustainability in several courses. This year the College initiated an engineering graduate program with an emphasis on renewable energy and sustainability.

Since 2010, the senior-level course in Sustainability has served as an environmental elective for the majority of Civil Engineers. Environmental and Civil engineers at FGCU share the same course sequence for the first two years; performance in the senior level Sustainability in Engineering course varies according to major even though the topics reflect a medley of infrastructure components including energy efficiency, construction, transportation and water and waste infrastructure as well as project planning, life cycle analyses and economic topics.

To address learning variations and to expand and deepen student understanding, we continue to implement project-based learning curriculum-wide that includes an emphasis on sustainability concepts. In our ongoing analysis, we use survey instruments to assess student attitudes and depth of knowledge throughout their Junior and Senior years. In the capstone Engineering Senior Design Course, sustainability in design is assessed at the end of the term for comparison to previous years. We examine ongoing survey and senior design assessment results to quantify our progress in implementing sustainability principles and practices curriculum-wide. Assessment results enable weaknesses to be identified and addressed in course modification.

1 Introduction

Florida Gulf Coast University (FGCU) is the public regional university in SW Florida founded in 1998. In its mission statement, Florida Gulf Coast University emphasizes “innovative, student-centered teaching and learning”, “promotes and practices environmental sustainability”, and promotes “habits of lifelong learning and the discovery of new knowledge.”

The FGCU U.A. Whitaker College of Engineering (WCOE) first admitted students in 2006, and now offers four Bachelor of Science majors in Bioengineering, Civil Engineering, Environmental Engineering, and Software Engineering. This year FGCU began its Master of Science in Engineering with emphasis areas in environmental engineering and renewable energy engineering.
In concert with the FGCU mission, ABET criteria require engineering programs to produce “graduates who pursue life-long learning through continuing education and/or advanced degrees in engineering or related fields. Additionally, ABET criteria requires that graduates be able “to design a system, component, or process to meet desired needs within realistic constraints such as economic, environmental, social, political, ethical, health and safety, manufacturability, and sustainability.” (ABET 2018)

At FGCU, sustainability knowledge is now recognized as an imperative and in need of application in the engineering disciplines, principally in the Civil and Environmental Engineering curriculums. The ASCE Body of Knowledge initiative and Policy Statement on sustainability (ASCE 2013) promote the ability to analyze the sustainability of engineered systems and associated natural resources. Lifelong learning is inherent in the principles of sustainability, leading to updated skills required for innovative and adaptive solutions to the problems of sustainable development (Bondehagen et al., 2016)

To prepare students for future professional practice campus-wide, FGCU has an increased focus on sustainability in engineering with driving forces present to incorporate concepts of sustainability into the undergraduate curriculum. For the past two years, FGCU has conducted a workshop “Integrating Sustainability Across the Curriculum (ISAC)”. Outcomes for this workshop include discussing options for integrating sustainability content and activities into class and designing activities and course modules that include sustainability.

The general topic of sustainability integration in specific engineering curricula is reflected in many educational studies (Oswald et al., 2014; Liu, 2014). The reported methods reflect either the vertical integration or horizontal integration of sustainability concepts. Simply requiring one or two courses on sustainability or modules within courses may not change student perception of sustainability. Problem-oriented and project-based engineering coursework applied horizontally throughout the curriculum by FGCU successfully facilitates deeper understanding of sustainable development and design concepts (Bielfeldt, 2013; El-adaway et al., 2015)

At FGCU, Environmental and Civil engineers share the same course template for the first two years including Fundamentals of Environmental Engineering. By the first semester junior year, all students will have had a first course in Environmental Engineering and Engineering Mechanics and are enrolled together in Fluid Mechanics. Environmental engineers then take courses in water, wastewater, solid and hazardous waste and air pollution control, while Civil Engineers take courses in water, geotechnical, structural and transportation topics. The senior-level course in Sustainability is required for Environmental Engineers and serves as an environmental elective for many Civil Engineers.

Upper level courses in Environmental Engineering incorporate project-based assignments that incorporate principles of sustainability (Table 1) as defined at the Sandestin Conference as the “Principles of Green Engineering” and further developed as the Principles of Sustainable Engineering (Abraham and Nguyen, 2003).

Table 2. Principles of Green Engineering

| 1. Engineer processes and products holistically, use systems analysis, and integrate environmental impact assessment tools. |
2. Conserve and improve natural ecosystems while protecting human health and well-being.

3. Use life-cycle thinking in all engineering activities

4. Ensure that all material and energy inputs and outputs are as inherently safe and benign as possible.

5. Minimize depletion of natural resources.

6. Strive to prevent waste.

7. Develop and apply engineering solutions, while being cognizant of local geography, aspirations, and cultures.

8. Create engineering solutions beyond current or dominant technologies; improve, innovate, and invent (technologies) to achieve sustainability.

9. Actively engage communities and stakeholders in development of engineering solutions

## 2 Assignments and Problems Incorporating Sustainability

In the *Sustainability in Engineering* class, students work in teams on two projects over the course of the semester. In the first project, students perform life cycle analyses of alternative energy sources and compare them with current practice. For example, they are required to assess costs, environmental and societal impacts of the use of biofuels (algal biomass, switch grass, jatropha etc.) for transportation, including aspects of land use, impacts on food production, water and fertilizer use, crop residues, and the possible implications for fueling infrastructure if these approaches become widespread.

In the second project, students preform service-learning projects aimed at understanding and improving sustainability on their own campus, again using life cycle approaches. For example, several teams have assessed water use on campus and have explored the potential for using dual flush toilets and other low-flow approaches, urine segregation, stormwater capture and re-use, and more detailed metering to improve awareness. Energy use on campus was examined with lighting inventories, building energy audits (site inspection and data analysis of energy use records), designs for more fine-grained metering, and plans for additional solar photovoltaic and solar thermal (hot water) systems utilizing rooftops, parking lots and walkways. Several of these projects were presented to university administrators and are being implemented. Additionally, students have examined waste streams on campus, addressing recycling behavior, food waste disposition (designing composting systems and anaerobic digestion systems), paper waste minimization (recycled paper content in procurement, alternatives to the use of paper towels, and implications of the use of electronic dissemination of materials for classroom use). A list of the 2018 Sustainability in Engineering topics is found in the Table 2.

<table>
<thead>
<tr>
<th>Campus Sustainability Projects 2018</th>
<th>Key ideas explored</th>
</tr>
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Table 2. Sustainability in Engineering Projects

74
<table>
<thead>
<tr>
<th>Project</th>
<th>Evaluation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carbon offsetting</td>
<td>Current climate commitment</td>
</tr>
<tr>
<td></td>
<td>Evaluation of campus energy use to determine what can be done “to move the needle.”</td>
</tr>
<tr>
<td></td>
<td>Cost comparison of various ideas normalized to $/Kg CO2</td>
</tr>
<tr>
<td></td>
<td>Price of buying carbon offsets</td>
</tr>
<tr>
<td>Redesign of food waste systems on campus to promote recycling; redesign of new “bussing” stations at food / dining locations</td>
<td>Current waste removal practices</td>
</tr>
<tr>
<td></td>
<td>Life cycle analysis of alternatives for dealing with food waste (common garbage vs. composting vs. digestion)</td>
</tr>
<tr>
<td></td>
<td>Behavioral changes vs physical changes</td>
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<tr>
<td>Conversion of campus electric golf carts to solar power</td>
<td>Current data on electricity and / or gasoline usage for campus golf cart fleet</td>
</tr>
<tr>
<td></td>
<td>Conversion costs</td>
</tr>
<tr>
<td></td>
<td>Impacts including costs, GHG etc</td>
</tr>
<tr>
<td>Expansion of a campus sustainability map: creating a storm-water layer in an ARCGIS system built during previous semesters</td>
<td>Campus Storm water system design: permeable and impermeable surfaces, gutters, drains, flows, retention ponds, and sampling and discharge points; connecting to ongoing water quality assessments.</td>
</tr>
<tr>
<td>Expansion of Solar Energy on Campus: Evaluation of rooftops, asphalt parking lots for carports, top floors of parking garages, solar powered road and walkway lighting</td>
<td>Current STARS Rating and Climate Action Plan</td>
</tr>
<tr>
<td></td>
<td>Determine costs and benefits of (1) charging stations on campus for electric vehicles (2) solar powered lighting (3) use of roof-tops including costs of retrofit installation (wind loads) (4) solar carports or covered parking.</td>
</tr>
<tr>
<td></td>
<td>Using appropriate time horizon for design</td>
</tr>
<tr>
<td></td>
<td>Promotion of “behind the meter” installation of solar: Return on Investment</td>
</tr>
<tr>
<td>Waste Minimization through improved design and placement of receptacles</td>
<td>Evaluate current recycling data; attempt to verify</td>
</tr>
<tr>
<td></td>
<td>Inventory of type and placement of receptacles</td>
</tr>
<tr>
<td></td>
<td>Consider nuisance animals: raccoons, squirrels, bears etc.</td>
</tr>
<tr>
<td></td>
<td>Design of containers; placement of containers; how containers are “serviced”</td>
</tr>
<tr>
<td>Retrofitting older buildings to LEED O&amp;M standards</td>
<td>Costs to get LEED O&amp;M; Inventory of current energy use; costs of replacement of LEDs, energy star plug loads, control systems, meters, etc.</td>
</tr>
<tr>
<td></td>
<td>ROI</td>
</tr>
<tr>
<td></td>
<td>Energy and GHG savings</td>
</tr>
<tr>
<td>Solar Hot Water for Aquatic Center, Alico Arena, Housing, new Student Rec. Ctr</td>
<td>Current water use and hot water associated heating bills</td>
</tr>
</tbody>
</table>
Building specifics: Gross square footage, Building Orientation
Solar Hot Water system design; costs; projected ROI
Impact on GHG/energy usage; ROI

In *Atmospheric Pollution* and *Hazardous Waste Management*, students also focus on campus sustainability in their semester projects outlined in Table 3

Table 3. Hazardous Waste/Atmospheric Pollution Projects

<table>
<thead>
<tr>
<th>Air Pollution/Hazardous Waste Remediation Final Projects 2017 (Spring, Fall)</th>
<th>Sustainability focus</th>
</tr>
</thead>
<tbody>
<tr>
<td>A Review of Greenhouse Gas Emission Reduction Due to Meat Production</td>
<td>Impact on carbon emissions</td>
</tr>
</tbody>
</table>
| Rocket Fuel Emissions | Toxic substances/gases generated in rocketry  
Methods to minimize pollution |
| Maritime Emissions | Analysis of air emission.  
Reduction technologies researched |
| Urban Transport | Focus on urban emissions, sustainable solutions presented. |
| Atmospheric Pollution: Wastewater Treatment | Wastewater design approaches to reduce nitrous oxide emissions |
| Stratospheric Aerosol Injections: The Theory and Potential Risks | Examination of theoretical approaches to cooling the earth via aerosols. |
| Phytoremediation to Improve Indoor Air Quality | Using plants inside and outside building to reduce pollution |
| Sustainable and Innovative Solutions for Urban Air Pollution | Remediation approaches.  
Strategies to minimize contamination at source |
| Comparison of emissions between gasoline, diesel, and biodiesel | Advantages/disadvantages of fuel sources in terms of sustainability |
| Oil, Gas Spill Remediation | Investigation of sustainable approaches to clean-up |
| In situ Bioremediation/Phytoremediation | Present research on plant remediation |
| Fracking Practices and Sustainability | Focus on engineering controls to reduce pollution |
In the capstone *Engineering Senior Design Course*, sustainability in design is assessed at the end of the current year. Table 4 lists current capstone design projects. Student perception of sustainable education at FGCU is continually surveyed with additional survey questions included in the assessment this year (Gomez et al. 2014; Watson et al. 2013). Our senior design assessment results will provide a continued view of our progress in implementing sustainability principles and practices curriculum-wide, given our current proposed strategy of incorporating concepts into several courses across the curriculum.

Table 4. Senior Capstone Design Projects

<table>
<thead>
<tr>
<th>Community Oriented Projects with a Major Sustainability Component 2017 - 2018</th>
<th>Key ideas explored</th>
</tr>
</thead>
</table>
| Sustainable alternatives for treatment of septage and portable toilet waste in SW Florida | Current practices, including transit costs and tipping fees in Tampa  
Biological Reactor Design alternatives  
Life Cycle Analysis of alternatives based on economic and energy metrics |
| Storm water mitigation alternatives for the City of Bonita Springs (post Hurricane Irma severe flooding) | Changing land use (growth and development) and changing hydrology (climate change)  
Flow modeling  
Retention systems; green stormwater infrastructure |
| Sustainable and resilient alternative energy systems for major traffic intersections working with County DOT | Energy needs assessments  
Solar power calculations  
Storage needs  
Costs |
| Green Design components for new Alumni and Community Ctr | Green building alternatives  
Costs: Capital vs. O&M  
GHG impacts  
Water impacts |
| Septic System Water Quality Impacts in Lake Okeechobee | Water Quality conditions in the lake  
Inventory of total number of Septic systems  
Proposed alternatives wastewater collection and treatment  
Cost analysis  
Impacts on nutrient loadings  
Downstream economic impacts of improved water quality |
Questions were formulated with focused literature search on survey methods (Stanikis and Katiliute 2016; Azapagic, 2005). The survey continues to assess student knowledge of sustainable practice and to identify variables including engineering major (Civil or Environmental or Dual), years of study, student interest and knowledge of environmental issues and policies.

Beginning the survey, students read the following: “We are asking for your help in learning more about the level of understanding and knowledge that undergraduate students have regarding the environment and sustainable development. The results of this survey will help us to improve the existing courses and develop new teaching programs related to this area. Please respond to the following items as honestly and carefully as possible”. Student gender and years of study are entered with the survey itself organized into the following sections: 1) Environmental Issues, 2) Environmental Legislation, Policy and Standards, 3) Environmental Tools, Technologies and Approaches, and 4) Sustainable Development.

The survey questions are listed by question. These questions are then ranked by students on a 4-point scale: 1) not heard of, 2) heard of but cannot explain, 3) have some knowledge, and 4) know a lot.

The students are also asked to rate the importance of sustainable development 1) as a person, 2) as an engineer, 3) for your country, 4) for global society and 5) for future generations. In addition, students indicate if they had any environmental education in school in general and in particular in their university courses. The survey questions specific to the importance of sustainable development are ranked on a 4-point scale as follows: 1) not important, 2) possibly important, 3) important and 4) very important.

Students in all environmental classes are invited to take the survey, including Civils enrolled in dual enrollment sections and the Sustainability in Engineering course.

4 Results and Conclusions

To date, there are 212 responses to the online survey, including students enrolled in Fundamentals of Environmental Engineering (typically taken by sophomores), Atmospheric Pollution, Hazardous Waste Remediation, Sustainability in Engineering, Wastewater Engineering and Solid Waste Management at FGCU. Surveyed fourth year students take Atmospheric Pollution, Wastewater Engineering and Sustainability in Engineering courses while third year level students surveyed are enrolled in Hazardous Waste and Solid Waste Management. The current survey differentiates response by years of study (not by student level). The following Table illustrates survey response averages.
A statistical analysis was performed to test the null hypothesis that there is no difference between the civil and environmental engineering students in surveyed overall knowledge of sustainability. Low P-values (less than 0.01) indicate that the data do not support the null hypothesis. A significant difference is found in both 2015-2017 and 2017-2018 survey results. An additional analysis comparing scores for 2015-2017 and 2017-2018 for civil students indicate that again data do not support the null hypothesis. However, doing the same comparison for environmental students supports the null hypothesis, which seems to reflect the increased exposure of environmental students to sustainability and higher scoring on the survey.

The Environmental Issues section shows consistently higher ranked responses for environmental engineering students with both majors exhibiting weak knowledge on Environmental Policy. There are weak areas present for both majors on Environmental Tools, Technologies and Approaches. Responses on sustainable development topics continue to be weak for both majors (< 3, heard of but cannot explain). However, on the final section ranking the importance of sustainable development 1) to them personally 2) as an engineer, 3) for your country, 4) for society worldwide, 5) for future generations, the average for both civil and environmental students is higher. Still, differences again manifest with environmental students scoring 3.94 and civil students scoring 3.61 over a 3-year study period. Given the continuing lower civil scores in all areas including ranking of importance of sustainability, it appears that there is a need to incorporate sustainability more effectively in additional civil engineering classes.

As evidenced by projects and completed assignments, the increased implementation of sustainability concepts and activities generally in engineering courses has promoted student critical thinking skills and awareness of challenges related to sustainable engineering practice. The application of sustainability in the capstone-engineering course has resulted in innovative projects focused on the local community.
7 References


An Electrical Engineering Design Project with a Sustainability Theme

Sampath Satti

Abstract

In recent years, there has been increased focus and effort towards engineering systems and devices that enable sustainable practices. A few visible examples are innovations in renewable energy generation and storage leading to grids based on solar energy, transportation technologies resulting in electric cars, waste reduction and management systems, among many others.

Sustainability awareness and integration is one of the key graduate attributes in the engineering curriculum of many North American universities, including the University of British Columbia (UBC). Embedding sustainability themes in engineering undergraduate design projects, therefore, is a natural intersection of the demand for engineering graduates to be sustainability-aware, as well as industry-ready. Balancing these top-down pushes towards sustainability with bottom-up pulls such as everyday observations and real-world impact provides a perfect foil. Projects with real-world impacts not only have shown to enhance students’ engagement and motivation [1], but also open the door to other sustainability awareness opportunities on campus, for example, through showcasing students’ innovations and/or implementing pilot devices based on students’ work.

Electrical Engineering Design Studio I, ELEC 291, is a second-year project-based course in the department of Electrical and Computer Engineering at UBC, involving electronic devices and microcomputers. In a section of the course, which runs intensively over the six weeks of summer, one of our objectives has been to integrate sustainability with the course curriculum by incorporating real-world sustainability topics into the course project. One example of a sustainability system that could be scaled down and implemented in an electrical engineering design course is a recycling machine. To our knowledge, such a project has not been introduced in another undergraduate electrical engineering design course before.

Industrial systems used for automated recycling and waste sorting feature robots focused on achieving high throughput. In order to integrate a real-world industry project with an undergraduate design course, careful prototyping procedure is required to ensure the feasibility of the project within the course scope and time frame. In our case, many elements of the problem statement to develop a waste-sorting robot were simplified, through fabrication and testing of individual modules, in order for the students to make tangible progress over the course duration.

Our finalized implemented project statement took the form of a simplified recycling robot, capable of detecting recycling bins around it, correctly identifying the bins based on their color, and disposing of objects into the right bin after determining the nature of objects. In this work, we will describe the project details and our prototyping procedure, discuss student results and the challenges involved, and share our thoughts on the advantages of a project topic with sustainability theme. We will then offer a few recommendations, based on insights gained.
Integration of sustainability-oriented themes into design projects is a non-trivial task. With proper planning, however, the potential of engineering design courses to expose students to real-world sustainability problems can be tapped. We believe that this framework would be suitable for catalyzing student innovations in a variety of sustainability-related topics across disciplines.
Ecological economics and engineering education

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Abstract

Humanity is on an unsustainable path. Technology can play a major role in contributing to a concept of sustainability which envisages human flourishing within ecological limits. If this is accepted, then it stands that engineering students require an education which facilitates the development not just of functional design of technological artefacts and processes, but they also need to be equipped to understand and engage with their wider implications and context. This necessarily leads one into the socio-economic domain, which it could be argued, is where the real “game-changers” to transitioning to a sustainable future lie. Consequently, as part of the formation of sustainability informed engineers, there is a clear necessity to integrate the socio-economic aspects of sustainability in order to posit technology in appropriate contextualised settings. The four-year chemical engineering degree programme at University College Cork incorporates a strong emphasis on integrating the socio-economic dimension of sustainability, including ecological economics. This paper focuses on ecological economics, and specifically how it can connect with engineering and why it is important that engineering students receive a basic grounding in ecological economics. Ecological economics is first and foremost economics; it believes in the importance of markets. However, it recognises that there are “ecological limits” within which the economy is bounded. Technology has a big role to play in moving to within ecological limits in our contemporary society, however so does economics and the social values that underpins it. Furthermore, technology’s contribution to sustainability is not just influenced by technical innovation; it is driven by the prevailing economic paradigm, because economics has a key influence on investment. Ecological economics has a strong social component to it; issues around wealth distribution, employment, income inequality and consumerism are all very much within its domain of the socio-economic disciplines. This may initially appear unimportant to engineering but actually the opposite is true. This is explored in the paper. The formation of engineers with an exposure to the tenets of ecological economics can provide a basis for genuine sustainability informed engineers with the necessary in-depth awareness of the socio-economic dimension of sustainability to demonstrate the value of context to their technical education. It is hoped that this awareness will help engineers contribute to and influence the socio-economic domain in a meaningful way, whether this be within their organisations or within broader society, so that this can hasten the application of appropriate socio-economic and engineering approaches as part of a transition to sustainability.

1 Introduction

John Ehrenfeld (Ehrenfeld & Hoffman, 2013) has nicely framed sustainability in terms of humans (and other life) be able to flourish on the Earth forever. Engineering is a technical discipline that has great scope for contributing to the sustainability of such flourishing by 1) assisting the provision of the vast variety of goods and services required to enable people to survive and flourish, and 2) developing the greener technologies and
approaches to increasing resource utilisation efficiencies and reduction of wastes / emissions that are needed to transition to within the limits of ecological systems.

Most people who study engineering do so because they like science / technology, want to earn a good living and importantly, want to contribute to the well-being of society. However, it could be argued that engineering and technology in themselves are not enough, and within the current dominant neo-classical socio-economic paradigm, technology is only moving humanity faster along an unsustainable path (Barry, 2017). Sure, technology has an important role to play in moving towards a sustainable future, however the major challenges to moving to a sustainable future may lie in the economic, social and ethical domains (McKibben, 2007, Jackson, 2009; Gilding, 2011) and engineers need to engage with and influence these domains (Byrne & Fitzpatrick, 2009). Engineers cannot just be technological “guns for hire”, and cannot just reside in isolated “tech silos”. This paper builds on a paper presented at EESD 2015 in Vancouver (Fitzpatrick, 2015) and a subsequent journal paper (Fitzpatrick, 2017) by outlining how ecological economics can help engage engineering students in the importance of the socio economic dimension and how it can influence engineering, sustainability and their lives.

![Figure 1: Engineering as practiced within the current dominant neo-classical economic paradigm (adapted from Meadows et al., 2005).](image)

2 Motivation for teaching ecological economics to engineering students

Engineering’s potential contribution to sustainability is not just influenced by technical innovation; it is highly influenced by the prevailing economics and the social values that underpin it (“money does talk”). The prevailing economics has a key influence on investment, which determines 1) which technologies get developed (R&D investment), and 2) which technologies get deployed (investment in infrastructure and operations). For example, in energy, fossil fuels dominate over cleaner energy approaches, because they are more economically favourable in the current economic system in terms of return on investment and profitability. But economic favourability is a function of socio-political policy (e.g. tariffs and supports, carbon taxes, etc.) which is in turn a function of underpinning political and societal values, and hence ethics. Developing cleaner technologies and greatly improving natural resource utilisation efficiencies are very important in the move towards a sustainable pathway. However, technological efficiency represents only one side of the coin; to constrain consumption levels within physical limits and global carrying capacity also requires inherent drivers to invert or curb consumptive growth. With this, increased efficiencies only lead to increased consumption (driven by reduced unit costs) as Jevons paradox or the rebound effect invariably
demonstrates (Herring & Sorrell, 2009). However, following the modern paradigm of competition and economic neo-Darwinian “survival of the fittest”, the result is a model of neo-classical economics which privileges technological efficiency in a way which invariably leads to a path of unsustainable consumptive growth. Thus, the application of engineering in the current socio-economic paradigm may only be producing benefits to humanity in the short-term, at best. This is unsustainable and detrimental to humanity in the longer-term, as illustrated in Figure 1.

This paper tries to highlight the importance of economic, social and ethical levers in moving towards a sustainable pathway. It could be argued that these levers are in fact the “game-changers” which underpin the emergence of such a paradigm, while they in turn have a major influence on the technical levers. Consequently, the prevailing socio-economic paradigm needs to be modified to provide a framework which facilitates and incentivises engineers to deliver technological improvements to people’s well-being in the long-term, that is, they are sustainable, as schematically illustrated in Figure 2.

![Figure 2: Moving to a sustainable socio-economic paradigm that promotes engineering which delivers technologies to enhance long-term human flourishing.](image)

The next section briefly outlines the content of ecological economics taught to undergraduate final year chemical engineering students, as a condensed four lecture series with accompanying notes as part of a module on Safety and Environmental Protection. These lectures endeavour to describe an economic system that facilitates a vision of sustainability based on human flourishing, and a corresponding economics which fundamentally and explicitly recognises planetary limits and resource regeneration capacity, and thus seeks such flourishing without resource intensive GDP based economic growth, as recognised by proponents and pioneers of ecological economics (Daly, 1996; Jackson, 2009; Dietz & O’Neill, 2013).

3 Ecological economics content: An economic system that facilitates human flourishing

Dietz & O’Neill (2013) authored an appropriate book that underpins this section, entitled “Enough is Enough – Building a Sustainable Economy in a World of Finite Resources”. Books like this have the potential to engage engineering students with economic and social levers that may have potential for moving humanity away from
its current unsustainable path. Students of the Process & Chemical Engineering programme at UCC are exposed to this book on two occasions during their degree. In the first instance, they have the opportunity of reading the book as it features on a book list for an assignment on a core third year module (“Sustainability in Process Engineering”) developed and taught by both authors, whereby students are required to read and review at least one book from the list. The book also informs a core final year module (“Safety and Environmental Protection II”) where in considering issues and drivers around industrial and corporate sustainability, students are introduced to some basic tenets of ecological economics. Students are initially told that this material is not like studying the laws of thermodynamics (though it necessarily coheres with them!); it is much less definite; it is alright for them to agree or disagree with some of the content presented as it is inherently normative and a function of values and worldviews/paradigms. The objective is to further engage them with the socio-economic dimension of sustainability, help them develop their own thinking on the importance of the socio-economic dimension and how it influences engineering and sustainability. There is only one assessment that specifically relates to ecological economics. This assessment is of the four lecture series given in the final year module (“Safety and Environmental Protection II”) and is simply through the final exam. There are three questions in the environmental part of the exam and the last question is on ecological economics. The students are told this in advance and it is hoped that this acts as an incentive to consider and study this material, and to re-inforce its importance for them as sustainability-informed engineers and global citizens.

Ecological economics is first and foremost economics and has much in common with neoclassical, in particular the fact that markets are necessary. However, its focus and premise is on an economic system that facilitates the sustainability of human flourishing within planetary limits. There are two broad elements to a sustainable economy, as illustrated in Figure 3 and outlined by Dietz & O’Neill (2013), that can facilitate the sustainability of human flourishing, namely: Environmental and Social.

3.1 Environmental

A key concept is that the size of the economy, in terms of throughputs of material, energy and information, must be kept within ecological limits. Ecological limits are described in terms of limiting mass flowrates of natural resources extracted from the natural environment and limiting mass flowrates of wastes and emissions that are discharged back to the natural environment. In many parts of the world, key natural resources are being used at rates that are unsustainable. It is estimated that currently our global society consumes over one and a
half times the earth’s regenerative capacity, and this figure continues to increase, clearly an unsustainable situation. Resource depletion is evident to various extents, across a range of areas including water, fish, forestry, land and biodiversity. Stocks are being depleted and this will eventually impact on the dependant economies at some stage in the future. Likewise, some wastes and emissions, in particular greenhouse gas emissions, are entering the environment at rates that nature cannot assimilate them, thus they have the potential to change the natural environment which may impact human well-being and nature’s ability to provide for human well-being.

As part of the fourth year module, a variety of strategies are presented to the students that could be deployed to facilitate the environmental element, most of which are obtained from Dietz & O’Neill (2013). These strategies presented to the students for reducing material throughputs include:

- Economic methods for reducing material and energy throughput.
- Reduce unnecessary consumption and consumptive growth.
- Technical approaches for reducing material and energy throughput.
- Application of economic measures to counteract the rebound effect.
- Reduce population growth / stabilise population (global population growth will most certainly continue to progressively fall over the coming decades, heading towards (or perhaps below) zero by the end of this century (UN, 2017)).

3.2 Social

Ecological economics does not just focus on the environmental element; it also has a strong social and ethical dimension to it for the following reasons:

- Ecological economics is not just ecological, it is first and foremost economics, though one which is premised on the recognition of ecological boundaries. It thus focusses on an economy that produces and provides access to necessary goods and services, especially provision of basic human needs, which enable all people to flourish.
- The goal of the economy of increasing GDP is replaced by the goal of improving quality of life.
- Economics should be inclusive to all people, and strive to distribute goods and services to all.
- The environmental dimension and social dimension are interconnected. Implementing strategies to reduce or constrain unsustainable natural material throughputs is highly influenced by social justice. If much of a population is receiving a small portion of economic income then, it is less likely to support these strategies because if you are starving then your priority is survival and you don’t have much interest in strategies for environmental protection. Furthermore, in societies with high income inequality, there is less social cohesion, worse societal physical and mental health outcomes (among all social strata), greater societal dysfunctionality and a lower tendency to work for the common good (Wilkinson and Pickett, 2009), which gives sustainability a lower priority and impedes progress in the use of socio-economic tools and engineering approaches to solving sustainability problems like climate change.

Considering the above, the social aspect focusses on providing access to goods and services that all people need to sustainably enable them to survive and flourish. Some of the strategies presented to the students that can be deployed to achieve the social aspect include:
• Reduce income inequality.
• Provision of meaningful employment for all.
• Reduce poverty.

3.3 The “next” steps – Overcoming critical barriers to transitioning to a sustainable economy

Sections 3.1 and 3.2 highlight a variety of strategies that could be implemented to achieve an economic system that facilitates sustainability of human flourishing. These strategies won’t materialise on their own and Speth (2009) referred to them as not the “next” steps but the “next next” steps. The “next” steps involve facing a number of critical barriers that must first be overcome in order to foster the further development and implementation of the strategies mentioned above.

A number of these barriers are presented to the students (Dietz & O’Neill, 2013). It is suggested that the most critical barrier is:

• **Lack of will to change and act** especially amongst the leaders within society: The lack of sufficient political will and that of other key influencers, such as business leaders and the media, is a critical barrier to change and must be overcome if progress is to be made. Politicians and business leaders, by and large, are unwilling to consider and discuss topics like the downsides of economic growth, the need for limits to materials throughput through the economy, sustainability and alternative economic strategies to attaining a sustainable economy. This is perhaps because it requires casting a cold eye over the current system and considering the prospect that nothing less than paradigmatic and transformative change may be required. It is very difficult for (economic and political) winners by the existing system to seek or promote fundamental and disruptive systemic change. Thus it is far easier for politicians and others who influence public opinion to share a common perception that economic growth equates to prosperity and progress. The dogma of the pursuit of economic growth as the number one priority appears to be common to most of the leaders with influence. Even in schools and universities, alternative economic paradigms (whose basis is ecological economics) are also largely absent from discussions and curricula. In many universities they have large economics programmes with many courses but very little if anything on ecological economics, thus limited opportunities exist for students to become acquainted with ecological economics and models of a sustainable economy. Given what’s at stake, i.e. the health of the biosphere and the well-being of humanity, politicians, business leaders and higher education need to consider and discuss alternatives to perpetual economic growth. This is a critical step toward developing and implementing the needed economic reforms for hastening the transition to a sustainable economy.

Other related barriers presented to the students include:

• **The culture of consumerism** and shifting away from it to a culture of sustainability.
• **International co-operation**: Lack of international co-operation amongst nations can act as a major barrier to a nation trying to implement sustainability orientated strategies, because if other nations are not doing something similar then the nation may be putting itself at an economic disadvantage (certainly from a neo-classical economics perspective which privileges a competitive advantage “survival of the fittest” mentality) and this will obviously impede implementation of strategies. Consequently, there is a need for international co-operation on a global level or at least amongst a
critical mass of nations (e.g. USA, China and EU) to co-operate on strategies for moving towards a sustainable paradigm.

4 Ecological economics and how it might impact on engineering students

It is not easy for engineers and engineering educators to actively engage and influence the socio-economic dimensions of sustainability, as it appears to be outside their disciplinary “silo”. Engineers somehow need to find ways of engaging with and influence these socio-economic factors, otherwise their engineering effort may only have short-term benefits and ultimately be detrimental to humanity in the longer term. Some suggestions on ways by which engineers may actively influence a move towards a sustainable economy and society are:

- Take sustainability into consideration when choosing career options post-graduation.
- Some engineers progress into roles of responsibility which enable them to contribute to important decisions within organisations. This provides them with opportunities to integrate sustainability into their contribution to the decision making process.
- Become change-leaders, like the late Ray Anderson, an engineer and industrial leader who was a pioneer in trying to incorporate sustainability into his business (Anderson, 2009).

At the end of the four lecture series on ecological economics as part of the final year module, the lecturer becomes a little sentimental and tells his students that there are a couple of things that make him cry with joy. Firstly is seeing his home team win an “All-Ireland” football championship. Secondly, and more seriously, is sometime into the future when watching television, he sees one of his former students having some real influence or making some real contribution to moving their organisation or society towards a sustainable paradigm, whether this be in the technical or socio-economic domains or both.

5 Conclusions

Engineers cannot just be technological “guns for hire” who reside in “tech silos”. Engineers cannot just leave it to other disciplines to determine the socio-economic landscape. Engineers need to contribute and have influence. Engineering education can play an important role in facilitating recognition of the need for and value of working with, learning from, and influencing other disciplines (Byrne & Mullally, 2016). Engineering education therefore, has an important “foundation” role to play in the formation of sustainability informed engineers, who acquire an in-depth awareness of the importance of the socio-economic dimension of sustainability that compliments their technical capabilities. To this end, education of engineering students in ecological economics can make a major contribution to the development of engineers with the awareness of the socio-economic dimension of sustainability. Some of these engineers, equipped with this awareness, may be able to couple this with their own innate talents that favours a move towards a sustainable direction within their own work organisations, and/or within broader society.

The modules discussed here, and the inclusion of ecological economics represents a real and explicit attempt to provide a useful intervention at a key point in the educational formation of undergraduate engineers, one which, in time may produce a valuable positive impact. It is hoped that by providing engineers with some basic tools, in particular the ability to think critically around sustainability issues and narratives that they may, over
the course of their future careers and lives, engage in a positive manner with the issues at hand, resulting in greater societal good.

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Circular Design - adventures in interdisciplinary collaboration and learning for a circular economy


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Abstract

The Circular Design (L4IDS- Learning for Innovative Design for Sustainability) project was conceived by members of the EESD network following a three-year application and development stage to secure funding under the European Union Erasmus + Knowledge Alliance scheme. The Partners include four academic institutions, four design led SMEs and four national or regional design representative bodies from Catalonia, Sweden, Netherlands and Ireland.

The goal of this Circular Design project is to support the development of skills necessary to promote sustainable production and consumption of products and services in Europe. The project falls within the Innovation, Higher Education and Business area and is aligned with European policies on the Circular Economy.

Design has a key role to play in developing innovative solutions to current local and global challenges – approaches that must consider the needs of end users and integrate sustainability criteria in processes and strategies for creating products and services.
Project Goals:

The project is leading an increase and improvement of the learning strategies of Design for Sustainability, and is identifying opportunities for sustainably designed products and services as well as business opportunities in both higher education institutions and industries in the four partner countries.

Open educational resources and training courses in Innovative Design for Sustainability are currently being co-created and targeted at academics, students and companies and industry staff.

Common goals among Circular Design partners are to train up innovative and entrepreneurial designers (and non-designers) who are capable of dealing with a transition towards Design for Sustainability as a mainstream design approach, as well as to promote cooperation and mobility with the EU’s partner countries.

The researchers involved with the project demonstrate how an interdisciplinary co-design approach to tackling ‘wicked design problems’ can develop viable sustainable product and product service systems in partnership with SMEs and students.

As this project is currently underway, this paper outlines the progress to date of the first and second interdisciplinary student internship programs held in Autumn 2017 and in Spring 2018. It also summarizes the ‘Best Practice Publication’ developed through the project and outlines the development of OER (Open Educational Resources) to support the project and for future use by SMEs and Educational Institutions.

1 Introduction and method

The Circular Design - Learning for Innovative Design for Sustainability (L4IDS) project is a three year (2016-2019) Erasmus + Knowledge Alliance financed project. The goal of the project is to promote sustainable consumption and production of products and services in Europe. This is achieved through a knowledge co-creation process and the development of training materials, through Open Educational Resources (OER), in order to teach and train students, faculty and enterprise staff of the design sector in Innovative Design for Sustainability (IDfS) strategies (Figure 1). The project is aligned with European Circular Economy policies and contributes to the realization of a more sustainable society.

The evolution of the DfS field has broadened its theoretical and practical scope over the years (Ceschin et al, 2016). While the first approaches of the early 90’s, were focusing predominantly on the technical approaches of sustainability (Adams et al, 2016), the following ones have recognized the crucial importance of the role of users, resilience of communities, and more generally of the various actors and dynamics of socio-technical systems (Joore, 2010, Joore & Brezet, 2010). This evolution has been accompanied by an increased need for human-centered design knowledge and know-how. Initial DfS approaches related to the product innovation level predominantly requiring technical knowledge and knowhow. On the other hand, more recent DfS approaches require designers to be provided with a different set of expertise. For example techniques to gather insights from users, news ways of satisfying customers and techniques to co-design with them are essential (Ceschin et al, 2016). The project presented here aims at influencing the overall
system, from the physical product to the socio-technical level.

To map the position of potentially new educational tools and methods, this research builds on the overview of previous initiatives around DfS in higher education which some of the consortium partners have been involved with researching (See section 2). By mapping these initiatives on the triangle Design for Sustainability (DfS) - Knowledge Co-Creation – Innovation we have articulated the gap which the Circular Design project aims to bridge. As a basis for this inventory, the DfS evolutionary framework has been used (see figure 2).

2 Overview of design for sustainability in higher education

The concept of sustainable design as a specialization within design, business and manufacturing is not a new one. Writers and educators such as Victor Papanek (1971) and Buckminster Fuller (1969) were advocating a change in the way we taught students how to design and look at the world in which they live. In parallel with this, many other experts (Carson, 1962, Lovelock, 1979) were highlighting the difficulties being caused by industrialization and global trade in the natural environment. Issues such as the dramatic impact of the global population on ecosystems; the strains on the global and local economic systems and the
challenges meted by social inequity were starting to be raised by scientists, economists and even designers as early as the 1960s. These are now finally accepted as real problems for today’s students and professionals and for the world as a whole. They now provide clear opportunity both to graduates and to businesses as fields in which they can provide and develop expertise with a view to mitigating past and future problems. Many of the collaborators and authors on the project have previously published research work in this area at EESD and elsewhere and this experience has proven invaluable to informing the project formation. (Dewulf K et al, 2009, de Eyto et al, 2013, Wever et al, 2015, Mulder & Segalas, 2012 & Mc Mahon et al 2008)

![Circular Design Project within the DfS evolutionary framework Published by Segalas et Al. E&PDE 2017](image)

**Figure 2.** Circular Design Project within the DfS evolutionary framework Published by Segalas et Al. E&PDE 2017

### 3 Circular Design Internships

The internship programme is being developed by the four higher education institutions in four different
EU countries, who share similarities on their approach to design education (i.e. practice-based learning in studio environment). Challenges persist in structuring of curriculum and content (e.g. duration of bachelor education, courses, trainings, access to workshops, etc.). This complicates the development of a standardised internship programme with respect to the students differing backgrounds and inclusion of the programme in existing curricula. On the other hand, the focus of the internship (i.e. sustainability and circular design) clarifies the common educational goals that help structure the internship programme. Hence, four higher education institutions agreed upon adopting a Collaborative Action Research methodology (Oja & Smulyan, 1989) through iterating the internship programme by reflecting on and building upon the previous implementation of it, and providing reflections and guidance for the subsequent internships.

The internship programme was announced in the four partner universities, calling for students of varying backgrounds that were interested in issues of sustainability and wanted to experience design for sustainability in real-life contexts. The industry collaboration, interdisciplinary nature and multi-cultural approaches of the internship were clarified in this announcement. Students applied to this internship through a portfolio, an academic reference and a short video addressing their interests in design for sustainability and their expectations from the programme. The applications were assessed according to academic and design performance, evidence of team work, interest in design for sustainability and demonstration of motivation to take part in this internship. As a result of this assessment, 10 interns from different backgrounds (i.e. Product Design, Business, Materials Science) were selected to participate. It should be noted that these participants were novice designers and accordingly the internship needed to provide two kinds of learning experience: general design practice and design for sustainability.

![Figure 3. Collaborative Action Research Framework developed in the Circular Design (LAIDS) project, indicating the internship cycles.](image)

3.1 First CD Internship program (September–December 2017):

This program took place in Limerick, Ireland over a 12-week period in the autumn of 2017 with the
collaboration of three industry partners with diverse needs, who are capable of realising projects of different scales, three different design briefs were developed which are summarized as follows:

- **Material Explorations** with *Mamukko, Kinsale*, Exploring the potentials of a reclaimed material – used fishing nets – and developing innovative solutions on reusing it along with leathercraft.
- **Retrofitting** with *OneOff, Dublin*, Designing bespoke, high-end office furniture with a take-back system and reusable products/parts/materials
- **Preventing Food Waste** with *Southern Regional Waste Management Office, Limerick*, Reimagining the food waste management in/around Limerick and develop solutions for prevention and reuse of food waste.

These projects presented three distinctly different scales in terms of circular design. The *material explorations* project focuses on the reuse/recycle of a problematic material that is discarded in oceans, contaminating the sea and endangering marine life. The purpose of the project was to explore ways of introducing this material into SME production processes thus giving it a second life. The *retrofitting* project focuses on the problem of underused, high-end furniture with valuable materials being discarded before their potential life span ends and aims to explore ways of reusing the furniture or the materials used in the furniture with the limited organizational capabilities of a design consultancy. The *preventing food waste* project identifies the issue of excessive amounts of food waste produced by citizens and the cultural implications of this issue. The project aims to intervene into existing models of discarding food waste and its waste stream to explore ways of preventing food waste in the first place.

*Figure 4. The 1st Intern Group with their Industry Collaborators at the final presentation in UL*

### 3.2 Second CD Internship program (February-April 2018):

At time of writing the second Circular Design Internship is underway in Barcelona, Spain with Student groups working again with a variety of local companies and enterprises.
• **Waste management** in municipalities with user identification technologies with [ENT](#), environment and management consultancy.

• **Selective separation of waste in the workplace.** PC Recircula, a project that promotes the circular economy in the use, purchase and responsible management of resources and waste of Universitat Politècnica de Catalunya.

• **Material innovation for urban application.** [ZICLA](#), a company that innovates with recycled products and with the management of residues.

Although the challenges of each of the projects are quite diverse, they were regarded in the scope of the Circular Economy. These projects were well-aligned to observe the implications of Circular Design at different scales and how this internship programme can train the next generation of designers to respond to the diverse challenges imposed by a Circular Economy approach. It should also be noted that the industry partners for these projects were aware of the global and local issues related to sustainability, however they needed assistance to respond to these challenges in the context of their businesses. The outcomes of this internships did not have to be applicable right away, rather these industry partners were interested in the Circular Design process and the opportunities it presented for their businesses. The enthusiasm of the industry partners is important to support the design process, and concurrently, the interns.

### 4 Best Practice Publication

The Circular Design Project consortium is currently in the final stages of developing a Best Practice Publication (BPP) for educators, SMEs and others to use as a suite of exemplars for current best practice in design for circular economy. The Case studies have been generously provided by a wide variety of industry and societal stakeholders in the partner countries that are involved with the project. By Developing the BPP as an open source platform

The Best Practice Publication in Circular Design is the first tangible outcome of the project for those not directly involved with the Internships and aims at inspiring designers and design students in the process of developing more sustainable products and services. In it you can see a selection of projects of a great variety of sectors, from furniture to food packaging, lighting, clothing or accessories, with the common characteristic of being created from a perspective of sustainability, including circular design strategies that involve improvements throughout their life cycle. The main difference of this publication with others of a similar scope is that it is more focused on the process, on the actions that were necessary and on the actors involved than on the final result of the project itself, with the aim of providing methodological tools to those who consult it, in addition to including a strong graphical load with infographics to make its reading as clear as possible.

While there are examples of case study or best practice publications within circular economy (e.g. (Bakker et al 2014, Tempelman et al, 2015 & MacArthur foundation, 2017) , the one the Circular Design project is developing:
has a focus on projects utilizing co-creation approaches,
• describes the actual processes, and not only final results,
• explicate the learnings for the stakeholders involved.

As this will be a co-design for sustainable learning processes publication, the successful learning will be more important for the inclusion of cases than the successful innovation. This is also interesting because of the fact that we are studying the combination of DfS strategies with Co Creation processes, so that the publication will showcase a methodology than combines the environmental approach with the social sciences leading to the IDfS.

By doing so, the relevance of the case descriptions for designers is hopefully maximized, and therefore the usability of the publication within the Circular Design project. It will be utilized as study material in the student exchanges, and in the training material for the Professional Development Course, and within the Open Educational Resource.

5 Conclusions to Date

The Circular Design project builds on the experiences of the undergraduate and masters’ level of learning around DfS and links it with SME needs in a CE environment. Many of the DfS programs that currently exist have a real challenge in implementing their learning within societal and industrial contexts. The multidisciplinary internships that use co-design methodologies alongside of CE strategic approaches are providing a link between stakeholders within the real economy. i.e. the SME sector and the students.

As the project is ongoing it is difficult to articulate all of the outcomes and new learnings however the reflections by participants and educators on the first two stages of the collaborative action research cycles has shown promise as students and industry participants suggest that they are developing their understanding and implementation of CE and Circular Design practices in an applied and practical manner. Turning the Theory of CE into a reality and grappling with the wicked problems that Design for a Circular Economy presents. The Project is due to conclude in 2019 so further publications of the final outputs and learnings will follow.

References


Ceschin F. and Gaziulyosy, I. 2016 Evolution of design for sustainability. From product design to design for system innovations and transitions. Design studies, 47, 118-163.


Typical frameworks for sustainable design or sustainable development emphasize pursuit of three objectives: social equity and quality of life, environmental protection and restoration, and economic viability and development. Sustainable design, in theory, seeks harmony among all three objectives. In practice, when it comes to engineering courses and curricula focused on sustainable design, is harmony or balance among the three objectives achieved? Prior studies suggested an imbalanced approach to curricular development that leaned towards environmental aspects of sustainability. In response, curricular efforts focused on social objectives and human-centered design approaches. We will use student generated definitions and concept maps from multiple years and institutions, multi-national and multi-disciplinary faculty/researcher priorities for assessing student project work, and literature review of sustainable design frameworks and research studies to expose well-developed and under-developed areas of student and faculty conceptualizations of sustainability. Using evidence from multiple research threads and both direct and indirect assessments, we have determined that the economic dimensions of sustainable design are currently underrepresented in curricular efforts and thus in students’ applications of sustainable design. We will begin to explore potential causes for and implications of this gap. In order for future engineers to make harmonious decisions, students should experience the social, environmental, and economic dimensions of sustainability and practice applying all three in an integrated manner.

1 Introduction

1.1 Systems Frameworks for Sustainability

Literature on sustainable development almost invariably includes mention of the Brundtland definition, which originated in the World Commission on Environment and Development (WCED)’s 1987 report, Our Common Future. The definition, which states that sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs, is generally viewed as the starting point for sustainable development discussions (Counsell, 1999; Selman, 1996). In the three decades since the term “sustainable development” emerged, many variations (or expansions) of the Brundtland definition have appeared in the literature, making it difficult to say that there is one common definition. Rather, sustainable development is widely accepted as a theoretical concept or end goal (Counsell, 1999). That said, most definitions recognize at a minimum three dimensions - social, environmental, and economic (e.g., Giddings et al., 2002 and Strezov et al., 2017) – that can be organized
in different ways like the triple bottom line or Venn Diagram model (Marshall & Toffel, 2004), triple top line (McDonough & Braungart, 2002), and nested dependencies or Russian doll model (Parkin *et al.*, 2003).

Many sustainability or sustainable development frameworks involve additional dimensions like the political system, technical decisions, temporal or spatial variations, etc. Other frameworks sub-divide or explore dimensional overlaps in order to define more specific objectives. For example, “social” sustainability often incorporates both intergenerational and intragenerational equity, thereby using temporal and spatial variations to further define the social dimension (Selman, 1996). As another example, environmental justice involves interactions of social and environmental systems with a spatial factor. Regardless of the specific dimensions, the different frameworks tend to emphasize systems thinking (i.e., interactions of different actors and systems at different scales) and striving to maximize positive benefits across systems while justifying inevitable trade-offs (Selman, 1996; Harris, 2000). When engineering educators shift from defining sustainability or sustainable design to identifying competences (or learning outcomes) that students should be able to demonstrate, the list of dimensions becomes much longer. For example, Lozano *et al.* (2017) identified twelve categories, each with several individual competences, for education for sustainable development. For purposes of this paper, we are using the simplified definition of balancing environmental, economic, and social dimensions when making design decisions while also acknowledging the interdependencies and interactions of multiple dimensions.

1.2 Assessing Knowledge of Sustainability Dimensions

Authors have used a variety of assessment tools to capture students’ knowledge of and/or valuation of sustainability dimensions. According to a 2017 systematic review of conference proceedings from the American Society of Engineering Education (ASEE), knowledge of sustainability is most commonly captured using student self-report surveys. In fact, over half of ASEE records that assessed students’ conceptual and/or applied sustainability knowledge used self-report surveys (indirect assessment). While such tools can provide a rough picture of student knowledge, direct assessments (e.g., qualitative coding of student definitions, concept maps, etc.) often provide a more complete picture of student understanding (Watson & Barrella, 2017).

Many summaries of student self-report surveys support that students often over-emphasize the environmental dimension while under-emphasizing the social dimension. For example, Barth & Timm (2011) indicated that a sample of German students \( n = 1000 \) demonstrated a ‘sophisticated” understanding of sustainability, although many students highly emphasized the environmental dimension. Kagawa (2007) also used a survey to show that students from the United Kingdom (UK) \( n = 1889 \) were most familiar with the environmental dimension. Even still, Tuncer (2008) reported on the results of a survey of Turkish students and showed over half supported environmental protection over economic growth.

Although reported on less frequently than indirect student surveys, several authors use direct assessments to show that student knowledge and attitudes favour the environmental dimension, while often under-emphasizing others. For instance, Segalás *et al.* (2010) scored over 500 concept maps from students at 10 different UK institutions and concluded that students (before engaging in sustainability courses) generally emphasized concepts related to natural resources and the environment and under-emphasised social concepts. More recently, Perrault & Clark (2017) analysed free-response definitions provided by students \( n = 779 \) from one of the “greenest” US institutions and found that the environment emerged as the second most frequently mentioned component (31.9%), behind “maintaining the status quo.” Further, few students
even mentioned the social or economic dimensions. Similarly, a rubric-based-assessment of Spanish graduate engineering students’ projects showed that environmental criteria scored highest, social criteria scores were mixed depending on type of project, and economic scores were low across all projects (Crespo et al., 2017). Despite efforts to broadly educate students about sustainability, gaps and imbalances seem to persist.

1.3 Paper Scope

While prior reports often discuss the over-emphasis of environmental aspects of sustainability, at the expense of social aspects, much of our prior work suggests that economic sustainability may indeed be the forgotten sustainability dimension. We will first summarize a variety of indirect and direct assessments of students’ and professionals’ knowledge and/or valuation of sustainability dimensions. Subsequently, we will use findings from our own prior work, as well as literature from other authors, to discuss the implications of under-valuing the economic dimension for engineering curricula and professional practice.

2 Summary of Prior Work

Through several studies, we have used a variety of both indirect and direct assessments to gather insights into students’ conceptual and applied knowledge of sustainability dimensions. In addition, we have recently gathered input from higher education professionals (engineering and non-engineering) on the importance of sustainability dimensions using surveys.

2.1 Student Surveys

A survey was administered to Civil and Environmental Engineering (CEE) seniors \( (n = 153) \) at a large, research-intensive institution in the southeastern United States (Watson et al., 2013b). Students reflected on both the importance for engineers to conceptually understand sustainability dimensions, as well as their own levels of conceptual knowledge. Over 80% of students indicated that it was very important for engineers to discuss environmental sustainability, while just over 60% indicated that it was very important for engineers to discuss social sustainability. Approximately 70% of students indicated that it was very important for engineers to discuss economic sustainability. Only one-third of students indicated that they were very confident in their abilities to discuss any of the three sustainability dimensions. Overall, environmental and social sustainability was most and least valued by students, respectively. However, economic sustainability was also valued less than the environmental dimension.

2.2 Student Definitions

Senior CEE students at a large, research-intensive institution in the southeastern United States \( (n = 63) \) were asked to “define sustainability in their own words” (Watson et al., 2014). Concepts and topics included in student definitions were coded according to the ten sustainability categories proposed by Segalás et al. (2010). Just over 50% of concepts and topics reflected in student definitions were related to the social dimension, while just over 40% were related to natural resources and the environment. In contrast, less than 5% of concepts and topics were related to economic sustainability. Consequently, student definitions favored social and environmental dimensions, while largely ignoring the economic dimension.
2.3 **Student Concept Maps**

Using a more direct measure of student sustainability knowledge, Watson & Barrella (2016) evaluated student concept maps from two different student populations in order to understand the impacts of a learning-cycle based sustainability module. Interestingly, pre and post concept maps for both groups reflected the environmental dimension the most and the economic dimension the least. Many students, but not all, identified “economic sustainability” as one of the pillars of sustainability, but beyond that presented fewer distinct terms and shallower hierarchies for economic compared to the other pillars. Comparing pre and post concept maps, students identified a few more distinct economic terms after completing the module but the prevalence of economic terms only increased from 11% to 12% of all terms for one group and actually decreased from 12% to 10% of all terms for the second group.

2.4 **Student Rubric Application**

A sustainable design rubric was developed and applied to CEE capstone projects \((n = 30)\) completed over 10 years at a large, research-intensive institution in the southeastern United States (Watson *et al.*, 2017). At least two experienced judges rated student projects based on their consideration of a variety of economic, environmental, and social design criteria. Application of criteria was rated using a three-point scale with “1,” “2,” and “3” representing *developing*, *competent*, and *exemplary* knowledge/skills, respectively.

Overall, students demonstrated ability to most adequately address social design criteria. In fact, only the social dimension included criteria which received an average score of “2” or higher. Specifically, *protects human health and well-being* and *addresses community and stakeholder requests* received average scores of 2.7 and 2.2, respectively (out of a possible 3 points). The environmental dimension included only one criterion which received an average score of “1” or higher. The average score for *protects natural ecosystems* was 1.7 (out of a possible 3 points). Similarly, only one criteria in the economic dimension received an average score of “1” or higher. The average score for *conducts a cost and/or cost-benefit analysis* received an average score of 1.4 (out of a possible three points). Furthermore, the average score for *conducts a cost and/or cost-benefit analysis* was substantially impacted by the fact that it was a course requirement for student teams to at least conduct a cost analysis. Consequently, the CEE seniors were most equipped to address the social dimension, while their abilities to address economic sustainability may be somewhat limited beyond traditional cost-benefit analyses (Watson *et al.*, 2017).

2.5 **Professional Assessments**

As part of a project to develop new sustainable design assessment tools, we surveyed professionals from multiple disciplines and countries in order to discern priorities among sustainable design criteria. As part of this survey, participants were asked to select and order their top ten sustainable design criteria from a list of 34 criteria organized into Environmental, Social, Economic, and Other categories (Barrella *et al.*, 2017). The percentage of participants prioritizing each criterion was ranked according to quartiles. Ultimately, each criterion was assigned a score of 1-4, depending on its quartile. Criteria ranked in the first, second, third, or fourth quartiles were assigned to categories of *Very Important*, *Important*, *Slightly Important*, or *Not Important*, respectively. In total, 55 participants fully completed the criteria ranking question with respondents representing a variety of disciplines: civil engineering (14.5%), electrical/computer engineering (9.1%), environmental engineering (16.4%), mechanical engineering (30.1%), and other engineering or non-engineering fields (29.1%).
When ranking criteria by quartiles for all participants, criteria from the Social and Environmental categories emerged as especially important, while criteria from the Economic category were less important (Table 3). Within the social category, four criteria were designated as Very Important and none were designated as Not Important. Within the environmental category, three criteria were designated as Very Important and two were designated as Not Important. Within the economic category, no criterion was designated as Very Important and three were designated as Not Important. Ultimately, the social and environmental categories contained the most Very Important criteria, while the economic category contained the most Not Important criteria.

Few economic criteria were commonly ranked as very important or important across disciplines (Table 3). All disciplinary groups (except for Other) indicated considers economic impacts of an environmental design criterion to be “very important” or “important.” Within civil engineering, only one additional economic criterion (considers affordability) was considered “very important.” Within electrical and computer engineering, no additional economic criteria were ranked above “not important.” Within environmental engineering, two additional economic criteria (demonstrates cost competitiveness or cost reduction and considers affordability) were ranked as “important.” Within mechanical engineering, one additional economic criterion (conducts a cost and/or cost-benefit analysis) was ranked as “important.”

Table 3: Professionals’ perceptions of the importance of economic sustainable design criteria (% = percent of participants ranking criterion; D: decision on importance based on quartile analysis).

<table>
<thead>
<tr>
<th></th>
<th>ALL (n = 55)</th>
<th>CIVL (n = 8)</th>
<th>ECE (n = 5)</th>
<th>ENV (n = 9)</th>
<th>MECH (n = 17)</th>
<th>OTHER (n = 16)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Consider economic impacts of enviro design criterion</td>
<td>25 (I)</td>
<td>25 (I)</td>
<td>20 (I)</td>
<td>22 (I)</td>
<td>41 (VI)</td>
<td>13 (SI)</td>
</tr>
<tr>
<td>Consider economic impacts of a social design criterion</td>
<td>11 (SI)</td>
<td>13 (SI)</td>
<td>0 (NI)</td>
<td>11 (NI)</td>
<td>18 (SI)</td>
<td>6 (SI)</td>
</tr>
<tr>
<td>Conduct a cost and/or cost-benefit analysis</td>
<td>13 (SI)</td>
<td>0 (NI)</td>
<td>0 (NI)</td>
<td>11 (NI)</td>
<td>24 (I)</td>
<td>13 (SI)</td>
</tr>
<tr>
<td>Demonstrates cost competitiveness or cost reduction</td>
<td>4 (NI)</td>
<td>0 (NI)</td>
<td>0 (NI)</td>
<td>22 (I)</td>
<td>0 (NI)</td>
<td>0 (NI)</td>
</tr>
<tr>
<td>Stimulates labor/jobs</td>
<td>0 (NI)</td>
<td>0 (NI)</td>
<td>0 (NI)</td>
<td>0 (NI)</td>
<td>0 (NI)</td>
<td>0 (NI)</td>
</tr>
<tr>
<td>Considers affordability</td>
<td>18 (I)</td>
<td>50 (VI)</td>
<td>0 (NI)</td>
<td>22 (I)</td>
<td>18 (SI)</td>
<td>6 (SI)</td>
</tr>
<tr>
<td>Promotes low-carbon economy</td>
<td>4 (NI)</td>
<td>0 (NI)</td>
<td>0 (NI)</td>
<td>11 (NI)</td>
<td>6 (NI)</td>
<td>0 (NI)</td>
</tr>
</tbody>
</table>

1^{1\text{st}} \text{quartile} = \text{Not Important (NI)}, 2^{\text{nd}} \text{quartile} = \text{Slightly Important (SI)}, 3^{\text{rd}} \text{quartile} = \text{Important (I)}, 4^{\text{th}} \text{quartile} = \text{Very Important (VI)}.

3 Discussion

Which sustainability dimension is the least emphasized by students and professionals? Synthesizing findings from our five prior studies reveals that the economic dimension is by far the most under-emphasized dimension among students and professionals (Table 4). In fact, economic sustainability was least valued and/or applied in four out of five of our previous assessments. Furthermore, the economic dimension was not most valued/applied in any of our previous assessments. Recently, a few other researchers have also identified the economic gap in students’ sustainability knowledge and applications (e.g., Crespo et al., 2017).
Table 4: Summary of valuation and/or application of environmental, social, and economic sustainability dimensions among students and professionals.

<table>
<thead>
<tr>
<th>Assessment</th>
<th>Sample</th>
<th>Environmental</th>
<th>Social</th>
<th>Economic</th>
</tr>
</thead>
<tbody>
<tr>
<td>Self-Report Knowledge Survey (Students)</td>
<td>153 CEE students at a US research institution</td>
<td>~80% students reported as very important; ~30% confident in abilities</td>
<td>~60% students reported as very important; ~30% confident in abilities</td>
<td>~70% students reported as very important; ~30% confident in abilities</td>
</tr>
<tr>
<td>Coding of Student Definitions (Students)</td>
<td>63 CEE students at a US research institution</td>
<td>~50% of concepts in student definitions</td>
<td>~40% of concepts in student definitions</td>
<td>&lt;5% of concepts in student definitions</td>
</tr>
<tr>
<td>Concept Maps (Students)</td>
<td>72 CEE students at US research institution &amp; 89 EGR students at US comprehensive university</td>
<td>35% and 32% of concepts in final concept maps from two institutions</td>
<td>19% and 27% of concepts in final concept maps from two institutions</td>
<td>12% and 10% of concepts in final concept maps from two institutions</td>
</tr>
<tr>
<td>Assessment of Student Projects using Rubric (Students)</td>
<td>30 CEE projects at a US research institution</td>
<td>One criterion received average score above 1 on a 3-point scale</td>
<td>Two criteria received average score above 2 on a 3-point scale</td>
<td>One criterion received average score above 1 on 3-point scale (course requirement)</td>
</tr>
<tr>
<td>Survey of Professionals' Perspectives</td>
<td>55 professionals from various disciplines</td>
<td>Three “very important” criteria; Two “not important” criteria</td>
<td>Four “very important” criteria; Zero “not important” criteria</td>
<td>Zero “very important” criteria; Three “not important” criteria</td>
</tr>
</tbody>
</table>

*green = most valued/applied; yellow = moderately valued/applied; red = least valued/applied

**Why do students under-emphasize the economic dimension of sustainability?** One hypothesis explaining the under-emphasis of economic sustainability by engineering students is that educators themselves do not consider economic factors to be as fundamental to sustainable design as environmental and social factors or are less comfortable teaching economic decision-making to engineering students. Indeed, our survey of educational professionals supports that representatives from few disciplines found economic design criteria to be very important (Table 3).

**What are the implications of under-emphasis of economic sustainability by educational professionals on engineering curricula?** Under-emphasis of economic sustainability by educational professionals may contribute to development of engineering curricula that do not prepare students to address economic factors during sustainable design. For instance, a content analysis of CEE course syllabi from the US research-intensive intuition where many of our assessments were conducted (Table 4) showed that only 12% of sustainability content was related to the economic dimension (Watson et al., 2013a). Using the same content analysis framework, Lozano & Lozano (2014) show content for a degree in Engineering for Sustainable Development to be more balanced among the economic, environmental, social, and cross-cutting aspects of sustainability. Consequently, it is possible that under-emphasis of economic sustainability among curricular designers may lead to a similar imbalance in disciplinary engineering curricula. This is problematic, given that training of sustainable engineers likely requires more balanced presentation of sustainability dimensions.

**What are the professional implications of engineering curricula and future professionals that under-emphasize economic sustainability?** Those who do not understand economic sustainability may come to the conclusion that sustainable designs are more costly than traditional designs. In the context of sustainable buildings, one report showed that 1400 professionals believed the cost of green buildings to be 300% higher than their true cost (which is typically only 5% more than traditional construction costs) (Sisson & Van...
Misunderstanding the economic implications of sustainable design may be problematic, since most engineers base design decisions on cost feasibility. Consequently, if students (as future professionals) continue to hold the same economic misconceptions as current practitioners, sustainable designs may be seldom implemented. Given a growing emphasis on entrepreneurship in higher education in the United States and other countries and economic initiatives by global organizations like MacArthur Foundation, it seems imperative that engineering students learn about the economic or financial factors for project feasibility and be able to defend a business case for sustainable design.

How should these results impact our practice? At our own institutions, the consistent results from across studies, indicate a need to incorporate lessons on engineering economy, economic development, and entrepreneurial thinking early in the curriculum, as part of cornerstone projects or problem sets, so that students learn the foundational concepts and vocabulary. We can then continue to scaffold student learning toward a capstone or other significant project that requires students to conduct more complex economic analysis and evaluate trade-offs with technical, social, and environmental objectives. Course learning objectives and assessments need to explicitly incorporate economic dimensions in order to reinforce the importance of weighing technical, social, environmental, and economic aspects of engineering decisions. For example, despite the low value placed on economic criteria by professionals in the survey results, a future sustainable design rubric will require projects to demonstrate economic evaluation and trade-offs.

Acknowledgement

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EDINSOST is a Spanish R&D+I funded project. The objective of the EDINSOST project is to facilitate the training of graduates capable of leading the resolution of challenges in our society through the integration of sustainability training in the Spanish University System. The project focuses in engineering degrees, given their great impact of engineering graduates on the short-term, and education degrees, in view of its multiplier and long-term effect, because graduates from these courses will be the future teachers of new generations of citizens. The project is organized around four specific objectives:

1) To define the Sustainability Competency Map of each of the participating degrees and establish a framework for incorporating the map into the degree in a holistic way;
2) To validate different didactic strategies for addressing sustainability from a constructivist and community pedagogical approach;
3) To diagnose the status of the sustainability training needs of the teachers of each degree, as well as to develop and test training proposals and
4) To diagnose the sustainability competency level of current university students and to develop and test training proposals.

The EDINSOST project involves fifty-five researchers from ten Spanish and Catalan Universities. This paper presents the results of the project in the field of engineering education. In relation to the first objective it has been defined a sustainability competency map. Based on this map, the most appropriate didactic strategies for sustainability training are been analyzed and tested, the state of the sustainability training requirements in teachers and students are diagnosed, and finally, proposals will be made for training both groups. In this paper, the objectives of the EDINSOST project are presented, as well as early results: the sustainability competence map for engineering degrees, faculty capability and training needs to teach students according to the competence map.

10 Introduction

Sustainability issues are widely recognized as wicked problems (Yearworth, 2016), which should not be regarded as problems to be solved, but rather as conditions to be managed. A general agreement exists about the need to reform the scientific expertise required to deal with sustainability challenges by developing new ways of knowledge production and decision-making. In that sense, Stephen Sterling (2005) maintains that the nature of sustainability requires a fundamental change in epistemology, and therefore in education. As regards technological education, the experience here presented aims at graduating engineers with the
competences stated by the Barcelona Declaration (2004), approved during the Engineering Education for Sustainable Development Conference in 2004.

11 The EDINSOST project

EDINSOST is the acronym for the project "Education and social innovation for sustainability. The training in Spanish Universities of professionals as agents of change to face the challenges of society". The project is funded by the "Spanish Program for Research Facing the Challenges of Society" over the period September 2016 to August 2019.

Fifteen degree courses in the fields of education and engineering are involved in the project. These degrees are taught in ten Spanish Universities (Universidad Autónoma de Madrid, Universidad de Cádiz, Universidad Camilo José Cela, Universidad de Cordoba, Universitat de Girona, Universitat Internacional de Catalunya, Universitat Politècnica de Catalunya, Universidad Politécnica de Madrid, Universidad de Sevilla and Universidad de Salamanca). Fifty-five researchers belonging to the research team and the work team are engaged in the project. The ten universities work on sustainability within the framework of the Sustainability Commission on Sustainability (SCS) of the Conference of Presidents of Spanish Universities.

The EDINSOST research methodology adopts an interpretive approach employing both quantitative and qualitative techniques. The work is carried out in different degree courses at three levels of incidence:

- Six Bachelor engineering degrees and one Bachelor Degree with significant implication in short-term social challenges: the Bachelor degrees in Mechanical Engineering, Design Engineering, Electrical Engineering, Informatics Engineering, Chemical Engineering and Architecture.
- Three degrees related to the three dimensions of sustainability (environmental, social and economic): the Bachelor degree in Environmental Sciences, the Master degree in Science and Technologies of Sustainability and the Bachelor degree in Administration and Business Management.
- Finally, and in view of their multiplier and long-term effect, the project is working on five education degree courses, given that such graduates will be the future teachers of the new generations of citizens: Bachelor degree in Early Childhood Education, Bachelor degree in Primary Education, Bachelor degree in Pedagogy, Bachelor degree in Social Education, Master degree in Secondary Teacher Training and Inter University Master Degree in Environmental Education.

The EDINSOST project has the following four specific objectives:

- Objective 1 (O1): To define the Sustainability Competency Map of each of the participating degrees and establish a framework for incorporating the map into the degree in a holistic way;
- Objective 2 (O2): To validate different didactic strategies for addressing sustainability from a constructivist and community pedagogical approach;
- Objective 3 (O3): To diagnose the status of the training needs, in terms of sustainability, of the teachers of each degree, as well as to develop and test training proposals;
- Objective 4 (O4): To diagnose the sustainability competency level of current university students and to develop and test training proposals.
The scope of this paper is limited to the results in the engineering education degrees in February 2018: Objective 1: Sustainability competency Map and Objective 3 Diagnose of the statute of engineering faculty in relation to the competency map. The results generated by the project will be transferred to other universities nationally through the SCS, and to other universities internationally through its diffusion and transferability plan. An Education in Sustainability observatory will be established to carry out this dissemination.

12 Sustainability Competency map.

The SCS (CADEP-CRUE, 2012) identified four sustainability-related competencies to be developed for inclusion of the ESD in the curriculum.

- C1: Critical contextualization of knowledge by establishing interrelations with social, economic, environmental, local and/or global problems.
- C2: Sustainable use of resources and prevention of negative impacts on the natural and social environment.
- C3: Participation in community processes that promote sustainability.
- C4: Application of ethical principles related to the values of sustainability in personal and professional behavior.

Around those competences and based on previous experiences in developing sustainability competency maps the Sustainability Competency Map for Engineering Degrees was developed (Table 1). This map shows the definition of learning outcomes at three domain levels for each of the competency units.

The Sustainability Competency Map of engineering Degrees defines the learning outcomes in sustainability for students when graduating. Subjects must set realistic goals to achieve these learning outcomes, and these objectives must be developed in different subjects for the entire map to be covered. One of the greatest challenges to the achievement of this objective is the lack of adequate training for teachers in sustainability. The Sustainability Competency Map helps to correct this problem, since it clearly defines the aspects in which teachers must be trained. Objective O3 of the project is aimed at identifying these teacher-training needs. Furthermore, teachers also need help in using the most appropriate educational strategies to achieve the learning outcomes. The purpose of Objective O2 is to define those strategies. The Objectives O3 and O4 are just focused on developing training proposals for teachers and students, including the corresponding rubrics for competences’ assessment. On the EDINSOST project, experts on pedagogy are discussing about the final format of the assessment of the learning outcomes.

With regard to Objective O1, one of the most important results is that the Sustainability Competency Maps developed may easily be adapted to any degree in the university system. This observation may be verified by the fact that the five Engineering degrees involved in the project (Mechanics, Design, Electrical, Informatics and Chemistry), as well as the Bachelor Degrees in Architecture, Environmental Sciences and Administration and Business Management, make up a map based on the one presented in this paper (with very few differences between them, except those related to the specificity of each degree).
Table 5: Sustainability competency map for undergraduate engineering education. (adapted from Fermin et al, 2018)

<table>
<thead>
<tr>
<th>C</th>
<th>Competency unit</th>
<th>Domain levels (according to simplified Miller Pyramid )</th>
</tr>
</thead>
</table>
| C1 | Has a historical perspective (state of the art) and understands social, economic and environmental problems, both locally and globally. | **1. KNOW**知悉主要原因、后果和解决方案，以及它们在社会、经济和/or环境问题中的影响，无论是本地还是全球的。  
**2. KNOW HOW**分析不同维度的可持续性，以解决与工程相关的具体问题。  
**3. DEMONSTRATED + DO**识别主要的原因和后果，一项产品或服务对工程的可持续性可能产生影响，并能够将它们与之前应用的已知问题和解决方案联系起来。  
**C1**  
- 有历史背景（现状）并理解社会、经济和/or环境问题，无论是本地还是全球的。  
- 知道关于社会、经济和/or环境问题的主要原因、后果和解决方案的文献。  
- 分析解决与工程相关问题的可持续性不同维度。  
- 识别一项产品或服务对工程的可持续性可能产生影响的主要原因和后果，并能够将它们与之前应用的已知问题和解决方案联系起来。 |
| C2 | Takes into account sustainability in his/her work as an engineer.                | **1. KNOW**了解产品和服务的生命周期以及与工程相关的技术支持。了解工程在可持续性中的战略性作用。了解社会正义、资源回收和循环经济的概念。了解社会经济的概念，合作 vs 竞争的优势。了解为共同利益而经济的原则。  
**2. KNOW HOW**能够评估不同产品和服务对社会和可持续性的影响力。了解如何通过使用创新手法来评估工程项目的经济可行性，与环境和社会可持续性兼容。  
**3. DEMONSTRATED + DO**通过项目和工程解决方案所带来的环境影响。包括在项目中指标来估算/测量使用资源对环境的影响（例如：能量消耗、污染物排放、资源消耗等）。  
**C2**  
- 在其工程工作中考虑可持续性。  
- 了解产品和服务的生命周期以及与工程相关的技术支持。了解工程在可持续性中的战略性作用。了解社会正义、资源回收和循环经济的概念。了解社会经济的概念，合作 vs 竞争的优势。了解为共同利益而经济的原则。  
- 能够评估不同产品和服务对社会和可持续性的影响力。了解如何通过使用创新手法来评估工程项目的经济可行性，与环境和社会可持续性兼容。  
- 通过项目和工程解决方案所带来的环境影响。包括在项目中指标来估算/测量使用资源对环境的影响（例如：能量消耗、污染物排放、资源消耗等）。 |

Calculates the ecological footprint of an Engineering project.
<table>
<thead>
<tr>
<th>Takes into account the social impact of his/her work as an engineer.</th>
<th>Knows the problems associated with accessibility, ergonomics and safety of products and projects of the Engineering. Knows the problems associated with social justice, equity, diversity and transparency (gender perspective, needs of the most vulnerable groups, strategies against corruption, etc.). Knows the direct and indirect consequences that the products and services related to the Engineering have on the society.</th>
<th>Knows how to assess the degree of accessibility, ergonomic quality, the level of safety and the impact on society of a product or service related to the Engineering. Takes into account the rights of people in their work as an engineer. Understands the need to introduce social justice, equity, diversity, transparency (gender perspective, needs of the most vulnerable groups, anti-corruption, etc.) in projects of the Engineering. Can assess whether an engineering project contributes to improving the common good of society.</th>
<th>Takes into account the aspects of accessibility, ergonomics and security in technological solutions. Takes into account social justice, equity, diversity and transparency (gender perspective, needs of vulnerable groups, combating inequality and corruption, etc.) in his/her projects. Includes in his/her projects indicators to estimate / measure how they improve the common good of society. Is able to maximize the positive impact of his/her professional activity on society. Is capable of designing projects that contribute to improve the common good of society.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Is capable of successfully carrying out the economic management of a project of the Engineering.</td>
<td>Knows basic concepts about organizations. Knows the fundamental points of a business plan. Knows the process of managing a project. Knows project-planning techniques.</td>
<td>Understands the different economic parts of a project: amortizations, fixed costs, variable costs, etc. Analyses real planning cases and project budgets.</td>
<td>Is able to plan an Engineering project (both short and long term) and to prepare a complete budget based on the material and human resources required. Is able to follow economic development of a project and detect deviations from the initial planning. Is capable of carrying out the economic management of a technological project throughout its useful life.</td>
</tr>
<tr>
<td>C3 Identifies when the sustainability of a project can be improved if it is done through community collaborative work. Responsibly performs collaborative work related to sustainability.</td>
<td>Knows the concept of community collaborative work and its implications in the transformation of society. Knows examples of projects that have been successfully implemented with community collaborative work in the field of the Engineering. Knows the tools of collaborative work in the field of the Engineering.</td>
<td>Given a project in the field of the Engineering, that includes a collaborative community work, is able to assess the implications of such work in the sustainability of the project.</td>
<td>Knows how to use collaborative work tools related to Engineering projects.</td>
</tr>
<tr>
<td>C4 Behaves according to the deontological principles related to sustainability.</td>
<td>Knows the deontological principles related to sustainability. He is aware that there are laws and regulations related to sustainability in his professional field. Knows the concept of social and corporate responsibility in general and its possibilities and limitations.</td>
<td>Is able to assess the implications of the deontological principles related to sustainability in a project in the field of the Engineering.</td>
<td>Does not make decisions that contradict the deontological principles related to sustainability. Is capable of proposing solutions and strategies to promote projects in the field of the Engineering, consistent with these principles.</td>
</tr>
</tbody>
</table>
13 Training needs of Engineering Faculty.

In order to evaluate the training needs of Engineering faculty a questionnaire has been validated. The questionnaire evaluates three dimensions of the teaching-learning: competences of the faculty in relation to the competency map (21 questions), pedagogical approaches (20 questions), and teaching practice (8 questions). This paper present the results in the competency dimension.

The questionnaire has been applied to the University of Cordova (faculty population: 211; sample: 26; participation: 12%), Universidad Politécnica de Madrid (faculty population: 2919; sample: 182; participation: 6%) and Universitat Politècnica de Catalunya (faculty population: 3056; sample: 322; participation: 11%) with an overall faculty population of 5196, a sample of 530 questionnaires and a participation rate of 9%.

The questionnaire uses a Likert scale of four levels (Totally disagree, Quite disagree, Quite agree and Totally agree) to statements related to each of the four competences and competency units and evaluating the three levels of the competency. (See example in figure 1)

Figure 5: Example of question. Question related to Competence 4 of the competency map.
We are still on the process of analyzing all statistical data. The first results show that most of the surveyed (63%) agree with the statements, therefore they master to a certain extent the competencies, however there is still a 37% of the surveyed that show disagreement with the statements so there is a clear need of training for that sample. The analysis by competences shows (see figure 2) that competence C1 (Critical contextualization of knowledge by establishing interrelations with social, economic, environmental, local and/or global problems) is the most mastered (71% of agreement). The analysis also shows that the competence C2 (Sustainable use of resources and prevention of negative impacts on the natural and social environment), with a 38% of disagreement, is the least mastered.

![Agreement with the statement of the Competence](image)

**Figure 2:** Results of the faculty assessment in relation to the four sustainability competences evaluated.

## 14 Conclusions

In this paper, the Sustainability Competency Map for engineering degrees, as the initial result of the EDINSOST project, is presented. The map may easily be adapted to any engineering degree.

While a general agreement exists about the importance of sustainability in today's world, and given the need to include it as professional competency for university graduates, sustainability is also one of the most difficult competencies to address in engineering studies, especially if it is holistically approached throughout the curriculum. A tool such as a Sustainability Competency Map, that is easily adaptable to any degree, may prove to be of great help for curriculum designers. The Sustainability Competency Map will enable teacher-training needs, as well as the didactic teaching strategies enabling educators to train their students in sustainability, to be defined, thereby providing them with the competencies defined at the 2004 Education in Sustainable Development Conference.

The analysis of engineering faculty in relation to the competency map shows that there is still around 40% of the faculty members that need training in relation to the sustainability competences analyzed. However we should take into account that only 9% of the faculty answered the questionnaire which we can assume they are the most concerned about
sustainability education and are going to be easily involved in the training. There is still need to analyze the other 91% of
the faculty members and diagnose their concerns and training needs.

Over the next two years, the EDINSOST project will continue working on the O2, O3 and O4 objectives, for which the
Sustainability Competency Map obtained in Objective O1 and faculty assessment are used as a starting point.

15 Future work

As regards Objective O1, the next step is to compare the curricula of the degrees analyzed in the project with the
competency maps introduced herein. From this diagnosis, suggestions for improvements in each degree curriculum will
be made to the Spanish accreditation agencies and CSC. The different educational strategies for addressing sustainability,
that must therefore be validated in Objective O2, are currently being analyzed by considering each of the competency
units of the map and each of the learning outcomes. With regard to Objectives O3 and O4, we are now analyzing the
questionnaires of faculty and collecting questionnaires from students. Questionnaires have been designed in accordance
to the Sustainability Competency Map. Questionnaires will be surveyed the second semester of 2017 and the first semester
of 2018. As a result of the diagnosis, training action plans and educational resources will be developed for both faculty
(Objective O3) and students (Objective O4).

Acknowledgments

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Testing Effectiveness of a Proposed Template for Supporting Multidisciplinary Research Communication in the Engineering Field

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Abstract

A big trend in higher education is the emphasis being placed on multidisciplinary research. Researchers are being encouraged to communicate across disciplinary boundaries. However, the multitude of information obtained through research activity brings difficulties especially when solving complicated research problems with expertise from multiple different fields. This paper describes a novel research communication template based on two research stages got from the TRIZ concept which states that a problem is a conflict of parameters. The template was tested through evaluation of five research abstracts from engineering students. The authors concluded that the research communication template is effective on the basis of the observation of the evaluation results.

1 Research Background

Research in higher education is increasingly shifting towards multidisciplinary research with researchers being encouraged to communicate across disciplinary boundaries. Efforts such as the reorganization of departments and changes to curricula, as well as other efforts aimed at creating environments where students can have access to broader knowledge (Taya et al., 2006) all point at a shift towards multidisciplinary engineering education. However, while this should be welcomed, solving complicated research problems through utilization of expertise in multiple different fields is difficult. Even within the engineering, as shown in Fig. 1-(a), there exists a big wall between various engineering fields. For example research viewpoints, terminology used and even the existing research culture, make multidisciplinary research communication more complicated (Imai et al., 2017).

In addition to the difference in disciplinary culture, there is also a multitude of information obtained through research activity which poses problems when communicating across disciplines. Researchers usually experience a complicated research journey, through trial and error, going from a research problem to its solution as shown in Fig.1-(b). This complicated maze like process often leads researchers to lose clarity when trying to describe their research purpose. It also hinders the interaction and sharing of potential solutions through the collaboration across various engineering fields.

The following sections introduce the development of research communication templates based on two research stages got from the TRIZ concept which states that a problem is a conflict of parameters. The the template is tested through evaluation of five research abstracts from students in engineering fields.
2 Abstraction of Engineering Research using the Functional Analysis Approach

The authors have recognized that the concept of functional analysis, which is a part of TRIZ, can be an effective tool that researchers in engineering can utilize for sharing information across disciplines. So far, the authors have attempted to develop a research communication framework using concepts from TRIZ (Theory of Inventive Problem Solving) and applied it to the training course on academic writing (Nishiyama et al., 2017), as well as at international workshops where multidisciplinary research communication is encouraged.

TRIZ is a methodology specialized in problem solving developed by Altshuller, a Soviet patent officer in the middle of 20th century (Mann, 2002). Altshuller and his fellows analyzed more than 2 million patents and concluded that patents on all technologies have solved conflicts without compromising.

The conflict mentioned here refers to a state shown in Fig. 2 where one parameter deteriorates when one is trying to improve another parameter. For example, when attempting to improve the fuel efficiency of a car, one may consider lowering the thickness of body parts. However, such a measure would expose drivers to the higher risk of fatal accidents.

Needless to say, papers and patents are recognized as the main achievements in engineering laboratories. New knowledge in patents is usually based on contents of published papers. So, one can assume that the ultimate purpose of research in engineering is solving the conflicts mentioned above.

Based on the above, the discussion in this paper abstractly defines research in the engineering fields from the functional analysis viewpoint as the process of developing a “New Engineering System” that solves the
conflict in an existing engineering system.

Fig. 3 illustrates the abstract definition of a problem state and ultimate ideal solution in an engineering research. A “Conventional Engineering System” generates a “Positive Effect”, a functionality needed by human beings, but it inevitably also generates a “Negative Effect”. A research in the field of engineering is aimed at proposing a solution by developing a “New Engineering System” without the “Negative Effect”.

The term "Engineering System", here, defines a mechanism for generating a specific function through the interaction of the system elements within a certain boundary (Fey, 2005).

![Figure 3: Definition of a problem state and ultimate ideal situation in an engineering research](image)

3 Two Research Stages and Question Based Research Communication Template

In general, the expertise required in different fields of engineering differs. However, the assumption that a research in engineering ultimately seeks the solution of conflict as shown in Fig. 4 allows researchers to share a limited number of research patterns across engineering fields.

The authors, so far, recognized two research stages. Stage 1 attempts to clarify the generation mechanism of “Negative Effect” in an “Engineering System”. Stage 2 attempts to develop and verifying a new engineering system, through discussion with researchers in the engineering field. Both the two stages have the common problem situation. The “Conventional engineering” system is used to obtain a “Positive Effects” for human beings, however, it inevitably generates “Negative Effect”. Here, “to verify” refers to the ascertainment of the sufficiency of the “Positive Effect” and the successful reduction of the “Negative Effect”. Similarly, “to clarify the generation mechanism” means to breakdown a system into more detailed components and specify their interactions.

The information elements for effective research descriptions are defined by exploiting the concept of abstract definition of a problem illustrated in Fig.4. The following sections briefly describes the flow of the research story of stage 1 and 2. Table 1 is a question-based template for research communication which identifies the essential research information elements. A researcher may organize his or her research information simply by answering the checked questions after selecting own research stage.

Table 1: Question based research communication template

<table>
<thead>
<tr>
<th>Questions</th>
<th>Stage 1</th>
<th>Stage 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>1  What is “Conventional Engineering System” of your research interest?</td>
<td>✔️</td>
<td>✔️</td>
</tr>
<tr>
<td>(Notation, or concise explanation)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2  What is “Positive Effect” obtained from “Conventional Engineering System”?</td>
<td>✔️</td>
<td>✔️</td>
</tr>
<tr>
<td>(Notation, or concise explanation)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Stage 1. Clarifying a Mechanism of “Negative Effect” Generation

The generation mechanism of “Negative Effect” is considered to be unknown. The research aims to clarify the generation mechanism of “Negative Effect” from “Engineering System” to propose “New Engineering System” as its solution. The hypothesis of generation mechanism of “Negative Effect” is developed, then it is verified using specific apparatus. Future work from this stage may involve moving on to Stage 2 to realize “New Engineering System” proposed with the research findings, or to clarify the remaining unknown generation mechanism of the “Negative Effect” focusing on the point that has not been completed in the initial research.

Stage 2. Developing and Verifying “New Engineering System”

Previous works clarified the generation mechanism of “Negative Effect” and proposed “New Engineering System”. However, it is unknown whether it satisfies the required performance. The research aims to
develop and verify the “New Engineering System”. The prototype of “New Engineering System” is developed and operated to prove generation of sufficient “Positive Effect” and less “Negative Effect” compared to the “Conventional Engineering System”. Future work may be to clarify the generation mechanism of “New Negative Effect” found through this research stage.

4 Methodology for Testing the Research Communication Template

samples of research abstract were written and evaluated by engineering students to test the template. One abstract sample is designed strictly following the template shown in Table 1, while the other four samples were research abstracts written by students in engineering fields. Students in engineering fields voluntary evaluated the understandability of these samples by selecting one of the five options: “Clear”, “Somewhat clear”, “Neither clear nor unclear”, “Somewhat unclear” and “Unclear”.

An abstract sample of research in Stage 2, was developed strictly following the research communication template of Table 1. The research abstract sample is shown below together with its content inserted into Table 2 to demonstrate important information elements in the sample for each of the question items from Table 1.

Sample 1: Drones are used for various applications such as transportation of goods under remote control, aerial photographing, spraying of agricultural chemicals and others. Recently, cooperation of multiple drones is expected for more advanced applications including creation of a three-dimensional map and far-field observation with high resolution. However, coordinating and operating multiple drones, power consumption variations among the drones become a significant problem after a certain period of time. Although the operator manually could adjust the operation fluctuations of the drones caused by the power consumption variations, it requires operators to have higher operation skills and burden on them. This research aims to develop an autonomous control system of multiple drones with constant monitoring of power consumption variations of drones by applying newly invented indicators. The experiment with actual machines proved that the burden on the operator was lower and operation time was longer than the conventional operation methodology.

<table>
<thead>
<tr>
<th>Questions</th>
<th>Answers (Information elements)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 What is “Conventional Engineering System” of your research interest? (Notation, or concise explanation)</td>
<td>Cooperation of multiple drones</td>
</tr>
<tr>
<td>2 What is “Positive Effect” obtained from “Conventional Engineering System”? (Notation, or concise explanation)</td>
<td>Drones are used for various applications such as transportation of goods under remote control, aerial photographing, spraying of agricultural chemicals and others. It is expected for more advanced applications including creation of a three-dimensional map and far-field observation with high resolution.</td>
</tr>
<tr>
<td>3 Explain the reason why “Positive Effect” is recognized as positive? (How “Positive Effect” influences human beings?)</td>
<td></td>
</tr>
<tr>
<td>4 How “Conventional Engineering System” generates “Positive Effect”?</td>
<td>Coordinating and operating multiple drones</td>
</tr>
<tr>
<td>5 What is “Negative Effect” generated from “Conventional Engineering System”? (Notation, or concise explanation)</td>
<td>Power consumption variations among the drones become a significant problem after a certain period of time</td>
</tr>
<tr>
<td>6 Explain the reason why “Negative Effect” is recognized as negative? (How “Negative Effect” influences human beings?)</td>
<td></td>
</tr>
<tr>
<td>7 What is the component that generates “Negative Effect” in “Conventional Engineering System”? (Notation, or concise explanation)</td>
<td>It requires operators to have higher operation skills and burden on them</td>
</tr>
<tr>
<td>8 Explain the generation mechanism of “Negative Effect” that has been clarified in previous research.</td>
<td></td>
</tr>
</tbody>
</table>
What is the feature of “New Engineering System” as the solution for “Negative Effect”? (Clarify the contrast to “Conventional Engineering System”)

It is with constant monitoring of power consumption variations of drones by applying newly invented indicators.

Autonomous control system of multiple drones

Autonomous control system of multiple drones reduces the burden on the operator without losing operation time

Actual machines were built and tested.

The experiment with actual machines proved that the burden on the operator was lower and operation time was longer than the conventional operation methodology.

No “New Negative Effect” was observed.

Below are the other four research abstract samples. The abstracts were written by students and have been modified so that the original research contents cannot be identified. These samples have also been roughly translated from Japanese and have been presented as is without any correction made. The samples have many problems such as, the “Positive Effect” or “Negative Effect” not being clearly defined, the descriptions of multiple engineering systems are contained thus obscuring the flow of research story, and others.

Sample 2: This research aims to develop a speech interactive disaster warning system that operates considering its surrounding environment. Recent technological advancement in speech recognition and vocal hardware has grown expectations for realizing smooth voice dialogue between machines and humans in real situations. For this purpose, in addition to proper utterance as signal and language, it requires flexible reactions based on recognition and understanding of the “atmosphere of the place” such as the situation of the surrounding environment. This research challenges to install functions on the disaster prevention warning system. The functions are to infer the situation types of environments surrounding mainly human beings at the time of a disaster and to take warning action corresponding to the “atmosphere of the place”. This new technology, for example, may enable to judge a group of people that keeps talking despite a disaster event has no intention to evacuate. It is significant that this research may realize a warning system that is capable of voice dialogue as well as estimating human intention. The system, for example, includes a function that not only to continuously generate warning sound, but also to consider the situations and the environments surrounding humans in a disaster, such as, to detect the ambient environment where a person is hesitating to evacuate, and to put an interactive dialogue warning in addition to a normal warning sound.

Sample 3: BB structure and CC junction composes the energy conversion part in AA-type fuel cell. Appropriate combination of power generation materials, which should be based on detailed knowledge about the process, is required to realize the energy conversion part of higher efficiency. On the other hand, although microscopic factors such as molecular arrangement and excitation distribution are considered to influence the energy conversion process, details have not yet been clarified. In this research, a system that makes CC junction structure with YY molecular material of XX property, and consistently evaluates microcurrent and open circuit voltage related to energy conversion performance is constructed to identify physical factors that improve conversion efficiency.

Sample 4: It is known that X and Y compounds with A, where X and Y belong to the Alpha-group of elements, are categorized into three types: I, II, and III. Each of those exhibits interesting properties such as I, II, X1A4 that are used as practical sound absorbing materials. On the other hand, III - Z3A4 is known for Z, which is also an Alpha-group element and may be suitable for magnetic materials and electrode materials, has been observed so far. As mentioned above, one can say that the compounds of Alpha-group elements with A exhibits unique properties with a wide variety of features, and research on new compounds of Alpha-group elements with A will contribute not only to the development of the material science related to the compounds of Alpha-group elements but also has significant meaning as a pure material research. This research focuses on Z, which is the most reactive among X, Y and Z. A new type ZA compound, which is different from III-Z3A4 containing higher amount of A, by combining Z directly to A under high pressure conditions of in A-atmosphere, was synthesized, then, its crystal structure, physical and other properties were investigated and clarified from the viewpoint of material science.
Sample 5: Delta-method is a biophysical analytical method that calculates the time formation process of biological tissue. Autonomous growth mechanisms of bio-related tissues include organic autonomous growth accompanied by organic reaction such as XX growth and inorganic autonomous growth without organic reaction such as YY growth. Various researches have challenged on each autonomous growth mechanism resulting in many findings. However, these researches have not clarified the biochemical understanding of organic and inorganic growth including both organic reaction type and organic autonomous type enough. Then, this research aims to deepen the understanding of the growth mechanism by numerical analysis of organic and inorganic type growth models. Currently, our research group has proposed growth mechanisms classified as organic and inorganic type and investigate the mechanism of the unique mechanical properties observed in this biomaterial focusing on the growth mechanism of nano-domains observed exclusively in ABC-biological tissue material.

5 Results of Research Abstract Evaluation

The research abstract samples were evaluated by 38 students in the engineering fields. The results of this evaluation are shown in Fig. 4-(a). One may notice that larger number of the students selected “Clear” and “Somewhat clear” for Sample 1 than the other samples. The breakdown of the students’ disciplines is shown in Fig. 4-(b).

![Evaluation results](image1.png)

(a) Evaluation results

![Breakdown of the students’ disciplines](image2.png)

(b) Breakdown of the students’ disciplines

Figure 4: Evaluation results and breakdown of the students’ disciplines

6 Discussions

This section analyses and discusses the results shown above. The evaluation ranks were allocated with points as follows; “Clear”=2; “Somewhat clear”=1; “Neither clear nor unclear”= 0; “Somewhat unclear”, =--1; and “Unclear”= -2. Fig. 5-(a) shows the average points obtained by each of the research abstract samples. It shows that Sample 1 was evaluated higher than the other samples.

Sample 1 describes a research on a method for drone control, which may be recognized as a part of Mechanical and Aerospace Engineering. Therefore, the influence the higher ratio of students in Mechanical and Aerospace Engineering had on the higher evaluation on Sample 1 might be an issue.

For further analysis, Fig. 5-(b) shows the average evaluation points made only by the students in Mechanical and Aerospace Engineering while Fig. 5-(c) shows evaluation by students excluding Mechanical and Aerospace Engineering.
From the above results, the authors conclude that the research communication template is effective from the observation of Fig.5-(b) and (c). Fig.5-(b) shows evaluation made only by the students in Mechanical and Aerospace Engineering, where Sample 2 also obtained higher points than Fig.5-(c) which is an evaluation by students excluding Mechanical and Aerospace Engineering. Sample 2 describes a research on the application of speech recognition and vocal hardware to disaster warning system, which is also near the field of Mechanical and Aerospace Engineering possibly influencing the understandability of the research abstract. So, higher evaluation given on Sample 1 in both Fig.5-(b) and (c) indicates the effectiveness of the research communication template.

7 Conclusion

This paper describes a novel research communication template based on two research stages got from the TRIZ concept which states that a problem is a conflict of parameters. Five research abstracts written by students in engineering fields were evaluated for testing and demonstrating the effectiveness of the research template in the communication of research. The authors conclude that the research communication template is effective on the basis of the preliminary observation of the evaluation results.

8 References


At a time of significant global environment challenges and need for sustainable development, University education face a challenge to equip the graduates with theory, knowledge, and applications of sustainability. There have been global dialogue about sustainability but still it is confined to seminars and conferences. The university education needs to be redesigned or reformulated to include these topics in engineering curriculum. Most universities and colleges have yet to address seriously the sustainability theories in curriculum. There is urgent need for graduates to acquire the knowledge and skills to provide innovative solutions to issues being faced. Engineering profession has a vital role to play in addressing the climate change and helping the society to sustainable development. Thermodynamic concepts are applied in various engineering fields in study of environmental degradation and sustainability. Thus, thermodynamic study is also utilized in ecology, economics and engineering. First and Second Laws of Thermodynamics defines Exergy is viewed as providing the basis of a tool for resources and emission accounting. There is need for a lock-step approach to undertaking rapid curriculum redesign and integration of sustainability considerations and principles in mechanical engineering curricula. The design and manufacturing are core (required) courses for mechanical engineering and should include the concept of green design and manufacturing sustainability.

1 Introduction

The UN Commission states,” sustainable development is the development that meets the need of the present generation without compromising the ability of future generation to meet their own needs”. Due to depletion of resources, global warming, water, air, and soil pollution, there is need for rethink for developmental strategies of present generation. New ecological consciousness has emerged as a result of the direct assault on the ecosystem by human activity, threatening to obliterate many species, including ourselves. The unsustainable development of global economy, with its insatiable desire for energy, is at the root of ecological crisis.

Engineers are at forefront of development and the concept of sustainability must be taught schools. We believe that curriculum needs to be reformulated and sustainability concept green economy included. The production of goods and services are mainly profit driven rather than one to meet basic human needs for clean water, fresh air, and safe food. Engineering education need to emphasize on utilization of resources for needs of society not for making profit. The engineering education should incorporate green technologies or environmental friendly technologies and energy efficiency in context of sustainability considerations in the curricula. The concentration on energy and environment, within the mechanical engineering should prepare students to analyze technical problems in: 1) air pollution, 2) climate change, 3) energy efficiency, 4) environmental sustainability, 5) renewable energy, 6) timely issues facing the global community. Mechanical engineering labs need large capital investments, operation costs, and repair and maintenance costs.

1.1 Ecology and Engineering:

Industrial ecology applies the structure and processes of natural ecosystem for organizing activities across several domains of material, energy, environmental quality, and information exchange. The industrial ecology emphasizes the concept of sustainability-which means composite (integrated) development while consuming least resources and minimizing the pollution of land, water, and air.
Sustainability advocates systematic and global approach in order to minimize resources consumption, decarbonizes energy, minimize greenhouse gas (GHG) emissions, and encourage recyclability and reuse of materials. The emphasis on recycling and reuse in production process reduces the need for raw material extraction and waste disposal. It strives to encourage the use of renewable energy with low carbon emissions and GHG. The tools for sustainable engineering include life-cycle assessment, material flow analysis, input/output economic models, and indicators for measuring or assessing sustainability. According to ISO 14040 standards, LCA shall include four phases and they are goal and scope definition, inventory analysis, impact assessment, and interpretation of result as shown in figure below.

Figure 1: Process Flow Diagram

At the heart of industrial ecology is the knowledge of how to reuse or modify and recycle. This will save money for materials and reduce GHG emissions and energy consumption. The goal for mechanical engineers should be to take on design tasks such as managing the recycling and reuse of the product at end of life. The target should be to make more intricately networked and efficient design to disposal activities. The most important aspect for industrial ecology is material and energy balancing. Material balances are fundamental to the control of production, particularly in the control of yields of the products. Energy balances are used in the examination of the various stages of a process, over the whole production process and even extending over the total production system from the raw material to the finished and to the disposal. The process flow may be constructed stepwise i.e., by identifying the inputs/outputs/wastes at each stage of the process. A graphical representation is provided in Figure 1. The operating process parameters such as temperature, pressure, % concentration, etc. should be included. Material and energy balances can be very complicated at stages, but the basic approach is straightforward. The increasing use of computers facilitates the mass and energy balance models to be manipulated quite easily and therefore used for production management to maximize production and minimize costs. Carbon footprint can be calculated based on the total energy of embodied energy plus the processing energy in manufacturing processes. These balances are also useful for monitoring the improvements made in an ongoing project, while evaluating cost benefits.

1.2 Steps in Mass and Energy Balance Calculation:

Basically mass and energy balance calculation checks if directly or indirectly measured energy and mass flows are in agreement with the mass and energy conversion principles. A step by step approach is advocated as: 1) clearly identify the problem to be studied. In case of manufacturing system problems, we have to identify material removal process such as turning, milling, grinding, etc., as they work on different principles and the mechanics of material removal are quite different., 2) Define a boundary that encloses the complete system or sub-system or the equipment to be analyzed, 3) The enclosing boundary such that measurements is accurate and easy. 4) Select the appropriate test period depending on the type of process and product. Calculate the energy and mass flow based on the measurements in step 3, 5) Check the mass and energy balance. If the balances are outside the acceptable limits, then repeat the
measurements, 6) The energy release or use in endothermic and exothermic processes should be taken into account in the energy balance. Poor thermodynamic performance is mostly result of exergy losses in combustion and heat transfer. So, there is need for heat, mass, and energy balance study in thermodynamics. There is need for comprehensive curriculum development from undergraduate to graduate study with regard to sustainability.

**Basic Principles.** Representing the manufacturing system as a box in the figure below, the mass and energy going into the box must balance with mass and energy coming out. The law of conservation of mass leads to material balance equation; Mass In = Mass out + Mass stored, Raw Materials = Products + Wastes + Stored Materials

\[
\sum m_R = \sum m_{R1} + \sum m_{R2} + \sum m_{R3} \quad \text{(raw materials)(1)}, \quad \sum m_p = \sum m_{p1} + \sum m_{p2} + \sum m_{p3} \quad \text{(Products)(2)}, \quad \sum m_w = \sum m_{w1} + \sum m_{w2} + \sum m_{w3} \quad \text{(Waste) (3)}, \quad \sum m_s = \sum m_{s1} + \sum m_{s2} + \sum m_{s3} \quad \text{(Stored) (4)}.
\]

It is possible that in a manufacturing systems more than one product, i.e., \( p = 1, 2, 3, \ldots, n \) are being manufactured. Here only 3 products have been shown for illustration. The energy input is the embodied energy for separate products and materials. Waste materials in the manufacturing systems (particularly machining) are the chips being created after machining. We need energy during machining and must be included in the energy balance equation. Mass and energy both follow the conservation principles. The embodied energy into the operation and the energy used for manufacturing must balance the energy coming out and energy stored.

![Energy and Mass Balance](image1)

![Resources Analysis in Manufacturing](image2)

**2 Energy Balances**

Energy takes many forms such as heat, kinetic energy, chemical energy, potential energy but because of inter-conversions it is not always easy to isolate separate constituents of energy balances. Energy balances can be calculated on the basis of external energy used per kilogram of product, or raw material processed, Embodied Energy In + Energy Used in Manufacturing = Energy Out (Embodied Energy in the Products)

\[
\sum E_E = \sum E_{e1} + \sum E_{e2} + \sum E_{e3} = \text{Total Embodied Energy} \quad (5)
\]

\[
\sum E_m = \sum E_{m1} + \sum E_{m2} + \sum E_{m3} = \text{Total Manufactured Energy} \quad (6)
\]

\[
\sum E_w = \sum E_{w1} + \sum E_{w2} + \sum E_{w3} = \text{Total Energy Embodied Wasted in Chips} \quad (7)
\]
\[ \sum E_i = \sum E_{i1} + \sum E_{i2} + \sum E_{i3} = \text{Total energy loss to atmosphere (in form of heat)} (8) \]

\[ \sum E_{eo} = \sum E_{eo1} + \sum E_{eo2} + \sum E_{eo3} = \text{Total Embodied Energy out} (9) \]

For the energy balance equations 5 & 6 should be added on the left side of equality and equations 7, 8, & 9 should be on the right side. We can show the complete energy balance equation as

\[ \sum E_E + \sum E_m = \sum E_w + \sum E_i + \sum E_{eo} (10) \]

Energy balances are often complicated because forms of energy can be interconnected, but overall the quantities must balance. The thermodynamic analysis of resources used in manufacturing processes is shown below. Figure 3, above shows the inputs of raw materials and energy into the manufacturing equipment and outputs of product and wastes. Product is useful part coming out of manufacturing systems and wastes are scrap, chips, and heat.

2.1 Heat Balances

The most common important energy form is heat energy and the conservation of this can be illustrated by considering operations such as heating and drying. In these, enthalpy (total heat) is conserved and as with mass balances so enthalpy balances can be presented for various items of equipment or process stages, or round the whole system (plant), and it is assumed that no appreciable heat is converted to other form of energy such as work. Enthalpy (H) is always referred to some reference level or datum, so that the quantities are relative to this datum. Figure below illustrates the heat balance.

**Figure 4: Heat balance diagram**

Latent heat is the heat required to change, at constant temperature, the physical state of materials from solid to liquid, liquid to gas, or solid to gas. Sustainable Engineering should be an important part of Mechanical Engineering program to take care of modern interpretation of this rapidly changing field. Unlike the classical environmental engineering topics (e.g. water sanitation, brownfield remediation) many new environmental engineering and sustainability challenges require strong quantitative skills, as taught in mechanical engineering. Renewable energy technologies require skills in material science and physics, climate change research requires individuals trained in fluid mechanics and environmental transport, sustainable building design requires deep knowledge of heat and mass transfer in complex geometries. Mechanical engineers design and solve issues for all kinds of devices, from small toys to
large machines. The principles of mass balance, energy balance, and heat balance need to be included in mechanical engineering curriculum at every step.

3 ABET Requirements of Mechanical Engineering

The Mechanical Engineering Program has a traditional ABET accredited four-year curriculum involving mechanics, vibrations, thermodynamics, fluid flow, heat transfer, materials, control theory, and mechanical design. Graduates of this program are expected to have the following skills, knowledge, and abilities to work professionally in mechanical system areas including design and realization of such areas. New requirements of sustainability in thermal and design engineering should be included in ABET criteria. Mechanical Engineers should apply principals of green design to develop appropriate, cost effective, and high performance mechanical, and energy systems integrated into the projects. ABET should include: Reduce waste, re-use parts & components at end of life, rework & refurbish suitable parts, recycle as far as possible and remanufacture so far economical. This paper explored the need for engineers to be educated in sustainability and sustainability principles.

4 Sustainability and Thermodynamics

It is generally recognized that thermodynamics and fluid mechanics are very complex and challenging field for mechanical engineers and these courses explained further in thermal and fluid mechanics labs. These courses are also further explored through simulation in advanced Computer Aided Engineering lab. All engineering systems in design or manufacturing should follow the rigorous thermodynamic definition of system. The sustainability approach tries to identify how far from equilibrium (vs surroundings) a process and /or its outcomes are at any instant of the life cycle. At the end of useful life it returns to environment (landfill) , and it started its journey from its extractions from mines It is conceivable to consider such systems as closed systems instead of open system and all the thermodynamic properties of exergy and /or entropy generation should be applied for sustainability We can make best use of thermodynamics by focusing on bio-physical resources and using aggregate measures of the second law regarding conversion of resources, such as energy change and entropy production. Thermodynamic concepts have been utilized by practitioners in a variety of disciplines with interests in environmental sustainability, including ecology, economics and engineering. Mass, energy, and exergy balancing should be incorporated in all engineering courses to account for sustainability. Such analysis tools are applicable to diverse materials processing operations, such as machining, heat treatment, forming & forging processes, diffusion and phase change processing, etc. Here an outline of basic Thermodynamics course including sustainability considerations is presented.

1. Introduction to Sustainability and Thermodynamics; Flow diagrams principles.
2. First law of Thermodynamics: Heat, Work, thermal efficiency and difference between various forms of energy. (a) Heat Balance equations and examples, (b) Energy Balance equations & problems, (c) Mass Balance equations and problems, (d) Steady-flow energy equation; Open and closed systems (mass balance), (e) Conservation of energy (Energy Balance problems & examples).
3. Ideal Cycle Analysis; (a) Estimate thermal efficiency; energy balance, loss of energy, (b) Work as a function of pressure and temperature, (c) Mechanical Equilibrium, (f) Thermal Equilibrium (Thermal Balance).
4. Applications of first law of thermodynamics; (a) Thermodynamic cycle & Heat engines, (b) Otto cycle, (c) Brayton cycle
5. Applications of Steady-flow energy equation: (a) Mass balance or conservation of mass equations & examples, (b) Conservation of energy, (c) Steady flow energy equation, (d) Enthalpy & applications. (e) Examples applications of steady flow equations. Adiabatic considerations.
6. Second law of thermodynamics (concept of Entropy); The Second Law of Thermodynamics and the efficiency of resources utilization, energy consumption, and GHG emission is real and second law of thermodynamics should be studied from this angle. The relation between engineering, economic, and society are illustrated by sustainability and is shown below by Venn diagram shown in Figure 5.
Figure 5: Venn Diagram

The Venn diagram shows the practical framework for the use of thermodynamic ideas and analysis in second law in larger concept of environmental sustainability. The figure 6 shows all practical parameters for sustainability underpinned by thermodynamic principles.


5 **Green Design and Manufacturing for Sustainability**

In the design and manufacturing stream of mechanical engineering, the solid mechanics plays most significant part. All the basic theories of mechanics are helpful in component and system design including manufacturing. However, the mechanical engineering doesn’t include the concept of environmental degradation due to the decision made during design phase. Actually the design effects the manufacturing and manufacturing in turn effects the environment. We need to include the sustainable or green design including the concept of manufacturing for sustainability in mechanical engineering.

6 **Sustainable design**

Sustainability is defined as a requirement of our generation to manage the resource base such that the average quality of life that we ensure ourselves can potentially be shared by all future generations. Sustainability is the ability to continue a defined behavior indefinitely. Green design and manufacturing promises reduction in materials, energy use, disposal fees, and reduced pollution. Products should be designed keeping in mind the aspects of disassembly and recycling. Engineering curriculum has to catch up with the needs of society in general for sustainability considerations. The end-of-life considerations including recycling and reuse should be integral part of mechanical engineering curriculum. A curriculum revision and development of two separate courses on Green Design and Sustainable Manufacturing are being proposed.
Engineers need an understanding of whole systems, life cycle, and end of life utility of the product and they have been emphasized in the new courses being developed. This is in consistent with National Science Foundation (NSF) objective as well as the requirements of American Society of Mechanical Engineers (ASME). There is need to modify the undergraduate curriculum to include sustainability considerations in mechanical component design and manufacturing courses. The path towards sustainable engineering education is obvious and the engineering professors should recognize and communicate the epic nature of the sustainability discourse and should include sustainable engineering in curriculum. Unfortunately, few engineering schools have made major updates to their courses and curricula over the past few decades. Topics such as life cycle assessment, concepts in renewable energy, and methods of waste minimization need to be taught. The criteria used to accredit engineering education programs have also recognized this need. The Accreditation Board for Engineering and Technology (ABET) requirements for program outcomes and assessment, identifies that besides the knowledge in math, science, engineering principles, and problem-solving, engineering graduates should possess the ability to: function on multidisciplinary teams, communicate effectively, and understand professional and ethical responsibility. The core of the Venn diagram shown in Fig. 5 is sustainable, which should guarantee balance environment and economic development, along with equitability of society and the economic development. Enhancing the sustainability of manufactured product is a critical subject for the coming generation of engineers. It would result in reduced materials requirements, reduction in energy use, reduced disposal fees, reduced pollution and finally fewer problems for society in general. The aspects of disassembly and recycling should be included in product design. It would help to reduce toxic and otherwise harmful emissions to the environment causing global warming, and ensure sustainability. We should advance the following goals in engineering curriculum for sustainable future: 1. Reduce the use of resources including materials, energy, and water etc., 2. Reduce toxic and otherwise harmful emissions to the environment causing global warming, 3. Manage renewable resources to insure sustainability, 4. Quality and durability: Longer-lasting and better-functioning products will be replaced less frequently, reducing the materials requirements in future, 5. Design for reuse and recycling. Along with the traditional mechanical engineering design tools, the design for environment (DFE) should be integral component of mechanical design and it should be included in the ABET requirements. The extrinsic properties along with the embodied energy, GHG emission, and cost should be included in the
design process. A series of courses should be developed on Design and Manufacturing for Sustainability (DMS) or Green Design and Manufacturing for Sustainability (GDMS). These courses will present traceable information (topics) which are critical to product designers and manufacturing engineers so that they can incorporate sustainability in their occupation and comply with international regulations. Green design or design for environment (DFE) has the main aim of reducing the waste of material and greenhouse gas (GHG) emissions into the atmosphere. The curriculum developed emphasize on total life cycle of the product from grave-to-grave or at least from grave – to- gate. Some important aspects of design for the environment are; manufacture without producing hazardous waste; use of clean technologies; reduce product chemical emissions; reduce product energy consumption; use of non-hazardous recyclable materials; use of recycled material and reused components; design for ease of disassembly product reuse or recycling at end of life. The following topics are proposed to be included and integrated in undergraduate engineering curriculum.

**a. Designs for Assembly:** To improve percentage of recycling and reuse appropriate steps must be taken at design stage. Reducing the number of parts or components in the assembly makes it easier to manufacture and assemble. The proper material will also affect the assembly cost. Although slightly different in detail, focus on the following issues is needed. • Material e.g., reduce overall material diversity, avoid the use of laminates or make them out of compatible materials which can be recycled as a mixture, • Fastener, e.g., reduces fastener count and diversity; avoid incompatible adhesives which degrade recyclability of materials, use snap fits where appropriate, • Component design issues, e.g., avoid paints and laminates; build in planes for easy separation and access. Some of functions of one component may be integrated with other components or eliminated altogether to reduce cost. It will encourage recycling and reuse.

**b. Designs for Disassembly:** Design for Disassembly (DfD) must be incorporated in the early stages of product design, when the structure of the product is determined. The Design for Disassembly (DfD) saves money including reduces materials wastage, GHG emission, and landfill costs, and above all improves the environment. In traditional engineering design curriculum, the problems of recycling, reuse, and landfill or incineration were barely touched. This requires quite different thinking in a modern engineering education. An example of disassembly problem is presented below as module 1. Below an example for design of disassembly along with cost and the GHG emission estimation is presented.

**c. Reuse value** = Cost of component ($) – Miscellaneous cost ($)

Therefore, **Reuse value** = $per part reused x # of parts reused

**d. Remanufacture value** represents the value of component after disassembly the parts are reprocessed or refurbished before reusing them. The remanufacturing cost sometimes may involve machining, cleaning, removing paint, or cleaning for any corrosion on the part.

**e. Remanufacture value** = $per component x # of components – remanufacture cost/component x # of components The shredding cost needs to be accounted for in the EOL cost as well.

**f. Shredding Cost** =hourly shredding cost/hr. x # of hours used to shred one lb of material x weight of shredded material. The shredding cost seems very high and recycling may be uneconomical. After shredding material is reprocessed & sent at the entering point of production process.

**g. Embodied energy in recycling:** The value of embodied energy in the recycling (Jha) is also estimated. The energy saved due to recycling. **h. Carbon footprint estimation, i. Economics of End-of-Life in Design for Disassembly (DfD)**; The estimated life cost consists of the manufacture, assembly, maintenance, remanufacture and recycling costs as determined by the choice of fastening or joining method. The recycling cost represents (Feldman et al., 2001) the expense of material separation, and not material reprocessing. The assembly and disassembly costs are estimated using time required for disassembly and assembly of various fastening and joining methods.
j. **Recycling Cost**: The cost of separating parts made of different materials. Where Cr is cost of material recovery equivalent to the product of cost of material recovery (and weight of material recovered).

k. **Repair and maintenance Cost**: The repair and maintenance cost consists of disassembly and reassembly expenses, which represents time required for disassembly and reassembly and the expected cost of part and fastener replacement.

L. **Remanufacture Cost**: The remanufacture cost imposed by the fastening method also consists of expenses related to disassembly, reassembly and the probability of part and fastening method failure.

In general, the remanufacture cost is modeled as follows: 

\[ Crm = \text{Remanufacture cost}, \quad Td = \text{Disassembly time}, \quad Ta = \text{Assembly time}, \quad h = \text{Labor rate ($/hr)}, \quad = \text{Probability of fastener failure in disassembly and assembly}, \quad Cf = \text{Cost of fastener failure}, \quad = \text{Probability of part failure in disassembly/assembly}, \quad = \text{Probability of part failure in fastening-method extraction}, \quad Cp = \text{Cost of part failure}. \]

7. **Concept of Green Manufacturing**: For sustainable manufacturing profit is essential for all primary, secondary, or tertiary industries. Profit will encourage sustainable development. It is essential that costs including operation and maintenance are minimized. This shows that to make the enterprise more sustainable the costs of engineering and manufacturing must be decreased, so that profit increases. However, we must not miss the environmental impact of manufacturing and design. The mechanical engineering design and manufacturing courses should also include the energy required for the product manufacturing as well as the embodied energy. The reduction in the total energy not only reduce cost but it will reduce the GHG emissions as energy consumption is directly related to environmental degradation. ABET in their document Engineering Criteria 2000 states that students must be prepared for professional practice through a curriculum that includes “most of the following considerations: economic, environmental; sustainability manufacturability; ethical, health and safety; social; and political.” In part due to ABET, many US universities are beginning to introduce the principles of sustainable engineering into their curricula. Manufacturing processes consumes enormous energy resource and it has significant impact on the environment. The waste minimization requires knowledge of the production process, and tracking of materials from their extraction to their return to earth (cradle-to-grave).

8. **Curriculum development in green design and manufacturing for sustainability**

The course being developed will be able to integrate these considerations into their design and manufacturing practices. The course outline for Green Design and Manufacturing for Sustainability is presented below.


**7.1 Sustainable Manufacturing**
Manufacturers across many industries increasingly emphasize sustainability. Design-for-sustainability (D4S) takes a holistic approach analyzing operational efficiency, safety, functionality, productivity, materials use, ease of operation, and maintenance. The Sustainable Manufacturing would be open to undergraduate and graduate engineering students along with MBA’s. The course is multidisciplinary where project groups will comprise of students from all engineering disciplines including business major. The ABET outcome 9 emphasizes the importance of interacting with people in disciplines outside of mechanical engineering. The various aspects of sustainability will be presented through case studies from real world. The techniques and economics of waste reduction, recycling, cost/benefit analysis including life cycle cost are included: 1. Introduction to sustainability in manufacturing; Characteristics of successful product development. 2. Net shape manufacturing and minimization of energy; Sustainability measurement throughout life cycle. 3. Thermodynamics in manufacturing and Energy analysis. 3. Economic analysis; technological advancement for green manufacturing. allocation of resources. 4. Environmental impact & steps to reduce it through redesign, remanufacturing and data mining. 5. Green Product specifications; metrics of sustainability & cost model of the product and the process. 6. Sustainability in new product development; selection matrix; combine and improve the concept. 7. Design for manufacturing sustainability; cost, wastage, energy, quality and environmental impact. 8. Managing Green Manufacturing Projects; PERT & CPM, risk in green manufacturing, project evaluation.

9 Conclusions

This paper presents development of two courses for teaching sustainability in mechanical design and manufacturing along with modules for teaching. These courses offer integration of life cycle analysis, environmental impact, and end-of-life (EOL) considerations for engineering products. Design and Manufacturing are two core (required) subjects for undergraduate in several engineering disciplines including mechanical engineering, aerospace, civil, manufacturing and industrial engineering. In-depth coverage of such topics as environmentally friendly material, sustainability, green design of components, the life cycle cost including disassembly, and environmentally conscious manufacturing with examples and homework will prepare our graduates for tackling the sustainability problems of world.

References
Teaching Sustainable Development Using Algae
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Abstract
In 2015 at the United Nations Sustainable Development Summit, a set of sustainable development goals were formed and adopted by world leaders. These goals, which were set to be achieved in a fifteen-year period, address universal issues, including climate change, social inequalities, poverty, and more. In an effort to empower and prepare the next generation of engineers to create sustainable solutions to global issues, Rowan University, with funding from the National Science Foundation (NSF), has developed a curriculum based around algae. This curriculum utilizes algae-based experiments and lessons to teach foundational engineering principles, emphasize the link between engineering and humanities, and encourage students to pursue creative, conscientious solutions. The curriculum has been designed with adjustable complexity, suiting K-12 and college freshman students, and has been implemented in both middle school and freshman engineering classrooms. Calorimetry experiments allow students to investigate the nutritional benefits of algae-based products and challenge students to consider the application of algae in the fight against world hunger. Gas transfer experiments are used to research the sustainability of algae in the water treatment process. Algae can also be used to generate energy sustainably, as the oils found in some algae species can be used as biofuels. Students learn about biofuels and extract algae oils to generate energy in classrooms. This project places a strong emphasis on the humanities as well. While students will be learning principles of math, science, and experimentation, they are also encouraged to explore the political, cultural, and economic barriers that prevent algae-based solutions from being implemented in many places around the world. The objective of this curriculum is to give students the knowledge to help them solve sustainable development issues in the future, while also teaching them crucial engineering skills and awareness of global issues. Ultimately, the project aims at teaching a generation of future engineers the impact that algae can have on solving global sustainable development along with humanitarian issues.

1.0 Introduction

1.1 Algae Grows the Future
Algae Grows the Future is the name of the team at Rowan University comprised of junior and senior engineering students focusing on using algae as a teaching tool, as well as using algae to solve some problems faced by the modern world. The team is funded by the National Science Foundation (NSF), and was created in part by the Center for Aquatic Sciences (CAS) at the Adventure Aquarium in Camden, New Jersey. The Center for Aquatic Sciences works to promote aquatic education, as well as provide an understanding and appreciation for the aquatic wildlife and ecosystems that surround the United States, specifically that in the Delaware River area near Camden, New Jersey [1]. The Algae Grows the Future project and team help further the goals of the CAS and the NSF, since it researches green algae to develop experiments for K-12 and freshman engineering students, and the possible uses for algae in creating sustainable solutions to everyday problems, such as sludge management, food production, or energy production. The Algae Grows the Future team at Rowan University is dedicated to creating experiments and curriculums that implement algae as a tool
in creating a sustainable future, as well as teaching engineering concepts that will be useful for students further in their careers.

1.2 Project Goals

The Algae Grows the Future team is working to solve some of the United Nations Sustainable Development Goals that were first introduced in June of 2012, with additional goals added in 2015. These goals include creating a world with no hunger problems, no poverty, access to clean water for all peoples, and many other objectives [2]. The Algae Grows the Future team is researching the possibility of using algae to fulfill the United Nations Sustainable Development Goals, since it is relatively inexpensive, easy to grow, and sustainable. Algae’s high fatty acid and vitamin content makes it useful as a food source. The extracted algae oil has the potential to be used as a biofuel source. Algae can also be implemented into cosmetics and other everyday items to make them safer for human consumption, and has many other useful properties that make it a viable option for sustainably solving the problems set forth by the United Nations. Through this project, team members are researching algae and experiments using algae to determine the use of algae as a sustainable solution to the goals placed by the United Nations, as well as create curriculums to further engineering education in both the K-12 and college freshman levels.

1.3 Algae as a Learning Tool

Algae is a relatively simple organism, since it is a single-celled, photosynthetic organism that is commonly found in bodies of water around the world. While many people typically think of algae as a pest, since it grows on top of ponds and occasionally inside of recreational pools, it has many uses that are beneficial for humanity as a whole. Algae can be used as a source of food, since it is high in proteins and necessary minerals; it can be used as a source of oil for fuels and energy; it can be used to purify wastewaters and control fertilizer runoff; and it can be used to consume carbon dioxide emissions to lower the amounts of greenhouse gases in the atmosphere [3][4]. Algae is also relatively cheap to obtain and easy to grow, making it easily accessible in classrooms for education purposes. With these properties, algae can be used within classrooms for experiments for teaching sustainable development, such as uses for foods and energy sources, while also teaching engineering and scientific to young students.

1.4 Globally Conscious Learning

Solving the problems brought forth by the United Nations would require learning on the globally conscious scale, since many of the issues are not faced in every location. To fully understand the experiments using algae and the accessibility required for the use of algae, students can research different places and the needs of those places, and how algae could possibly be used to solve these problems. The different issues explored while researching and experimenting with algae include world hunger, world poverty, global warming, and other global issues that all tie into one another. The different issues currently being researching and solved are those on a global scale, and through the use of algae-based education and experiments, globally-conscious learning can be taught and maintained, allowing for future generations to be able to approach problems in a global perspective.
2.0 Teaching Sustainable Development

2.1 Engineering and Sustainability

As society continues to develop and grow, engineers are being called upon to design buildings that are more sustainable than before, especially with looming fears such as running out of resources or climate change. Civil engineers specifically are tasked with this, since they design structures meant to survive for many years. However, as engineers are introduced to these new challenges in the professional world, they seem to be finding themselves unfit to rise to the task, as sustainability is something that is not strongly implemented into the engineering curriculum. Because of this, teaching sustainability in engineering is becoming increasingly important, and implementing sustainability into the curriculum is necessary for the future [5].

While teaching sustainability in the classroom setting can be carried out in different ways, the Algae Grows the Future team focuses on creating a sustainable engineering curriculum based around algae.

2.2 Algae and Sustainability Education

Since algae is an inexpensive and easy to grow organism with many useful properties, it is ideal to use in classrooms to conduct experiments to teach students about sustainability. Algae can be used for different experiments, such as the creation of cosmetics, oil extraction, and calorimetry to teach students about the various uses of algae, and by growing algae in the classroom, students can learn about how algae is a sustainable resource, since it grows quickly and easily. Through the implementation of an algae-based curriculum, students can learn about the uses and sustainability of algae through hands-on experiments, useful skills in growing demand in society.

2.3 Algae Curriculum Implementation

Since the creation of the Algae Grows the Future team at Rowan University, the team has been creating experiments and curriculum built around algae and sustainable engineering practices for students in grades K-12 as well as incoming freshman engineering students. This curriculum has been implemented in three classrooms in the spring of 2017, with two of these classrooms being the freshman engineering clinic program at Rowan University. In these classes, students learned about and conducted experiments with algae, learning about the different products that could be made with an organism that is readily sustainable. Along with this, students were able to learn important engineering skills, such as creative problem solving, different experimental procedures, and how to use different programs such as Microsoft Excel in ways that would aid their success in the engineering program.

With the addition of algae-based learning to the freshman engineering curriculum, students were able to get an introduction into engineering, as well as being able to learn how to implement sustainability into future projects, which would allow them to be successful in both future classes and in their future careers.

3.0 Experiments

To teach students a better understanding of sustainability, experiments were developed with adjustable complexity. Experiments can be implemented into K-12 and university classrooms depending on the
difficulties of the experiments. There were a various of topics covered in experiments, introducing students to concepts of math and science and critical thinking skills. To make a connection with real life, many of the experiments replicate industrial applications of algae. Students can gain crucial hands-on experience through experiments and hopefully garner interest and enthusiasm for engineering.

3.1 Calorimetry

According to the World Hunger Programme, approximately 795 million people do not obtain proper nutrients through the food they eat every day. Algae has the potential for uses as a source of nutrients and food, specifically in poorer countries. Using a calorimeter, the amount of calories within algae can be determined by combusting the algae within the calorimeter. The amount of energy produced by combusting the algae can be used to determine the amount of calories within the algae, since calories are defined as the amount of energy required to heat one gram of water by one degree Celsius. Through this experiment, students gain hands-on experience conducting engineering experiments, as well as teaching students different possibilities for sustainable development in the future.

3.2 Coagulation and Flocculation through the Jar Test

The jar test experiment not only teaches students about the real-life jar test that is used to select the optimal coagulant dose for drinking water treatment, but also shows students the fundamentals behind the processes of coagulation and flocculation. As part of the preparation for the experiment, students can explore real world drinking water treatment processes around the world and about challenges with drinking water all over the world. Exploring the coagulation-flocculation part of drinking water treatment can help students understand the necessary steps for clean drinking water and encourage them to research innovative solutions to make drinking water more sustainable.

3.3 Cosmetics

Many algae produce nontoxic oils that can be used for a number of things, varying from energy sources to ingredients for cosmetics. In this experiment, students can create lip gloss using oils extracted from algae, rather than oil from other sources that may not be sustainable, or may be harmful for human consumption. This laboratory can also teach students laboratory safety, since hot plates are used for this experiment, and students must be careful around the hot materials. Students can also explore using algae in other cosmetic products, such as eyeliners, lipsticks, and other such types of cosmetics, so these products can be safer for human consumptions as well as more sustainable.

3.4 The Effect of Alternating Colored Lights on Algae Growth Rate

Algae has its potential to be used as biofuel, however it is important to produce algae efficiently and quickly for industrial use. One of the United Nation goals of sustainable development is to seek “Affordable and Clean Energy” [6]. In order for algae to be a feasible green energy source, a large supply of algae should be produced economically and environmentally-friendly to provide transportation, electricity, and other societal functions. Previous studies suggest that a light source with alternating wavelength better stimulates photosynthesis in comparison to a constant wavelength [7]. Students in this experiment are encouraged to discover the optimal colored light for better algae growth rate. By integrating physics basics, environmental engineering theories
and engineering ethics students will be able to gain various knowledge from different fields and think about how algae can be grown on an industrial scale.

3.5 Photosynthesis

Since algae are forms of aquatic plants, they undergo the process of photosynthesis in order to generate food and organic compounds. This process also allows algae to reproduce and remove carbon dioxide from the air to produce oxygen that can be released into either the air or the water. Since the oxygen released by the algae can be found dissolved in the water, the rate of algal photosynthesis can be determined by measuring the dissolved oxygen in the water, and how the amount of dissolved oxygen within the water changes over time. This experiment allows students to become more familiar with lab practices and equipment, such as lab safety and using tools such as dissolved oxygen meters, as well as how it can be used to clean air and produce oxygen in different situations.

3.6 The Effect of Light Intensity on Oxygen Production

In order to understand the potential for algae to be used as a carbon sequestration solution, students must understand the factors that can alter oxygen production. The Effect of Light Intensity on Oxygen Production experiment is a virtual laboratory that uses equations developed from the research of Shuler and Affens to understand how the distance of a light source and the concentration of a sample of algae affects the oxygen production of the sample. The students enter data into a given Excel Spreadsheet to understand the above relationships and create plots with the results. Through these results, students will achieve an understanding of the factors that contribute to increased oxygen production from algae samples.

3.7 Microtox

While algae can be useful to humans in many ways, there are a few instances where algae is considered undesirable, such as within personal ponds or swimming pools. In these cases, microtoxes known as algicides are used to get rid of the algae; however, these toxins can be transferred into other bodies of water and can harm surrounding ecosystems. In this experiment, the effects of toxic chemicals on algae are studied, and the toxicity of the microtx on algae can be determined using a Microtox 500 Analyzer. Through this experiment, students can learn how certain chemicals affect the algae cells, as well as determine which one is the most effective, and how these chemicals can negatively affect ecosystems if they are accidentally introduced.

4.0 Website

A website was developed to make the curriculum accessible to other educators. The website consists of handouts that can be easily edited using Google Drive tools to adjust to different educational standards and goals, video explanations of the experiments, and an explanation of the project history and goals. The website is available at http://algaeと思thefuture.wordpress.com and is still in the process of being finalized.
5.0 Conclusion

Through the Algae Grows the Future curriculum, K-12 and college students are learning fundamental engineering concepts and being trained to consider the global, sustainable aspects of engineering projects. Each of the experiments focuses on the scientific fundamentals behind algae, which shows the potential for solutions to global problems and ways to make current engineering processes more sustainable. Intertwining the experiments with a curriculum that stress humanities skills, students will understand the sustainable impact that algae-based solutions can have when it comes to global challenges.

References


A New Course on Sustainable Product Development for Low Resource Settings

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Abstract

In Fall 2016, a new International Development track was introduced in the Master's in Sustainable Engineering program at Villanova University. A foundation course introducing students to how to perform international development projects was piloted in Fall 2016 and then taught for a second time in Fall 2017. As a part of this track, a new course on Sustainable Product Development for Low Resource Settings was developed and piloted in Spring 2017 and is being taught again in the Spring 2018 semester.

While courses on appropriate technology have been taught in the past, focusing on developing new products that are long term sustainable, including technical and economic sustainability, for low resource settings, the aim of this course is to also provide students with tools to help them build successful ventures and expose them to new emerging technologies (such as virtual reality and blockchain) and considering how they may be used in the field.

The course begins with an overview of economic development and the role of the private sector and small businesses in particular can contribute to economic development goals. Students are introduced to the concepts of sustainable business model development and human-centered design and co-creation. They are then introduced to the concepts of iterative design and rapid prototyping. Logistics, supply chain, last mile distribution and manufacturing in low resource settings, are presented next. The students are then taught about monitoring and evaluation.

Some case studies of innovation for low resource settings such as the foldscope and work from the Little Devices lab at MIT are presented next. Then a number of guest speakers presented their innovations and programs in the health, agriculture, energy and WASH sectors.

The students are asked to design a product for a low resource setting as a term project and present their designs and prototypes at the end of the semester.

The paper provides more details about the pilot course, student feedback on the pilot offering of the course, and improvements to the course based on the student feedback.

1. Introduction

Sustainable engineering is becoming recognized as a separate engineering discipline comprising subjects such as life cycle analysis, whole systems analysis, sustainable materials design, etc. Indeed, Wikipedia defines sustainable engineering as: “the process of designing or operating systems such that they use energy and resources sustainably, in other words, at a rate that does not compromise the natural environment, or the ability of future generations to meet their own
Villanova University has offered a Master’s degree program in Sustainable Engineering since 2011 and the details of the program were presented in the 10th EESD conference in Gothenburg, Sweden [2]. The tracks in the program include: Alternate and Renewable Energy, Sustainable Materials, Sustainable Infrastructure and the Built Environment, and Water Resources Sustainability. Two years ago, a new track in International Development was initiated. This track is designed to prepare students to do work in the International Development field. It comprises a foundational course in Sustainable Engineering for International Development followed by a variety of optional courses including Sustainable Wash and Environmental Engineering for Development, Information, Communication and Energy Technologies for Development (ICT4D), and Sustainable Product Development for Low Resource Settings. The foundational course in Sustainable Engineering for International Development is offered during the fall semester and was first piloted in the Fall 2016 term. It was subsequently offered in the fall 2017 semester. The Sustainable Product Development course was first offered in the Spring 2017 term and is being offered for the second time in the Spring 2018 semester. This paper presents a brief description of the foundational course and is followed by a detailed description of the Sustainable Product Development course. Results of student surveys following the first offering of the course are presented. This is followed by a description of the changes made to the course based on this student feedback.

2. Description of Foundational Course

The foundational course’s purpose is to provide background knowledge related to international development practice. The course objectives of this course are listed below:

1. Establish a global perspective, considering development and the development aid sector in the context of geography, history, geopolitics & global trends, and viewing the role of development aid through a critical lens.

2. Introduce tools and frameworks for development practice on project and program scales, including tools and frameworks for project and program management, community appraisal, stakeholder analysis, capacity strengthening, research, and monitoring, evaluation, accountability & learning.

3. Consider the role of engineering and technology for development and present applications of engineering and technology to development challenges through case studies and projects.

4. Apply a systems approach to development practice, considering the multidimensional technical, social, economic, environmental, and institutional aspects of development challenges and engineering applications to development.

5. Give special consideration to the ethical dimensions of development practice, engineering for development, and intervention in vulnerable communities.

6. Build a knowledge base in a particular area of interest for exploring potential research or further engagement within the international development sector.

The course begins with a consideration of the global perspective with an introduction to
international development and the development aid sector, including economic development globally, the economic lives of the poor and critical perspectives on the role of development aid. This is followed by a focus on tools and frameworks for development practice. The topics covered in this part of the course include: Systems dynamics and development, Catholic Relief Services (CRS’s) Integral Human Development (IHD) framework, project cycle and project management, participatory community appraisal and stakeholder analysis, capacity strengthening and partnership and monitoring, evaluation, accountability & learning. The final set of topics in the course is focused on engineering technologies for development and human-centered design.

3. Description of Sustainable Product for Low Resource Settings Course

Students are expected to have taken the Foundational course prior to taking the sustainable product for low resource settings course. The course objectives for this course are as follows:

1. Identify potential opportunities to contribute to local development in low resource settings.
2. How to use a human-centered design process to design products/services for low resource settings
3. To understand how to develop sustainable business models in low resource settings
4. To develop a project design and business model for low resource settings.

The course is focused on developing entrepreneurial approaches to international development challenges. The introductory part of the course discusses some basic concepts in entrepreneurship such as value proposition, business model generation, marketing, and supply chain and product distribution. The students are introduced to a number of business model generation tools including the business model canvas [3], the e-spot canvas [4] and the BYU Developing World canvas [5]. The students then are presented with business models that have been found to successfully work in the context of developing countries. A good summary of these models is provided by the Monitor report [6] from 2009. In addition to the topic of entrepreneurship, the students are also given some directed reading to better understand how money is managed in poor communities. Readings are assigned from the book, “Portfolios of the Poor” [7] and a discussion was led on these readings by Prof. Jim Klingler, Professor Emeritus from the Villanova School of Business. Ethical and human-centered design/empathetic design considerations which were introduced in the foundational course continued to be reinforced in this course. Furthermore, in-class discussions are held with the students to bring their own international experiences to help contextualize the material that they are learning.

Some case studies of successful ventures in different sectors, such as health, agriculture, education and water, sanitation and hygiene (WASH) are presented. A few specific ones include the treadle pump by Kickstart [8], a lighting project using a bicycle generator by Nuru Power from South Africa [9], low cost solar greenhouses in Sierra Leone [10] and the Lifespring hospitals [11] and Aravind Eye Hospital models [12].

The next phase of the course discusses product prototyping, appropriate technologies and co-creation. The students watch a TED talk by Tom Chi on rapid prototyping [13] as well as some other prototyping techniques and approaches, including fabrication of simple prototypes with
scissors, paper, glue, cardboard, etc. Students went through a rapid prototyping in-class exercise. The exercise involved the students coming up with a prototype solution to meeting water needs in a developing country. A photograph of two students from this year’s class, Amy Heindel and Amanda Findlay, performing their prototyping exercise is shown in Figure 1.

![Figure 1](image-url)

**Figure 1.** Two students working on prototyping a water dispensing system

More sophisticated prototyping techniques, such as 3-D printing are also introduced at this stage of the course. Again case study examples are used to illustrate appropriate technologies and co-creation. Some of the examples included are the foldscope low cost microscope from Dr. Prakash’s lab at Stanford University [14], the briquettes made from agricultural waste from Dr. Amy Smith’s lab at MIT [15], Dr. Oloyumbo Awojobi’s work in Nigeria innovating low cost hospital tools [16], etc.

The final phase of the course is to consider emerging technologies and how they may be used for international development. These emerging technologies include 3-D printing, drones, virtual reality, augmented reality and Blockchain technologies. Additionally, guest speakers presented on their particular experiences in trying to launch ventures in developing countries and the challenges that they faced and overcame. Also, we had guest speakers from different non-governmental organizations including UNICEF and the US Agency for International Development (USAID).

The students are also assigned a course project which involves the development of a physical prototype of a product to be used in a low resource setting. In addition to the physical prototype, the students are also required to prepare a sustainable business model to support their product.

In the first offering of the course, the students prepared a number of projects including a containerized human waste system, a hydroponics system that combined fish raising with plant raising, and an atmospheric water evaporation system for harvesting water from the atmosphere.
in dry climates. A photograph of the student with his prototype of the containerized human waste system is shown in Figure 2.

![Student presenting his prototype of a container-based human waste disposal system](image)

Figure 2. Student presenting his prototype of a container-based human waste disposal system

3. Student Feedback from First Course and Modifications in Second Offering

The students in the first course had a number of useful comments from the first offering of the course. My intent initially with the course was to have the students develop a product for a local low resource setting. However, this did not work out so the final project description was not issued to the students until late in the semester, giving them a shorter period to work on the project than they would have liked. I have therefore assigned the project earlier this semester (in the fourth week of the course) and will be having a check-in with the students at about the eighth week of the course. This should help to provide students more time and guidance on their projects.

Another useful comment from the students was that there was too much overlap with the prerequisite foundational course. It seems some case studies that I covered, such as the Playpump, was already covered in the previous course. As a result of this feedback, I have taken out some of the material that reproduces the previous course material and added some different case studies.
One aspect of the first offering of the course that the students particularly liked was the rapid prototyping session in which they had to design, build and test a prototype product within 30 minutes, including getting customer feedback. The students enjoyed the pace of this exercise which forced them to rapidly develop a prototype rather than simply brainstorming and sketching ideas.

Two other aspects that the students enjoyed were the case study examples and guest speakers. Some of the case studies, such as the Foldscope example, were very well received. They also felt that the guest speakers sharing their experiences in the field provided a clearer sense of the issues that I had been conveying to them in the lectures.

4. Special Features of this Course

There are many sustainable product design courses being offered by various universities. In most of these cases the students are guided into developing low cost, innovative products and usually have the resources to go to the sites where the product will be implemented. However, in our case, the students in general have had experiences in international development settings, such as in the Peace Corps, and are now looking for knowledge and tools to help them be able to design sustainable products for these settings without necessarily traveling to the sites. The emphasis in this course is to provide tools to the students to accomplish these goals. For example, USAID has developed an innovation tool for developing products for the health care sector [17]. This tool was presented by Karen Clune from USAID as a guest speaker in the class. The students have also been introduced to the Business Model Canvas, the BYU Developing World Canvas, the e-Spot Canvas, and inspiring approaches by people working in this space. Other tools include the resources on the Engineering for Change website, including the Engineering for the Developing World content [18]. By providing students these tools and in-depth case studies, the students become equipped with the knowledge and tools to help them succeed in establishing future ventures for improving the quality of lives of people living in low resource settings.

5. Conclusions

This paper has described a new course on Sustainable Product Development for Low Resource Settings that builds on a foundational course in International Development that makes up courses in the International Development track in Villanova University’s Master’s in Sustainable Engineering program. The course covers an introduction to entrepreneurship, various business model development tools, a series of case studies on successful entrepreneurial ventures in the developing world context, innovative technologies, and guest speakers. The students are also expected to build a product prototype and an accompanying sustainable business model. The course is in its second offering and has been tweaked based on student feedback from the course. Overall, the course has been well received by the students and is contributing to their education in creating business ventures to improve the quality of lives of people in the developing world.

6. References


[5] BYU Developing World Canvas


Cycling for a sustainable future: Considerations around the Development of a Masters Level Module on Carbon Capture, Sequestration and Utilisation

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Abstract

This paper envisages a masters level module, as part of an integrated masters level degree in chemical engineering (but which can also be taken by other engineers, such as energy engineers), as a suitable module for bringing together broader (societal level) considerations around the implications of contemporary carbon cycle disruption with possible interventions. These would include interventions in particular at the technological level, through the preferential capture, storage and utilisation of carbon. In this way, the module can build on standard undergraduate chemical engineering modules in unit operations, mass transfer and environmental engineering to (while by drawing on research informed expertise of the lecturer) consider specific potential technological interventions in the CCS and utilisation space. It can also however both draw on and add to prior learnings from broader contexts and domains such as in the realms of industrial ecology, ecological economics, technological indeterminism, sustainability narratives and policy, in particular through the use of an overarching context of carbon cycles. It also affords the opportunity for graduate students to develop critical thinking in relation to an ever-evolving socio-technological, economic and policy landscapes, and to help the goal of facilitating the development of fit-for-purpose engineering graduates in the wake of the consequences of ruptured carbon cycles.

1 Introduction

Carbon is one of the most plentiful and essential elements to life on Earth. However, over the past number of decades, carbon’s increasing atmospheric levels have been linked to climate change, with the scientific community warning governments, industries and society of potentially catastrophic consequences. But what is actually the carbon cycle? How many carbon cycles exist? What is the anthropogenic effect in the carbon cycle and how could that be implemented to a sustainable future? What is the current world status on CO₂ capture, sequestration and utilisation? What is the current legislation for carbon tax? How “green” is actually carbon capture? What are the key sustainability metrics of carbon capture and carbon free technologies? These are some of the questions, that on successful completion of this masters level module, the students will be able to answer, having developed the required hard and soft skills in order to sustain the carbon cycles and the humanity to live in prosperity and harmony with the university.
The concept of sustainability is not new in engineering education (Desha et al., 2007; Ashford, 2004; Thompson, 2002; Tryggvason and Diran, 2006; Sanderson, 2008; Fitzpatrick et al. 2015). The issues of population growth, climate change, environmental impact, poverty and resource depletion have been well addressed and linked to sustainable development. However, the concept of sustainability is not just only on the physical resources and components (Al-Rawahy, 2012); the necessary ingredient for sustainability is an ethical and a moral decision maker, which in the case of the ruptured carbon cycles is the engineer. This module aims to frame engineers with high moral standards that recognise their ethical responsibilities and recommend solutions for the anthropogenic carbon cycle, towards the welfare of the society.

2 Thematic structure of the module and Bloom’s taxonomy of learning
The nature of the module is bilateral, drawing both the technical and the societal challenges of carbon capture, sequestration and utilisation. From an engineering perspective, this module focuses on the potential for technological intervention into the carbon cycle through the development of carbon capture and sequestration (storage) (CCS) and utilisation (CCU). This ranges from direct sequestration approaches (e.g. wood/biomass geostorage (Kreysa, 2009; Dufour, 2013)) to a range of end of pipe technologies around CO₂ capture from flue gases (post-combustion, pre-combustion, oxyfuel) and direct air capture, to CO₂ capture through respective unit operations and mechanisms (absorption, adsorption, membrane separation, cryogenic separation), to carbon storage (compression, transportation, trapping (Leung et al., 2014)) and utilisation (chemical and biological methods (Cuellar-Franca and Azapagic, 2015)), as well as the economics of CCS and CCU. From a societal perspective, this module focuses on the existing and future environmental legislation, on public awareness, public misconceptions and perceptions and environmental empathy and ethics of engineers (Walther et al., 2017). The two parts are feeding into the concept of green and sustainable engineering, as presented in Figure 1.
The thematic structure of the course (Fig. 1) is based on what the students are expected to be able to do at the end of the module (Kennedy, 2007), using an outcome based approach (Mager, 1984), rather than starting from the module objectives. The learning outcomes approach, as opposed to the module objective approach, is a student based approach and with focus on what the students are expected to achieve and the way to demonstrate it, in order to maximise understanding. The structure of the learning outcomes is following Bloom’s taxonomy (Bloom, 1975), where each level of thinking depends on the students’ ability to perform at the levels below it (Fig. 2). Bloom’s taxonomy describes the process of building upon former learning in order to develop more complex levels of understanding, before reaching the top level of synthesis, where an idea is integrated in a solution.

The six steps in Bloom’s taxonomy are (Kennedy et al. 2009):

1. **Knowledge**: the ability to know facts, theories or principles
2. **Comprehension**: the ability to understand and interpret learned information;
3. **Application**: the ability to use knowledge in new situations or problems;
4. **Analysis**: the ability to break down information into its components;
5. **Evaluation**: the ability to judge and to apply critical thinking;
6. **Synthesis**: the ability to integrate ideas into a solution or to formulate a new classification scheme.
The thematic structure of the module (Fig. 1) is following the structure of the learning outcomes (Fig. 2), placing sustainability in carbon cycles and green engineering on the synthesis level of Bloom’s taxonomy (Fig. 2). The sections of the module and the associated learning outcomes are presented and discussed in detail in the following paragraphs.

3 CO₂ and Climate Change
CO₂ and climate change is the introductory session of the module. It aims to address the problem, which is the increasing levels of anthropogenic CO₂, to provide facts and predictions about climate change and finally explain the important role of engineers in the solution of the problem. This section is the first step in Bloom’s hierarchy, providing generic knowledge on the topic.

**Learning outcomes**
- Recognise the greenhouse gases and the role of CO₂ in climate change;
- Apply general climate change science and the Keeling curve;
- List monitoring techniques and technologies available to reduce greenhouse gases;
- Identify the role of engineers as decision makers in the reduction of greenhouse gas emissions.

4 The Carbon Cycles
The global carbon cycle is constituted by the geological carbon cycle, the biological carbon cycle and the anthropogenic carbon cycle. This section aims to provide details for each cycle, to analyse the balance between the three cycles and finally address the recent effects of the anthropogenic cycle to the continuity
of the other two pre-existing cycles. The carbon cycles are placed on the second level of Bloom’s taxonomy, the comprehension step, assessing the students’ ability to associate human activity with raptured carbon cycles.

**Learning outcomes**

- Distinguish the geological, biological and anthropogenic carbon cycles and how they are related;
- Identify the differences and the relation between the carbon cycles and the human role in this interaction;
- Recognise the consequences of the raptured carbon cycles;
- Associate the effects of negative and positive feedbacks on the carbon cycle system.

5 **Carbon Capture**

Having identified the importance of carbon reduction, this section analyses carbon capture from the air and flue gases and examines the different processes to be used for this purpose. While the previous two sections are generic and theoretical, this section contributes to already obtained technical knowledge on unit operations and advanced separation processes, assessing the students’ ability to use this knowledge for new applications. Therefore, in terms of Bloom’s taxonomy, carbon capture is placed on the application step. A short summary of the topics to be covered is presented below:

- **Direct Air Capture**
  Direct air capture (DAC) refers to a set of technologies that have the potential to capture industrial-scale quantities of CO$_2$ from atmospheric air, as opposed to point-source carbon capture from sources where CO$_2$ is more concentrated (such as flue gases), which is an important tool in managing emissions that are difficult or expensive to eliminate at source.

- **CO$_2$ capture from flue gases**
  CO$_2$ capture is the first step in a CO$_2$ capture and storage or CO$_2$ capture and utilisation project. CO$_2$ is sourced from waste gases from post-combustion or pre-combustion and oxy-fuel combustion technologies.

- **CO$_2$ capture processes and materials**
  There are four methods available for the capture of CO$_2$: absorption, adsorption, membrane separation and cryogenic distillation, all of which have good potential depending on the specifications of the flue gas under treatment. The criteria for choosing the most appropriate method are high CO$_2$ purity and recovery, robustness, low energy consumption and cost.

**Learning outcomes**

- Distinguish Direct Air Capture (DAC) from carbon capture from flue gases;
- Assess the technical and economical differences between DAC and carbon capture from flue gases;
- Utilise approaches that have been developed to separate CO$_2$ from post-combustion, pre-combustion and oxyfuel processes, including their advantages, disadvantages and commercial readiness;
- Examine appropriate applications of each of the aforementioned technologies to different CO$_2$ capture scenarios;
• Operate unit operations and separation processes towards CO₂ separation;

6 Carbon Sequestration
Upon capture, CO₂ can be transported under pressure to geological sinks, either on-shore or off-shore. The process of CO₂ capture and geological storage (sequestration) is widely known as CCS. This section addresses compression and transportation systems and outlines the major types of formations in which CO₂ could be stored as well as the way CO₂ is trapped in these formations. Similarly to carbon capture, carbon sequestration is enlisted on the application step on Bloom’s taxonomy, assessing the ability to apply process engineering knowledge in the parts of compression and transportation.

Learning outcomes
• Examine CO₂ compression technologies and the main operating issues pertinent to CO₂ transport;
• Determine optimal pressure CO₂ pressure for transport;
• Examine the various options for transporting CO₂;
• Estimate compression and transportation costs;
• Assess the concept of geological storage and the techniques used for trapping CO₂ in sedimentary basins;
• Assess the technical challenges for CO₂ storage in sedimentary basins as well as the hazard potential of CO₂ leakage;

7 Carbon Utilization
Alternatively to sequestration, CO₂ being a source of carbon has the potential to be utilised in the manufacture of carbonates, fuels, chemicals and polymers. Carbon capture and utilisation, known as CCU, represents a new economy, using CO₂ as a raw material. Carbon utilisation involves organic chemistry; therefore, this section fits into the application step, assessing the students’ ability to apply chemistry in order to transform CO₂ waste into new products.

Learning outcomes
• Assess the various techniques for CO₂ utilization;
• Apply chemistry to examine the various options for recycling CO₂;
• Examine the economic and energy potential of CO₂ utilisation;

8 Strategic Planning: CCS and CCU economics
Economics are an essential aspect of the evaluation of CCS and CCU projects. This section sets out the methods and the assumptions used in conducting economic analysis of CCS and CCU projects, providing an overview of the required economic considerations and viability and commercial availability. In Bloom’s taxonomy, the economics of CCS and CCU fit into the analysis level, assessing the students’ ability to apply engineering economics and cost analysis.

Learning outcomes
• Identify the cost of CCS and CCU;
• Compare the economic viability of CCS and CCU;
• Examine the concept of CO₂ avoided, $ per tonne avoided and injected and $ per MWh in the context of CCS;
• Analyse the pitfalls in the cost estimation of CCS and CCU.

9 Public awareness, Environmental Laws an Engineering Ethics
The sociology and law aspects related to CCS in relation to the engineering code of ethics are embedded on this part of the module. The uncertainty over public acceptance of CCS is considered a major barrier for the development of a significant market, thus delaying a substantial commercial availability and constraining the economic viability and application of these technologies. For CCS to be implemented on large scales, work needs to be undertaken to inform and engage communities. Injecting large quantities of CO₂ into underground reservoirs creates new risks that need to be addressed within a regulatory framework. The associated risks occur in two scales: local risks associated with human or ecosystem health and global risks relating to re-release of CO₂ into the atmosphere and the role of engineers is to address and minimise these risks (fit-for-purpose engineering). This section of the module is placed on the evaluation step of Bloom’s taxonomy, aiming to assess the students’ ability of critical thinking.

Learning outcomes
• Evaluate the societal-engineering dynamics and the principles of effective community engagement in CCS/CCU;
• Identify the potential risks associated with CO₂ storage in geological reservoirs;
• Assess the potential environmental and ecological hazards, as a result of CO₂ leakage;
• Examine the Kyoto protocol as well as the international and national legislation relevant to CO₂ increasing levels, capture and storage;
• Defend the role of regulation in managing the risks of CO₂ storage and reducing anthropogenic CO₂;
• Relate the role of engineers to the regulation of CCS and CCU.

10 Sustainability in the anthropogenic Carbon Cycle
The module has addressed that the unsustainable ruptured anthropogenic carbon cycle is a threat to humanity because of its detrimental effects to environment, climate, economy and societies. The solution to this problem is to make the carbon cycle sustainable by recycling CO₂ to produce energy and to replace fossil fuel before they diminish. Biosources can only have a limited role in supplementing future energy needs due to the interference with the food chain, whereas the transformation of CO₂ in a source of energy could offer a win-win solution, because of utilising a harmful component effectively and liberating humankind from its dependence on fossil fuel. The last section of the module aims to assess the ability to formulate sustainable green engineering solutions; therefore, it is placed on the top of Bloom’s taxonomy, which is the synthesis part.

Learning outcomes
• Relate CCU with energy sustainability;
• Propose green solutions using CO₂ as raw material;
• Relate carbon sustainability with economic sustainability.

11 Conclusions
CO₂, as a by-product, has been considered as a major problem for humankind the last decades. On the contrary, CO₂ recycling could liberate humanity from fossil fuels and could help humankind to solve one of the most significant problems for a sustainable future. This master’s level chemical/environmental/energy engineering module aims to embed sustainability to the unsustainable anthropogenic carbon cycle, focusing on carbon utilisation, by incorporating socio-techno-economic aspects of carbon capture, sequestration and utilisation and emphasising to the concept of fit-for-purpose green engineering.

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Enhancing Engineering Education in Occupational Safety and Process Safety

Deborah Grubbe

Abstract

The speaker will address a productive way to introduce both occupational safety and process safety into the engineering curriculum. A recognized, international safety expert, and an Emeritus Member of the AIChE Center for Chemical Process Safety, Ms. Grubbe will outline what is currently missing in this area in education, with suggestions on how to begin to mitigate. She will also offer and discuss a progressive curriculum in broad safety concepts for both undergraduate and graduate students in all engineering disciplines.
Soft Skills: how to make the young engineers aware of their new talents? (EESD2018)

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Abstract

The competency framework attached to the Life science engineering Master at Gemboux Agro-Bio Tech, University of Liege (Belgium) is composed of technical and scientific skills but also soft skills which are not connected to academic courses. For the training of these skills, university needs the collaboration of the professional world. Therefore, the role of our teachers evolves towards a guiding or mentoring role. They will help students to analyse their professional experiences in order to shape their professional identity, to bring to light their acquired skills. This article describes how the portfolio, used as internship’s report, will help students to gain the self-confidence about their abilities and how professors can use these reflexive analyses to evaluate the acquisition of these soft skills.

1 Introduction

The “Commission des Titres d’Ingénieurs” (CTI, 2006) defines engineers as individuals who are able of resolving technical, practical, often complex and, usually, new problems. For a long time, recruitment and selection processes concentrated on hard skills which are attached to technical and scientific skills. Today, employers give much more importance to so called soft skills which include teamwork, management, communication and professional identity. In the first part of this article we will describe the philosophy followed from the design of our competency framework to the identification of the learning activities which support it. In a second part we will describe the particular case of the softs skills for which our professors feel less comfortable. This article will describe the procedure put in place for the first time this year to allow students to acquire these skills and become aware of their acquisition.

2 From the identification of the skills to the implementation of learning activities in our cursus

In order to prepare efficiently our students to these competencies we built a competency framework as the keystone of the curriculum. The competency is by definition general and complex. It is quite challenging to define precisely which learning activities train it efficiently. To be more explicit the competencies must be developed into real situations. That’s why we translated these competencies into relevant professional situations. The professional situations take into account the extent and diversity of the resources, skills and abilities that the competency needs in this context. It’s therefore the translation of the competency in the professional context. The professional situations are more concrete for the teachers. Although the professional situations are more concrete, there are not less complex. It’s difficult to imagine learning activities that will train our students to this high level of complexity without reaching some intermediate
states. Developing a professional situation takes time and involves going through various stages of development. Dreyfus (1980) established that in the acquisition and development of a competence, a student goes through five successive levels: novice, beginner, competent, proficient, expert which reflect various changes which take place during the acquisition of a competence (Hallam, 1992). Progressively, and as the result of acquiring a certain level of 'professional' experience, the novice ends up being an expert; a professional able to exercise his or her profession in an autonomous and considered way, offering appropriate services while respecting professional ethical values (Cheetham, Chivers and Hardcover, 2005). This justifies the concept of 'lifelong learning' and will oblige some teaching staff to reconsider their belief that they train experts across a large range of areas. Although the two most complex levels are only achieved after several years of professional experience, the others are usually acquired during the student's education. This notion of progressivity was therefore incorporated in our competency framework. In most situations, we decided to address the three first levels, each level being certified by a precise activity in the cursus. With these different stages description, it is easier for teaching staff to structure their courses and to organise appropriate and varied learning activities in order to support students on their way to skills acquisition. Figure 6 shows the trajectories development of the professional situation: “Design and size monitoring and production equipment in an agro-environmental context”. The courses implied in the development or the evaluation of each stage (four in this example), are identified. In accordance with this matrix, the professors developed specific learning activities and adapted evaluations.

Figure 6 : Matrix development trajectories versus courses implied in the learning or the evaluation of those different development trajectories of a specific professional situation of the competency framework.

3 The special case of soft skills training

Regarding soft skills, the approach is much more difficult (Chamorro-Premuzic et al., 2010; Haselberger et al., 2010; O ’connor et al., 2016). These skills are not connected to specific tasks trained during courses. Of course, some contents can be provided for students in order to “practice” their professional behaviours,
but the complexity of the situation, the interaction with colleagues, the context of hierarchy cannot be presented through courses as specialized as technical and scientific ones can be. University education is unable to mimic workplace and complexity. Professional identity development is fostered by the authentic experiences of students in workplace through internships for example (Billett, 2009; Bowen, 2016).

During their internship, the students can observe and use their observations for shaping their own professional behaviors. But they can’t do this without help, without advises and preparation. The professors still play a crucial role in students’ identity building. University has to assist students in learning from workplace experiences (Trede, 2012). For example, the professional situation “strengthen his/her skills and his/her critical thinking” is clearly part of what is called the professional identity (Figure 7). The critical thinking, the professional ethics, the deontology can be discussed during some courses but it is during the internship that students can really develop this particular skill. During their internship, the graduates can compare themselves to a professional community, they are better positioned to develop as professionals themselves (Trede, 2012).

Figure 7: Description of the development trajectories of a professional situation attached to a soft skill

But, professional ethics cannot be acquired only by osmosis in the workplace. Schön which is in favor of immersion learning in professional context insists on the importance of what he calls “Reflecting-on-action” (Schön, 1983). The professional ethics can be integrated progressively, when students encounter some professional situations of course but especially if they analyze some actual experiences, examine how decisions are made, processes are developed and finally thinking about how they would have reacted in similar situations. Reflecting-on-action is crucial to improve one’s capacity to act within a professional community and avoid repeating mistakes (Schön, 1983). Therefore if the learning of professional ethics is beyond the control of university, the process of reflection which is critical to develop this "professional posture" is the job of the university.
The role of the professors and the university concerning the soft skills development is therefore original compared to the classical technical skills. First of all, it is crucial in the learning process that students are proactive during their internship. They have to pay attention to those professional situations in order to analyze them. Professors’ role is to instill curiosity but mostly to encourage commitment to force students to confront their beliefs with the current professional situation in order to analyze it and build their own identity (Brookfield, 2012). If students form a professional identity on their own, without comparing their beliefs with their colleagues and professors, the risk is that they will simply imitate what they observed rather than critically evaluate those observations in relation to context (Trede, 2012). It is important to give the opportunity to students to share, critically analyze their observations and experiences with others students, with their professors. This step will help students to shape their professional values and build their professional identity (Brookfield, 2012). Students who critically observe practice and practice critical thinking can become more professional.

4 Portfolio as tool to help students to shape their own professional identity

A portfolio is the tool which is the most adapted to encourage personal reflection on experiences, to reflect the learning and the competences development by the students (Tardif, 2006; Bélanger, 2008; Prégent, Bernard and Kozanitis, 2009; Berthiaume and Daele, 2010; Michaud, 2012; Berthiaume and Rege Colet, 2013; Poumay, 2016). It provides a useful link between the academic knowledge and the professional situations, promotes critical thinking and makes students much more aware of their own learning, of the quality of their experiences. This last point is really important because too many students perceive themselves as under skilled and don’t feel ready to step into professional working life at the end of their curriculum.

According Tardif (2006), “a portfolio is a purposeful collection of selective traces selected by the student in order to reflect his/her learning”. But building a portfolio is not just collecting information without distinction. To become a proof of learning and a way to certificate the skills acquirement, a portfolio must be a “bundle of evidences”(Poumay, Tardif and Georges, 2017). According to Poumay et al., an evidence is a selected trace commented by the student him/herself (Poumay, Tardif and Georges, 2017).

Literature presents the reflective learning approach as a cyclic process which asks the students to collect information about his/her learning, to select the most pertinent and more importantly to analyse his/her experiences. This process of reflection is the key stage where students will integrate new information, realize the acquired skills and can plan his/her learning by selecting the activities which will help him/her to progress (Bélanger, 2008; Poumay, 2017; Stewart et al., 2017). In this step the student needs guidance, feedback, advice from professors. In literature, this process of mentoring is recognized as the most decisive factor in portfolio success (Bélanger, 2008; Cahour and Licoppe, 2010; Poumay, Tardif and Georges, 2017).

Since our students hardly realize their progresses on soft skills development, and since the learning and the evaluation of these soft skills is much more complex than technical skills, we introduced, for the first time in 2017-2018 academic year, the building of a portfolio of evidences in the frame of the Master's internship. It will therefore be centred on the soft skills competency named “Acting as a responsible engineer”.

Through this work, we will force students to reflect and start building their professional identity. Search traces, select and analyse them. It will help the students to acquire and perceive their real abilities.
Furthermore, this reflexive work will be exploited by the teachers to evaluate if the skill is really acquired. The next section will describe the process implemented during this test year.

5 From the Master’s internship to construction of their professional identity

5.1 Step 1: “traces” Workshop

In order to help the student in this new task, a “traces” workshop is programmed before the internship. The objective of this workshop is to help students to perceive what is expected in terms of development and proof of their skills. During this workshop we explain what can be a trace. Traces are numerous (Bélanger, 2008; Cahour and Licoppe, 2010): reports, research projects, videos, pictures, observations on professional situations, comments of supervisor, mind maps, emails etc. The important point is to select the relevant traces. The traces that can illustrate the level of skill acquired.

During this workshop, the professor explains to students what is expected of them. They have to instil curiosity, encourages students to imagine the situations in which they might collect some traces during their internship. The students have to be proactive, pay attention to each situation in order to collect those traces at the right moment. Generating discussion about the traces will enhance students’ observations during their internship.

5.2 Step 2: “Sharing of experiences” workshop

The next step is to help students analysing the traces, to practice critical thinking in order to create the evidences. A second workshop is organised later, during the internship, to guide the students in the analysis and writing process. During this workshop students can present and comment their own traces. Their colleagues can react and discuss about their interpretations with the help of the professor. When students compare their experiences and their visions, they will learn from each other. The students will suggest some ideas, some resources to their peers, help to step back from their analysis, and try to evaluate the quality of the traces. This questioning will be source of learning in itself. It is important to give them the opportunity to confront their analysis to other students, to professor.

At the end of this workshop the student must be more comfortable with his/her own analysis and the redaction of the portfolio.

5.3 Step 3: Presentation of the portfolio

At the end of their internship the students have to present their portfolio. Through this presentation they have to convince professors that they acquired the selected skills, how their internship has shaped their professional identity. The criteria of the evaluation have been explained to the students during the first workshop. The criteria will include “administrative” validity (authenticity, completeness) and criteria much more dedicated to the proof of competence. Those criteria are the relevance of the comments and the evidence that this learning is transferable to other contexts (bigger companies, global south context etc.)

In order to help student to visualize his/her progress, his/her level of acquisition, we opted for a graphical summary of the acquired stages (Figure 8). Thanks to this graphical representation the student can easily identify which skills are acquired and which ones he/she still has to work on.
6 Conclusion

The professional development of students and the learning of autonomy in self-knowledge are essential complements to the teaching of technical skills. Creating holistic engineers means giving this type of approach a significant role in curricula and adapting methods and assessments. Many initiatives are taking place around the world, it is essential that schools and universities communicate and exchange on these practices, because the diversity of practices and professional environments will only enrich the approach.

Our competency framework refers explicitly to soft skills which are difficult to train and evaluate in academic courses even the most specialized. To overcome this problem we introduced a portfolio combined to the internship during the master degree.

This process combined preparatory workshops to set the general framework of the portfolio (criteria, structure etc.) and to encourage students to remain alert during their internship to traces that can illustrate the level of acquired skills. A second workshop organised during the internship will be the place of sharing of experiences. During this time, students could compare, discuss about their own traces and the analysis they made of it. The role of the professor is therefore much more a guide than a teacher. At the end the student has to present his/her portfolio of evidences and prove to the professors but also to himself/herself that he/she developed identified soft skills.

We will follow our students during those workshops and evaluate the impact of this reflective practice on their learning and self-confidence. If this trial is a success, the portfolio could be extended to the whole competency framework.
7 References


Overview of a Whole Systems Multidisciplinary Sustainable Engineering Research Program

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Abstract

An overview of Villanova's sustainable engineering graduate research program that is open to all engineering disciplines and applies a whole systems (social, technical, environmental, economical and political) perspective to Master's and PhD level research problems will be provided. Villanova's program is unique in being truly multidisciplinary (reporting directly to the Dean of Engineering) and in fostering collaboration with discipline specific faculty across six tracks including energy, materials, infrastructure, water, climate change and international development. Examples will be provided of ongoing and proposed research in circular systems that minimize waste and maximize resource efficiency; systems designed for climate change resilience; and systems that provide more sustainable energy and materials. Highlights will include how nature is used in the design of improved solutions (biomimicry), how life cycle assessment methodology is used in concept development, and how internal and external cross discipline faculty and experts are engaged as advisors to increase the quality and value of the research and learning experience.

The program has been operating for over 7 years with more than 20 completed Master's theses, the introduction of a new PhD program in 2016, and a focus on industry sponsored research that was started in 2015.

1 Introduction

1.1 Characteristics of the program

The key characteristics of this program, that make it uniquely different from most other graduate research (Begg et al. 2015) is that it is:

- Multidisciplinary – students from all undergraduate engineering disciplines including chemical, civil, computer, electrical, and mechanical engineering are encouraged to do sustainable engineering research. Students with a non-engineering but related discipline may also do research. Typically related disciplines have included the sciences including biology and environmental science. Students in these non-engineering disciplines are required to take additional math or science courses as determined by their advisor and the program director. The program director reports to the Dean of the College of Engineering helping to reinforce the multidisciplinary aspect of the program and to encourage cross discipline collaboration.
• **Brings in a whole systems perspective** – a key characteristic of the research is that it is systems based from a perspective that cuts across the social, technical, economic, environmental and political (STEEP) dimensions. Reported and used as a foresight tool by Arup (ARUP, 2017) to ensure all stakeholders were adequately addressed in drivers for future change this has become a key element in our systems based program not only in research but also in our curriculum as each course addresses these five key dimensions (Schmidt et al. 2015).

• **Collaboratively engages specific disciplines** – students pick research problems and elective curriculum from six tracks that are related to their undergraduate discipline. These include energy, water, infrastructure, materials, environment and international development. Faculty across the College of Engineering and the University engage on an as appropriate basis to create a cross discipline collaborative research effort that enhances the overall quality and value of the research.

1.2 **Tiered research opportunities**

Students can engage in sustainable engineering research at various levels ranging from part of a team class project for an industry sponsored problem to a full PhD dissertation. These are described below and exemplified in the sections that follow.

- **RISE project** – RISE stands for “Resilient Innovation through Sustainable Engineering”. This is a consortium of local companies who have expressed interest in engaging students to investigate solutions to sustainability issues and problems they face. Typically teams of 3 to 5 students are assigned to company problems presented by the RISE members as part of a course project.

- **Capstone project** – this is a 3 credit primarily secondary research project that Master’s students typically do at the end of the 2 year program.

- **Master’s thesis research** – this comprises 2 courses and 6 credits that are done in the second year of the Master’s program and usually involves both primary and secondary research.

- **PhD Dissertation research** – this is intensive primary research on a major interdisciplinary problem with a whole systems perspective.

1.3 **Strategic Research Areas**

Based on the problems that have been brought forth by sponsors, as well as the ever emerging view of the critical needs in sustainability (see for example Friedman, 2014 and Rockstrom et al.,2015), the five areas shown in Figure 1 have been defined as key focus areas for sustainable engineering graduate research.

![Research Focus Areas](image)

**Figure 1: Strategic Research Focus Areas**
2 Examples of Sustainable Engineering Graduate Research

Examples will be provided for each type of research mentioned in Sections 1.2 above.

2.1 RISE Projects

More than 38 RISE company-sponsored projects have been completed since the initiation of this program in 2015. These projects are designed to be completed in a semester by a team of 3 to 5 graduate students as part of a course project. Starting in 2017 the focus has been on a phased approach where the first phase project in the Spring semester assesses the baseline current situation and proposes potential whole system sustainable engineering solutions to consider for further investigation. The first phase can be followed by a summer internship sponsored by the company that enables a more confidential deeper dive into the particular area of interest. This then nicely sets the stage for a new or second phase project in the Fall. All RISE projects are guided by a charter that is developed between the RISE member company and the Villanova team. Each charter clearly defines the scope, key deliverables and timing milestones. Weekly or biweekly meetings are then scheduled between the Villanova team and the Company leadership team for progress updates.

Examples of recent RISE projects have included a new screening tool for conducting a resource intensive vs. a less intense, higher level life cycle assessment, a quantitative valuation of the key drivers for sustainable business value, and an assessment of potential new supply routes for renewably sourced materials.

2.2 Capstone Projects

The Capstone research option was also implemented in 2015 and since then there have been over 10 completed capstones. This typically is the last course a Master student completes who is not performing Master thesis research but wants to do independent research. It is organized as follows:

- First third of the course: assess the current situation in the area from a whole systems STEEP perspective and identify opportunity for more sustainable solutions to address specific issues.
- Second third of the course: research the literature, the web, and other accessible evidence for more sustainable alternatives to address the issues identified in the first part of the course.
- Final third of the course: synthesize, create and provide a comparative whole system STEEP assessment for a recommended more sustainable solution or the absence thereof based on the overall, largely secondary research of the project.

Students present a 10 to 15 slide power point presentation at the conclusion of each part as well as a final 30 page word document report.

A capstone example that proposed an improved stormwater system for Philadelphia based on a biomimetic (inspired by nature) solution is shown in Figure 2. Similar systems such as Regenerative Stormwater Conveyance systems had already been implemented in Maryland (Hayes, 2016). This student
enhanced the design to use the flow more effectively, as beavers do in building dams (Rich, 2017) to filter out contaminants as well as provide for natural habitation and biodiversity. She presented a poster on this at the Villanova University Stormwater Conference in October of 2017.

Other capstones have included baseline assessments for supply chain sustainability (industry sponsored); biomimetic inspired three dimensional photovoltaic systems and water and sanitation systems for the developing world that required trips to the impacted areas.

### Capstone Example

**Biomimetic Stormwater Management**

- Proposed solution based on nature inspired tiered holding ponds with habitats and vegetation
- Replaces concrete trenches that do a poorer job of mitigating stormwater runoff
- Presented at VUSP conference chaired by Professor Robert Traver

Figure 2: Capstone Research Example – Biomimetic Stormwater Management

#### 2.3 Master’s Thesis Projects

Master thesis research formally begins in the Fall semester of the second year of the Master program. Students are encouraged, however, to choose their research problem at the end of their first year and conduct literature research over the summer.

Typically Master thesis level sustainable engineering research has involved a detailed whole systems STEEP assessment of the problem area, a detailed analysis and assessment of potential sustainable engineering solutions, and a final synthesis and creation of an improved tool or recommendation that provides new knowledge in the area. An example of thesis work in the circular systems area has been a novel waste to useful products system that has resulted in three published theses. This work, initiated at the request of a local waste hauler, started with a RISE class project using a life cycle assessment to evaluate a new circular system concept for treating biosolids to understand the net benefit (vs. business as usual) that turned out to be very strong. Three published Master theses (Jester 2016, Rogerro, 2016, and Spinner, 2017) describe the work leading to an integrated anaerobic digestion and hydrothermal carbonization process whereby biosolids, food waste and fats, oils and grease are converted to biomethane and hydrochar.
in a circular, symbiotic process. Figure 3 (Spinner, 2017) depicts a flow diagram for an integrated modular system concept to convert biowaste to useful hydrochar, nutrient streams and energy products.

**Master’s Thesis Example: Integrated Modular System to Convert Organic Waste to Energy and Other Useful Products**

As mentioned in section 1.1, a key characteristic of Master thesis Sustainable Engineering research is the involvement of discipline specific co advisors. In the above example, two Villanova College of Engineering professors served as co advisors: Dr. Metin Duran, a world class expert in anaerobic digestion, and Dr. Justinus Satrio, a world class expert in thermal conversions of biomass.

2.4 **PhD Dissertation Project**

The last example to be mentioned is from our newly launched PhD in Engineering for research in Sustainable Engineering. The PhD problem for this example is to develop a tool to help the Department of Defense take the impact of climate change into account when making acquisition decisions. The scope is focused on aircraft and the effect of temperature that directly affects density altitude and dew point. The work has integrated the extensive climate change models to provide statistically valid temperature projections at selected military installations and the performance impacts expected for both vertical and horizontal lift aircraft. The work is now focused on developing the vulnerability assessment tool that can be used in decision making and that brings in the whole systems STEEP perspective. A critical element of success in this work is the outstanding cross discipline advisory committee that comprises a former climate officer in the Navy, external academic advisors with specific expertise in related applications of climate change impact to other areas such as hydrology and sustainability modelling and assessments and internal professor co advisors in analytics and dynamic systems and the Geography and Environment. An overview of this PhD work is shown in Figure 4 (McRae 2017).
3.0 Conclusions

The Villanova Sustainable Engineering Research graduate research program is differentiated and unique in its engagement with industry, its whole systems and life cycle dimensions, its cross-discipline collaborations, and the tiered opportunities for students ranging from class projects to full time doctoral research. Work continues in all of the five focus areas mentioned in Section 1.3.

4.0 Acknowledgements:

The work described in this paper represents contributions from many student and faculty colleagues and industry sponsors.

The RISE forum is directed by Professor Karl Schmidt. Students who led some of the work cited as examples include Alicia Piscitelli for the high level LCA tool, Alyson Perez for the business value assessment and Nicole Meyer for the renewably sourced materials. Company sponsors for these RISE examples included Boeing, International Flavors and Fragrances and FMC.

Monique Philips did the work in the cited capstone example and Dr. Robert Traver served as a co advisor.

Dan Spracklin, CEO of Somax Environmental (DBA Gray Bros. Inc.) had the initial vision for the integrated waste to useful products system and sponsored the three Master students cited.

Finally, the Sustainable Engineering graduate program in general and the research program in particular evolved from the early vision of current Program Director Bill Lorenz along with Pritpal Singh, Randy Weinstein and Al Ortega.
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Environmental Engineering for Community Development -
Engineering Design for Non-Engineering Majors

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Abstract

In her landmark paper “Entering the Century of the Environment: A New Social Contract for Science”, Jane Lubchenco posed four key questions: (1) How is our world changing? (2) What are the implications of these changes for society? (3) What is the role of science in meeting these challenges created by the changing world? and (4) How should scientists respond to these challenges? In October 2004, the Barcelona Declaration provided an outline for engineers to answer the questions posed by Dr. Lubchenco and strive to achieve sustainable development. Understanding the commonalities and unique perspectives to create sustainable solutions applicable to the context of the engineering problem is paramount to the development of holistic engineers. Environmental engineers that complete an engineering design problem in both the developing and developed world contexts will be best served to meet the needs of the future, independent of the context they might find themselves. A semester-long course that addresses engineering challenges in the developing world focused solely at the undergraduate level is unique. At the United States Military Academy, a senior-level environmental engineering design course was created to focus the sustainable development principles outlined in the Barcelona Declaration on a real-world scenario often found in the developing world.

Environmental Engineering for Community Development utilizes a semester-long design project to integrate stakeholder analysis to inform the technical water, sanitation, and hygiene (WASH) solutions that culminates in an engineering decision-making exercise. This course is taken by non-engineering majors that choose to complete their STEM education requirement with the environmental engineering sequence. This course is taken by a unique, multidisciplinary student population that encompass a wide range of skills and attitudes toward engineering problems. The course content and creation of the engineering design project will be discussed as an example of how problem-based design courses can provide engineering students, both ABET and non-ABET majors, the opportunity to think more holistically about the interaction between stakeholders, engineers, and decision makers to ensure sustainable solutions are valued in future decision making. The course emphasizes the inclusion of social, cultural, economic, political, and technological perspectives to influence the engineering design that is proposed.
1 Introduction

In October 2004, the Barcelona Declaration provided an outline for engineers to strive to achieve sustainable development by understanding how engineering solutions interact with society and the environment to identify potential challenges, risks, and impacts (EESD, 2004). Understanding the commonalities and unique perspectives to create sustainable solutions applicable to the context of the engineering problem is paramount to the development of holistic engineers. Jane Lubchenco posed four key questions in her paper, “Entering the Century of the Environment: A New Social Contract for Science” consisting of (1) How is our world changing? (2) What are the implications of these changes for society? (3) What is the role of science in meeting these challenges created by the changing world? and (4) How should scientists respond to these challenges? The questions were developed as a need for different perspective on how the sciences can and should advance and also return benefit to society (Lubchenco, 1998). The need for an understanding how humans impact the environment also became evident in the 20th century through a number of high-profile environmental disasters, including those documented in Silent Spring (Carson, 1962) and Thomas Hardin’s paper on the tragedy of the commons (Hardin, 2003). Although the technical component will continue to be the core of an engineering education in developing solutions to complex problems, economic, political, social, and environmental contexts of engineering must also be addressed as highlighted by the National Science Foundation (NSF, 1995). The American Society for Engineering Education (ASEE) also addressed the value of focusing on the economic, political, social, and environmental contexts of engineering, primarily through attracting an ethnic and social diversity of students that better reflects the diversity of the U.S. and takes full advantage of the nation’s talents bringing different viewpoints to the classroom (ASEE, 1994).

The United States Military Academy’s (USMA) mission is to “educate, train, and inspire the Corps of Cadets so that each graduate is a commissioned leader of character (USMA, 2017).” With respect to the “educate” part of the mission, the Dean of the Academic Board publishes a strategic document outlining the specific aspects of the educational domain. The recently published document, Educating Army Leaders: Developing Intellect and Character to Navigate a Diverse and Dynamic World, states that, “West Point educates and inspires leaders of character who think critically, internalize their professional identity, and employ their education to help build the Army and the nation’s future (USMA, 2017).” The specific aspects of the educational domain directly align with the challenges addressed by the Barcelona Declaration by having students understand the contribution of engineering solutions and taking into account the different cultural, social, and political contexts. In order to focus on the sustainable development principles outlined in the Barcelona Declaration, a senior-level environmental engineering design course was created emphasizing a real-world scenario often found in the developing world. Environmental engineers that complete an engineering design problem in both the developing and developed world contexts will be best served to meet the needs of the future, independent of the context they might find themselves.

2 Course Design

West Point maintains a four-year program from which every student graduates with a Bachelor of Science degree. All students enrolled in a non-engineering program must complete a three-course engineering curriculum during their third and fourth year. The first course of the environmental engineering curriculum focuses on the global and local issues that affect public health and the environment. The second course builds upon these themes to teach engineering design using environmental engineering technologies
and evaluate proposed sustainable solutions in developed countries. The final course serves as a stand-alone capstone event for the three-course environmental engineering sequence addressing engineering challenges in the developing world. As such, the capstone course, is designed to be robust and challenges students to link concepts from the first two courses focusing on environmental science and environmental engineering technologies, to solve problems that are open-ended and contextually-based in the developing world. Students are expected to integrate concepts from core curriculum courses, their life experiences, and the experiences and training from the military program. A large portion of the course is dedicated to the students developing concrete answers to problems by applying science, technology, engineering, and mathematics (STEM) skills. However, the semester long design project is a realistic, open-ended problem representative of a humanitarian assistance or disaster response scenario. It is through this design problem that the students are challenged to synthesize potential solutions, assess their feasibility, and make a final recommendation based on the students’ analysis and judgment. The engineering design process threaded throughout the course is shown in Figure 1 as it pertains to the significant blocks of instruction.

In order to engage and inspire students with a relevant assignment, a semester-long design project was developed that focused on environmental engineering problems in the developing world. With a focus on the United National Sustainable Development Goals (SDG), the course specifically focuses on Goal 6: Clean Water and Sanitation and Goal 7: Affordable and Clean Energy. These two goals highlight the main challenges presented in the course, a method to provide clean water and sanitation while also developing a technique to produce clean energy for a community. Context for the course was selected in order to provide a challenging experience and perspective most students have not encountered before. Although students may have heard about the lack of natural resources as the population on the Earth continues to increase, the goal for the course is to design technologically and culturally appropriate solutions and then communicate the solution through both an oral and written presentation. With technical design calculation, drawings, and written communication as the main assessment components, the course is also structured to provide for a hands-on experience. Many universities have incorporated different hands-on approach in teaching
engineering concepts to non-engineering students particularly in lab experiments. The hands-on approach advances the knowledge and understanding of engineering and its overall importance in transforming society (Halford, 2004). The capstone course incorporates two water treatment lab exercises focused on particle removal and pathogen inactivation along with several in-class demonstrations in order to best visualize the concepts from the course content. The course is separated into four themes separated into blocks with the semester-long project requirements aligning with each block of the course. Block 1 focuses specifically on community and engineering assessments, framing the problem, identifying key stakeholders, conceptual analysis and conceptual overlays. Block 2 and 3 focus on General Engineering solutions within the context of water, sanitation and energy. Finally, Block 4 emphasizes decision-making, value-based trade-off analysis, and cost analysis.

During the semester-long design project, students address the aforementioned challenges affecting developing communities. Students analyze potential solutions and recommend a course of action to best meet the needs and wants of the community. At the end of the course, the design teams present their findings and results in a decision briefing. The unique aspect of the course is the analysis of social, cultural, economic, political, and technological perspectives to influence the engineering design through military doctrine reinforcing the challenges students will be confronted with during their careers. The strategic and operational environment is analyzed through eight interrelated operational variables: political, military, economic, social, information, infrastructure, physical environment, and time known as PMESII-PT (Department of the Army, 2011). Students are expected to use these operational lenses to evaluate the operational environment within the community. The operational variables analyzed reinforce the intent highlighted by both ASEE and the NSF in addressing the external factors of engineering coupled with bringing different viewpoints into the classroom. The critical analysis enables students to understand the role of key stakeholders, how they can apply influence over the project area, and ultimately affect the engineering solution. Tied to the military framework, students also analyze civil considerations using elements of ASCOPE (areas, structures, capabilities, organizations, people, and events) by highlighting key points of each operational variable as they apply to the community. Throughout the course we teach the essential PMESII-PT/ASCOPE framework principles and the application thereof. The goal of incorporating this framework into the classroom is to have the students integrate people and processes, using multiple information sources and collaborative analysis to build a common, shared, holistic knowledge base of the operational environment (Department of the Army, 2011).

With an understanding of the community and the various stakeholders, the next focus is to develop engineering solutions for water and sanitation challenges through data collection of the area, applying engineering judgement based on lessons learned in class, and identifying feasible solutions given the constraints within the community. Technology, like Google Earth, is integrated throughout the course within the engineering process to assist visualization of the overall layout of the community, identify key terrain features, and the impact of elevation changes. Students are provided with water usage data from the community to generate possible solutions. The possible solutions are distributed into three different assignments with the focus on water supply and distribution, sanitation services, and energy demand. The cost for these projects is not taken into account at this stage, rather, the feasibility of the engineering solutions are the main focus. As the course progresses, students are expected to analyze different courses of action available within the context of the design project through a functional hierarchy analysis. The functional hierarchy analysis entails identifying the functional objectives and their corresponding functions, objectives and corresponding value measures. Value Measures will typically correspond directly to specific outcomes. The economics factor combined with the value measures of the community identifies which
solutions are feasible based on their willingness to pay and their ability to pay. Students are provided with various engineering solution combinations to choose from, the cost for each solution, and the community’s average annual income to take determine which solution is the best based on the specific value measures analyzed.

3 Student Assessment Data

The student assessment data to support the claim that this course is a valuable approach for undergraduates to integrate sustainable development into solving engineering problems is represented through a population of stakeholders who assess if graduates demonstrate the expected level of intellectual competence and critical and creative thinking skills. The stakeholders in the survey are defined as the supervisors of recent graduates who serve alongside them and assess their critical thinking skills in an operational environment. One aspect that stakeholders identified as highly important was Critical and Creative Thinking. The ability to assess critical and creative thinking is often a great challenge during an undergraduate experience. It is during undergraduate education that students are learning the fundamental knowledge of the discipline and beginning to master the associated skills to apply that knowledge. Learning activities such as design projects assist in this aspect of student development. This is especially true when the design prompt is very “open-ended” with a wide range of potential candidate solutions that will involve some degree of “trade-off” analysis to make the best recommendation. It was hypothesized that it would be most valuable to students in the three to four year post-graduation period by developing broad design problems that mimic case study scenarios allowing maximum freedom to apply various solutions.

Longitudinal assessment data from the course demonstrates an increase performance in students’ ability to apply the environmental engineering design process to develop solutions that are both effective and adaptable to community problems in the developing world. Using a Likert-type scale with responses consisting of 1 to 5, where 1 represents a low understanding and 5 represents a high understanding, in the previous four years students scored an average score above a 4.0, ranging between a 3.98 and 4.38, as seen in Table 1. The focus on a “real-world” scenario in the developing world, changing from regions in Africa, Asia, and South America, provided students with the ability to engineer solutions based on the geographic location in question given resource constraints. The internal course assessment data also indicates an overall increase in the ability to identify and analyze the relevant dimensions (such as environmental, political, social, economic, and technological) of community problems in the developing world and their ability to use a value-based decision-making model to assess multiple engineered solutions to enhance community resilience.
Table 1. Course Assessment Data

<table>
<thead>
<tr>
<th>Course Outcome</th>
<th>2014</th>
<th>2015</th>
<th>2016</th>
<th>2017</th>
<th>2018</th>
</tr>
</thead>
<tbody>
<tr>
<td>Identify and analyze the relevant dimensions of community problems in the developing world (such as environmental, political, social, economic, and technological).</td>
<td>3.97</td>
<td>3.98</td>
<td>4.13</td>
<td>4.17</td>
<td>4.19</td>
</tr>
<tr>
<td>Apply the environmental engineering design process to develop solutions that are both effective and adaptable to community problems in the developing world.</td>
<td>3.90</td>
<td>3.98</td>
<td>4.12</td>
<td>4.23</td>
<td>4.38</td>
</tr>
</tbody>
</table>

4 Conclusion

The Preamble from the Barcelona Declaration states Universities need to prepare future professionals who should be able to use their expertise not only in scientific or technological context, but equally for broader social, political and environmental needs (EESD, 2004). The NSF previously mentioned that although the technical component will continue to be the core of an engineering education, economic, political, social, environmental contexts of engineering need to be explicitly addressed (NSF, 1995). The National Academy of Engineering has also stated that activities should highlight how engineering benefits people, animals, the environment, and society (NAE, 2008). A capstone course focused on community development designed to teach engineering to non-engineers meets the needs previously highlighted. This course was specifically developed to leverage the strength of project-based learning and applies military doctrinal frameworks within an environmental engineering body of knowledge. The capstone course itself may not produce environmental engineering experts, however, the course is designed to produce critical thinkers who possess fundamental engineering skills. Different from other institutions where graduates continue to pursue a career in engineering practice, the graduates from this course and USMA join the military to lead Soldiers in complex and dangerous environments, often faced with difficult, ill-structured problems. The semester-long project focused on water, sanitation, and energy issues replicate the set of challenges through realistic problem sets where students are challenged to apply both the military and engineering frameworks along with the engineering design process. Although these students may not practice engineering in their future, through their experience in the course, they gain an appreciation how of the impact of engineering solutions can transform a community.
References


2016 Feedback from the Field - External Stakeholder Assessment of USMA Graduate Performance, United States Military Academy, West Point, NY, 2016.


An Evaluation of Introduction to Industrial Engineering Course at Sabancı University Using CIPP Model

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Abstract

Identifying course objectives in accordance with the needs and expectations of students and industry with a focus on both efficiency and sustainability has been a challenge for engineering programs. The gravity of this complicated issue arises in designing the introductory courses to familiarize students with the profession as well as introducing the content of the successive years. Within this respect, we conducted an evaluation project at Sabancı University on the curriculum of an introductory course in industrial engineering. This study reports the findings obtained on content organization and alignment of learning outcomes with the main goals of the course. We adopted convergent parallel mixed method in which quantitative and qualitative data are collected and analyzed separately through content analysis and descriptive statistics (Creswell, 2014). We collected data from multiple qualitative (i.e., semi-structured interviews and document analysis) and quantitative sources (i.e., surveys and objectives alignment scale). Our results suggest that this introductory level course comprises rather theoretic and complicated subjects. Agreeing upon the complexity of the course content and incongruence of learning outcomes with the course goals, the lecturers recommended introducing more conceptual but less methodological topics.

1 Introduction

Bridging the gap between engineering curricula and industry needs and expectations has been an ongoing effort to raise more skilled engineering graduates which is otherwise underlined to pose a real threat to the competitiveness in the global market (Lang, Cruse, McVey & McMasters, 1999). In addition, challenges with incorporating the notion of sustainable development and aspects of sustainable engineering into higher education have been forthcoming more recently (Allenby, Murphy, Allen & Davidson, 2009; Segalàs, Ferrer-Balas, Svanström, Lundqvist & Mudler, 2009). Adopting a learner-centered, liberal education approach, which aims to facilitate the needs and desires of the learner to become a fulfilled individual (Cronon, 1998; Ellis, 2013), Sabancı University in Turkey intends to equip students with a broad knowledge of science, literature, history, mathematics and the arts. The Industrial Engineering (IE) is the largest diploma program declared by almost 700 students as their majors at the end of their Foundation Development Program (i.e., freshman year) as of 2016-2017 academic year. Equipping students with essential skills in congruence with the requirement of the profession to become problem solvers, entrepreneurs, advocates of sustainability, and change agents within the society constitutes the major aims of the IE program.

Traditionally, the profession of industrial engineering with a system-wide focus is engaged with designing and planning parts of systems to produce results in an optimal manner, concerned mainly with efficiency by reducing the consumption of resources. Considering the technological developments and environmental issues, this perspective should be expanded with the aim of reducing the hazardous impacts on resources as well. Falling behind the technological developments, needs of the society and demands of
the market, the IE curricula are undergoing a revision process with redesigning the three fundamental courses which are offered consecutively and built conceptually upon each other: ENS 208 Introduction to Industrial Engineering, IE 301 Deterministic Models in Operations Research and IE 302 Stochastic Models in Operations Research. ENS 208 is the first course of this chain and aims to introduce the industrial engineering field as well as laying the foundation of the successive courses. A course evaluation which provides information on program adoption, continuation or expansion was conducted in ENS 208 in Spring 2017 semester to help decision makers in forming judgments on necessary aspects for revision (Fitzpatrick et al., 2004). As a part of that evaluation project, this study focuses on content organization of ENS 208 and aims to shed light on following research questions:

1) Are learning outcomes and content organization of ENS 208 aligned with the main goal of the course?
2) Can students establish the relationship among content units at the end of semester?

1.1 Origin of the ENS 208 Introduction to Industrial Engineering Curriculum

ENS 208 Introduction to Industrial Engineering is a sophomore level first course in the IE program. As an introductory course, it is open to all students at the university; students may take this course either before or after they declare their majors. Upon completing ENS 208, sophomore students can decide to go on studying in Industrial Engineering or declare another major. Therefore, such a course might be a milestone for students in choosing their majors. Every regular semester, more than 200 students who would like to be acquainted with industrial engineering profession take this course.

The curriculum development process has been carried out as compilation of some related topics from a textbook and sequencing them in line with the goal of the course. The content is broken down into discrete subjects and planned in advance by the instructor(s) according to the textbook. Criticizing the adoption of course books as curriculum, Ellis (2013) states that this approach ignores the expressed learner interest despite the fact that it provides structure in the form of scope and sequence while ensuring equal access to knowledge and providing each student with the basic knowledge s/he needs.

1.2 Characteristics of Introduction to Industrial Engineering

With three lecture hours and one-hour recitation a week for 14 weeks, ENS 208 is studied at a very elementary level to teach fundamental notions and represent the course work in the later years of the program. The course content has been organized thematically around three major themes regarded as the most traditional and fundamental areas in industrial engineering:

- Deterministic models in operations research
- Operations in production and service systems
- Production and service systems planning problems

The main goal of ENS 208 is to familiarize students with the Industrial Engineering profession by introducing the content of the junior and senior year courses delivered later in the program. Table 1 illustrates the current learning outcomes of the course as planned. Each outcome encompasses skills in cognitive domain according to Bloom’s taxonomy that is a framework to organize educational objectives and explains the levels of expertise to achieve each measurable students’ outcome (Bloom et al., 1956).
Table 6: ENS 208 Current Learning Outcomes and Corresponding Cognitive Level

<table>
<thead>
<tr>
<th>Learning Outcomes</th>
<th>Cognitive Level</th>
</tr>
</thead>
<tbody>
<tr>
<td>To be familiar with and utilize the most important methods for forecasting demand.</td>
<td>Remember /Apply</td>
</tr>
<tr>
<td>To develop aggregate production plans.</td>
<td>Create</td>
</tr>
<tr>
<td>To model and solve linear programming problems</td>
<td>Apply / Create</td>
</tr>
<tr>
<td>To use graphical solution technique</td>
<td>Apply</td>
</tr>
<tr>
<td>To perform sensitivity analysis.</td>
<td>Apply</td>
</tr>
<tr>
<td>To model and solve transportation, assignment, fixed-charged, and knapsack type of problems.</td>
<td>Apply / Create</td>
</tr>
<tr>
<td>To be familiarize with basic concepts in deterministic inventory management and control individual item inventories.</td>
<td>Understand</td>
</tr>
<tr>
<td>To gain an understanding of the key methods for shop scheduling and assembly line balancing.</td>
<td>Understand</td>
</tr>
<tr>
<td>To utilize mathematical and graphical techniques for project scheduling.</td>
<td>Apply</td>
</tr>
</tbody>
</table>

Organizing the course outcomes regarding the can-do statements in the taxonomy allows the practitioners to choose appropriate techniques for the course. Figure 1 summarizes the cognitive levels in Bloom’s revised taxonomy and what students are expected to perform as they proceed from low-levels of thinking to higher.

![Bloom’s Revised Taxonomy](Vanderbilt University Center for Teaching)

2 Method

2.1 Research Design

The evaluation study adopted convergent parallel mixed method in which quantitative and qualitative data are collected and analyzed separately (Creswell, 2014). We collected data from multiple qualitative and quantitative sources separately and combined their results in the final stage to reveal whether the findings would confirm or disconfirm each other. Within mixed method designs, we utilized partially
mixed concurrent equal status design with two concurrent phases by giving equal weight to quantitative and qualitative data (Leech & Onwuegbuzie, 2007).

2.2 Evaluation Model

The complete evaluation project was planned to adopt the CIPP evaluation model (Context, Input, Process and Product) which is a management-oriented approach and regards the evaluative information as a crucial part of good decision making (Fitzpatrick et al., 2004; Stufflebeam, 1971). This part of the study discusses the findings obtained from only two phases: Input phase to identify and assess system capabilities including alternative program strategies, and Product phase to gather data about the outcomes of the program and relate them to objectives (Fitzpatrick et al., 2004; Stufflebeam, 1971). Whereas the Input phase was employed to seek answers on the alignment of ENS 208 learning outcomes and content organization with the main goal of the course, Product phase aimed to reveal the extent students can establish the relationships among units at the end of semester.

2.3 Data Sources, Participants and Instruments

Data were collected through the following sources to triangulate the findings and gather multiple perspectives:

- Course outline, learning outcomes and goals was examined.
- To investigate the alignment of current ENS 208 learning outcomes with the course main goals, a survey was administered to all lecturers in the IE program (N=15). Participants rated the relationship of each outcome with the main goals on a 4-point scale ranging from 1= None to 4= High relation. They were also asked three open-ended questions to reveal any irrelevant learning outcomes and to suggest new ones.
- Two distinct surveys including items on course outcomes were administered to current ENS 208 students (n=79) and senior IE students (n=66) through a Likert type scale.
- Individual semi-structured interviews were conducted with current ENS 208 students (n=8) asking questions on course organization and outcomes. Interviewees were selected based on their GPA scores with criterion sampling method.

The face validity of all instruments (appropriateness, clarity and wording of the items) was scrutinized by an expert in the field of Curriculum and Instruction, a subject-matter specialist and five Ph.D. students.

2.4 Analysis

The document analysis was conducted with the subject matter specialist to check the internal consistency of the curriculum. Quantitative data including lecturers’ outcomes alignment scale and the results of current and senior students’ questionnaires were analyzed by descriptive statistics using SPSS 23.0. Qualitative data consisting of interview results and open-ended items in the questionnaires were analyzed by a content analysis procedure using descriptive coding that helps categorize and index the data for further analytic work (Saldaña, 2011).

3 Results

Regarding the main goal of the course as familiarizing students with the IE profession and the content of the successive courses, we endeavoured to find clear-cut answers about the students’ and lecturers’ expectations from an introductory course content in a program adopting the liberal education approach.
3.1 Are current learning outcomes and content organization of ENS 208 aligned with the main goal of the course?

The lecturers in the program rated only one outcome of the course as highly related to the main goals of the course (60.2%) which is formulated as modelling and solving linear programming problems (Outcome 3). Three outcomes were considered to have low relationship with the goals (Outcomes 5, 6, and 8); five of them were regarded to have medium relationship (Outcomes 1, 2, 4, 7, and 9).

Emphasizing the complexity of the content, the lecturers underlined that current course organization should be modified to include more generic topics. Some of the lecturers marked that:

(Lecturer A) I think that these outcomes are not sufficient. There are some other basic IE concepts which are more conceptual and less methodological. For example, the students could get familiar with modelling a system (without technical details); like drawing a flowchart to see the big picture of a system.

(Lecturer B) We are pushing too much to teach several subjects. Instead, we need to focus on the general ideas in industrial engineering. I value two things very much:

1) Modelling of various deterministic and stochastic models in inventory management, transportation and scheduling.

2) Preparing students for computational thinking with a tool like Python or Matlab, where students need to go through the basics of optimization and simulation.

Table 7: Learning Outcomes Alignment Scale Results

<table>
<thead>
<tr>
<th>ENS 208 Learning Outcomes Alignment Scale</th>
<th>None</th>
<th>Low</th>
<th>Medium</th>
<th>High</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. To be familiar with and utilize the most important methods for forecasting demand.</td>
<td>7.7%</td>
<td>30.8%</td>
<td>46.2%</td>
<td>15.4%</td>
</tr>
<tr>
<td>2. To develop aggregate production plans.</td>
<td>15.4%</td>
<td>30.8%</td>
<td>38.5%</td>
<td>15.4%</td>
</tr>
<tr>
<td>3. To model and solve linear programming problems</td>
<td>-------</td>
<td>------</td>
<td>30.8%</td>
<td>60.2%</td>
</tr>
<tr>
<td>4. To use graphical solution technique</td>
<td>7.7%</td>
<td>15.4%</td>
<td>53.8%</td>
<td>23.1%</td>
</tr>
<tr>
<td>5. To perform sensitivity analysis.</td>
<td>15.4%</td>
<td>38.5%</td>
<td>30.8%</td>
<td>15.4%</td>
</tr>
<tr>
<td>6. To model and solve transportation, assignment, fixed-charged, and knapsack type of problems</td>
<td>-------</td>
<td>38.5%</td>
<td>30.8%</td>
<td>30.8%</td>
</tr>
<tr>
<td>7. To be familiar with basic concepts in deterministic inventory management and control individual item inventories.</td>
<td>7.7%</td>
<td>15.4%</td>
<td>46.2%</td>
<td>30.8%</td>
</tr>
<tr>
<td>8. To gain an understanding of the key methods for shop scheduling and assembly line balancing.</td>
<td>7.7%</td>
<td>53.8%</td>
<td>23.1%</td>
<td>15.4%</td>
</tr>
<tr>
<td>9. To utilize mathematical and graphical techniques for project scheduling.</td>
<td>7.7%</td>
<td>38.5%</td>
<td>38.5%</td>
<td>15.4%</td>
</tr>
</tbody>
</table>

Though the lecturers consider most of the outcomes not aligned with the main goals, both current and senior students agree that the course enabled them to gain an insight about the IE profession to some extent, and they became familiar with the content of successive courses (M scores range from 3.50 to
A senior student emphasized how this course led him/her to choose the IE program and helped him/her to understand the content of the successive courses:

(Student C) From the very beginning of the course, we were informed about the various fields where an industrial engineer can work. Besides, our lecturer invited a couple of foreign and Turkish industrial engineers as guests to introduce their projects which encouraged me to work in this field. (...) It is a very crucial course as it lays the foundation of the successive courses. I think students experiencing difficulty in this course should not choose the IE program. In this respect, it is a very useful course.

Despite the fact that both students and lecturers agree on the achievement of ENS 208 introducing the IE profession, they also assert that the course is comprised of too many topics to cover. In this context, senior students partially agree on the statement that the content of the course is appropriate for sophomore students ($M=3.70$, $SD=1.55$). To support this result, it was reported by both senior students and lecturers that some topics in successive courses overlap with the content of ENS 208 ($M=4.15$, $SD=.96$). The “overlap” refers to the similarities in the first weeks of some junior and senior level courses; this overlap causes some students to assume that they already know these topics and eventually result in their absence. For instance, the units on sensitivity analysis in linear programming and forecasting are suggested as appropriate to be moved to successive courses. To exemplify what similar contents are covered in the junior and senior year courses, lecturers stated that:

(Lecturer C) Most of those overlap with IE 401 such as aggregate planning, forecasting, and inventory management.

(Lecturer D) I would say any subject that constitutes the first few lectures of a latter course should be omitted. We need to gradually use them in modelling or computational thinking.

3.2 Can students establish the relationship among units at the end of semester?

Students indicated, in the questionnaires and interviews, that topics are somewhat interrelated and built upon each other leading to become familiar with the IE profession as well as the fundamental topics in the field. In this respect, current students partially agreed on being able to relate different topics to each other ($M=3.58$, $SD=1.15$) whereas senior students reported that they managed to build relationship among different topics in ENS 208 ($M=3.72$, $SD=1.09$). Two current students pointed out that:

(Student G) I think topics are interrelated. For example, we have just started to study a new topic which is based on a previous topic covered in this course.

(Student H) Yes, topics are interrelated but they sometimes remain too theoretical despite the fact that they are not too complicated.

As another indicator demonstrating the extent of students’ establishing relationships among units and overall success of the course, we consulted on the end of year achievement scores in two semesters of 2016-2017 academic year. Even though current ($M=4.11$) and senior students ($M=3.51$) thought that they are familiar with the profession as a result of this course, 36% of the students could not get a passing grade in Fall 2016 whereas it raised to 54% in Spring 2017.

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5 To interpret the results of items assessed on a 5-point Likert scale in students’ questionnaires, mean score intervals are determined as follows: Disagree: 1.00 - 1.79, Partially Disagree: 1.80 – 2.59, Undecided: 2.60 – 3.39, Partially Agree: 3.40 – 4.19, Agree: 4.20 – 5.00. $M$ denotes mean scores; $SD$ denotes standard deviation.
4 Conclusion

In terms of the complexity of the topics and formulated outcomes referring to higher-cognitive skills, senior students and lecturers agree that the course appears to be above the cognitive level of students who do not possess any prior background about the field. Students also frequently declared that the current curriculum comprises of subjects that are too theoretical or somewhat complicated. Thus, it is suggested to include more generic concepts and fundamental notions that belong to industrial engineering field such as systems thinking, decision making and problem solving. While doing this, the curriculum should also be aligned with technological developments and needs of the society as they stand out as the major motivational challenges. While training the industrial engineers to work towards the traditional goals of profit maximization or cost minimization, other goals such as minimizing the negative impacts on society and environment shall be considered along. Nazzal et al. (2015) suggest that industrial engineers should be aware of such goals and must also be trained to apply their skills to solve problems with a united focus on profitability and sustainability. In this respect, a sustainability perspective should also be integrated into an introductory level course while including more fundamental notions.

It is crucial to align learning outcomes with the main goal of the course to enable learners to equip with intended skills. In our case, the inappropriateness of the learning outcomes with the main goal of the course as revealed by the lecturers was confirmed by a high percentage of the failure of the students. Surprisingly, the majority of the students believe that the course provides connections among various content units.

5 References


Piloting the flight, a systems methodology for sustainability education

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Abstract

This presentation marks a three-year point in time, that communicates the sum of outcomes proposed to be complete in an exploratory fashion towards formulation of a robust systems and sustainability education research program. Research undertaken was based on coordination with Colorado School of Mines faculty but involved many interactions with professional organizations, society, and firms. Ultimately, replication of an approach was demonstrated in another community, i.e. Richmond VA. Overall, individual components of each separate experience-situation during exploration is termed a vignette. Ten exploratory vignettes comprise grass roots or on-the-ground exploration. Reflexive assessment considering interactions with all elements-actors resulted in the casting of a methodology termed: WEARS, i.e. Wicked problem, Experiences, Available Resources, Solution. Updates are provided for the two most recent vignettes: a nexus low cost transportation module and an internet of things approaches to energy-apps-controls. Finally, a pilot effort with international students is described that illustrates an inaugural cohort’s interests. Overall, it was concluded that program formulation is possible. In the future, iteration of a program in coordination with a higher education institution that promotes interdisciplinary education, innovation and professional skill development is proposed. Specifically, means to select program candidates and longitudinal study of overall impacts complement efforts to date.

1 Background

In previous research, bottoms up experiences within firms, in higher education and change agent roles were utilized to formulate reflexive education suited to student interests (Jensen 2016). Learned outcomes are relevant and aid in formulation of approaches to address proposed modern social desiderata (Fig.1) classically known as a category of challenges termed as wicked problems (Churchman, 1967; Rittel & Webber, 1973).
Research was undertaken in a call from higher education faculty-mentorship at the Colorado School of Mines for a robust actionable approach to sustainability topics including establishing relevant human elements and balanced (holistic) approaches to applied education outcomes. Overall, the author’s experiences indicate that interdisciplinary approaches are required to impact wicked problems. Generally, there are a lack of examples or rigorous analysis of multidisciplinary programs, with focus on global action plan elements\(^1\). Realistically, achieving sustainable development connects entrepreneurial spirit, innovation, hard and soft sciences as components of graduate programs\(^2\).

Clear and globally agreed upon indicators that account for social impact or that are qualitatively related to deep sustainability philosophies are rare to non-existent. The United Nations suggested facilitating strategies to promote sustainable development but again, deeper study demonstrating outcomes does not readily appear in the literature. It is perceived that the resultant favor of higher education institutions after the decade for higher education for sustainable development is to offer a number of shorter certificate programs. During the course of this research, it was found that liberal arts programs in the United States dominate educational opportunities that specifically make use of the term: sustainability. Some higher education institutions were found to incorporate international service learning projects into education.

\(^1\) More details of the UNESCO Global Action Plan for education on Sustainable Development can be found here: [https://en.unesco.org/gap](https://en.unesco.org/gap).

\(^2\) A flagship program in the United States involved the National Science Foundation program known as the Integrated Graduate Education Research and Training. [http://www.igert.org](http://www.igert.org).
programs. Chapters of the non-profit: Engineers Without Boarders are found at higher education institutions with focus on hard sciences. An emerging trend is that educators and professionals often suggest complimentary specific online classes. However, there is a lack of data detailing impacts, analysis and outcomes associated with individual courses vs. actual accredited programs, certificates or complimentary efforts. Surprising to the author, discussion can be contentious on education approaches despite Sustainability being recognized as a science (Matson et al. 2016).

2 Body

• Motivation

It was estimated that this research required a minimum of three-years, in order to formulate formalized education structure in a peer reviewed fashion. This presentation will share the process of how outcomes from efforts over the span of this time led to a specific personalized education approach. Each separate experience-situation during exploration is termed a vignette (Jensen 2015, Jensen 2016). After multiple professional interactions, central elements of this presentation include highlighting recent outcomes in a pilot program and the most popular vignette that could contribute to a competitive and experiential degree program (Jensen 2016). The presentation overall suggests delving further into the degrees -perspectives-elements of wicked problems via reasonable approaches towards achieving solutions central to a learner’s interests and driven by yet to be refined means of assessment with faculty.

Proposed supporting education includes policy skill development, innovation and reflexive thought processes. The suggested approach spotlights bridging undergraduate and graduate education (Jensen 2016A) to create a holistic learning environment centered on student interest. A focus for such a program is suitable for graduate education, that builds upon the accomplishments of undergraduate programs that contains essential core profession skills. Focus on graduate education allows for customized individual interests but contributes to the creation of so called T-shaped engineers. In conversations with educators and professional societies, undergraduate programs are decreasing in credit requirements therefore becoming strained to include topics that are considered to be important for individual professions. Graduate school is a natural setting that prompts dynamic student driven outcomes to replace traditional education, e.g. Cartesian means of learning.

• Methods

Methods utilized during the course of this research include semi-structured and unstructured conversation with actors from professional societies and via participatory action research (Jensen 2016). Personal resources and professional relationships were utilized to participate in professional meetings central to the principles of chemical engineering (e.g. via the American Chemistry Society and the American Institute of Chemical Engineers). Personal resources were also utilized to develop projects of specific interest to partners-stakeholders in local communities. Surveys with students were conducted after implementing a

* https://www.ewb-usa.org, accessed 4.10.18
* Specifically, massive online course offerings, e.g. https://www.edx.org, and those available through professional societies, e.g. https://www.aiche.org/academy are prominent.
model informed consent agreement. Pilot WEARS interactions involved regular use of email, meetings on Skype based on students’ needs in addition to regular monthly group meetings.

3 Results and Discussion

• Proposal of a Methodology

Collectively, the major result of research involves proposal of a learning methodology based on all outcomes, i.e., Wicked problem, Experiences, Available Resources, Solution or WEARS (Jensen 2016A). An outline of the methodology follows in section 3.1.

3.1.1 Wicked Problem

Wicked social and technical problems to be solved are abundant. For personalize learning, the learner should have significant input into a problem(s) being addressed, detracting from focus on linear problem solving thinking. Instead, personalized learning appropriate for an approached problem is proposed as a means for education. It is also proposed that pre-assessment be performed to determine if the WEARS method could appropriate for a learner. That is, assessment methods with faculty should be conducted to determined suitability of the student, project, resources, and method e.g., “Is there supportive and credible community member available in the desired project area?”. This is distinct and different from service learning where resources and needs have been identified with a purposeful outcome a priori. WEARS would not necessarily have a predefined or physical project outcome, e.g. the building of a bridge but instead be semi-structured and dynamic. WEARS proposes to enable individualized with personal skills and present interaction in the world as We, and not Us/Them. Consider higher level goals outlined by the National Academy and the United Nations (Fig.1).

3.1.3 Experience

The focus of the experience aspect of WEARS is to determine what skills would benefit the student and if there are specific learning settings that educators and students identify as appropriate. Engineers in full time roles often experience rotation through departments or assignment in several aspects of a company’s operations. The experience aspect of WEARS is to determine educational experiences to provide students with skills for their project, degree, and beyond. Further, the experience stage should be explored to understand the drive of the student in a reflexive fashion, considering interactions and dynamics throughout a project. That is, what are the motivation and capabilities of the student that can be enhanced with training and that will genuinely benefit the student, their project, and global society.

3.1.3 Available Resources

Simply, available resources will be thoroughly explored for a WEARS project explicitly to aid in minimizing wasteful practices towards promoting innovation and to work through evaluation all of the resources that could be used to complete the project. This stage should also identify additional resources required that may not be available directly to the student alone. One question that would be considered is: “How can university association support the student or team in a project?” For example, finding a broken down ad hoc moped inspired the author to refurbish it. This action was extended after connecting with a professor and collaborator, that expressed frustration in not being able to work with mechanical systems
and fuel additives in a non-proprietary nature. This prompted the author consider how to turn the refurbished form of transportation into a means to conduct collaborative research according to the mentioned researcher’s desires and to provide students with an experiential and customizable education tool (Jensen 2016B). Additional collaborators and industry expressed an interest in related vehicle, pollution, and supporting scientific inquiry-education. Overall, this example provides students with hands on and experiential learning that incorporates many deeper graduate education topics in relationship to: energy, sensors, materials, products, and the potential to innovate components.

3.1.4 Solution - Innovation

A substantial challenge to sustainability research is the importance of developing frameworks as means to assess complexity. For the purpose of a WEARS project, an outcome needs to be identified which could be as complex as creating a new widget but as simple as placing art in a community. However, assessing supply chain environmental impacts versus social impact involve two different types of frameworks for evaluation. Therefore, the means of assessment is equally important as the process or product subject to consideration.

Discussions and experience with a senior design program at the Colorado School of Mines was critical to explore how rapid innovation could take place in the author’s own research, but required balance with appropriate project controls. A mind map (Fig.2) is one means to capture brainstorming of how to achieve project goals and initiate innovative thought (Tucker et al. 2010). Similar methods can be applied to aid students in conceptualize of their goal or how to achieve-identify a solution within a reasonable timeframe (Jensen 2016A).

3.2 Most Popular Vignette

The vignette receiving the most interest-attention in presentation and peer settings through the course of this research makes use of repurposing waste for low cost transportation. The development of a low powered vehicle (a.k.a. lo-ped) is the basis for of a vignette which extends materials, systems, and engineering education presented in a choose your own adventure format (Jensen 2016B) to allow students to explore individual interests (Fig.3). Vehicles with combustion engines maintaining less than 50 cubic centimeters of displacement are legal in many states, subject to differing safety and legal requirements. Exploring policy and legal implications of the project supports soft skill development in both of these areas.

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![Figure 2: Brain storming and conceptualization of how to develop an indoor mobile green house by a CSM senior design team. The so called mind-map of creates linkages of concepts that can be expanded upon.](image-url)
The project specifically requires individual learners to develop their own low powered means of transportation, satisfying local laws and safety requirements. Price points for laboratory materials are estimated to be among $250 to $400 depending on student interests and engagement with the project. It was envisioned that the project allows for hybrid power modification, various means of systems-performance study and personal ownership. Further, there are several ways to extend interests from the project to transportation, engineering, design and science concepts.

Figure 3: Second generation model of a low powered moped, i.e. lo-ped, with many mechanical system components that can be utilized in a course tailored to the interests of individual students. The so called lo-ped is street legal and many jurisdictions in the United States have specific individual laws that designate where such vehicles can operate and the safety components that are required for their use.

Figure 4: Project outline that involved the development of an Android application focused on transforming the use of a PC and spreadsheet based quality control system to a hand held tablet. Thorough communication was essential throughout various aspects of project work. During software development new methods of communicating that remove emotion or personal bias were applied to clearly identify tasks, challenges and also illustrate progress. Colors on the pictured dry erase board indicate different stages of completion. Further, the entire project is represented in a straight forward fashion without layers of contracting or administrative support, i.e. it is representative of full stack development in a project.

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coordinated with small to medium enterprise that could be carried out by a single engineer. An example overview of the ins and outs of mobile app development can be viewed from many sources, one is provided on a recent blog: https://thebhwgroup.com/blog/mobile-app-development-process, accessed 3.12.18.

3.3 Pilot

To evaluate interest or potential, a general email call was utilized as outreach for potential pilot participants in a professional society. Based on ten responses, five participants completed a larger program geared to membership, learning sustainability concepts (that made use of the WEARS methodology), and team-work project to develop committee responsibilities with larger institutional impact. All participants were non - United States undergraduate engineering students.

This presentation shares details of the creation of a first year pilot with five students from interdisciplinary backgrounds using the WEARS methodology to approach so called wicked challenges or sustainability topics. Students were engaged based on their individual interests and voluntarily made use of individual and group meetings to apply the WEARS method. The method includes considering personal and social aspects of project development to promote holistic views of science, technology, engineering, arts, and mathematics from many lens, including that of policy. Finally, student pilot interactions were used to formulate initial means of assessing interests and characteristics of those that participate in the WEARS methodology. A general poll of sustainability related interests in three areas was conducted (Fig.6)

*Figure 5:* In a previous urban setting, the topic of sustainability was related via urban agriculture and recycle of waste with compost activities. Adaptation to a school that already had a robust environmental literacy program then allowed for the development of a ‘solar garden’, so to speak, infusing technology and Internet of Things concepts. The picture shows an Arduino microprocessor integrated in a circuit that makes use of 12v relays to power peripheral components via a battery that is charged by the solar panel (Left). The community stakeholder desired to develop wireless control and or data access to the ‘solar garden’ module, and is the current focus of the project. Pictured is handheld tablet with an Arduino controller and low energy blue tooth antennae demonstrating that the tablet can be used to turn a light on and off wirelessly (Right). Proposed education meets 3rd grade curriculum requirements on the topics of circuits and energy. It is even suggested that systems curriculum is supported by this proposed project.
3.4 Replicating an Approach

Several of the individual vignettes have been developed to states that could now be applied in formal education settings or recast in new collaborative partnerships (Jensen 2017). For example, an approach to urban agriculture vignette in Denver Colorado, USA (Jensen 2016) was reapplied to a community in Virginia (USA) via a program by the United States Green Building Council Connect the Dots program. A two-year interaction demonstrates that the approach can be replicated (Jensen, Hunt, Schwartz) in an adaptive fashion unique to a community’s specific needs (Fig.5). The project will be discussed more in depth during the presentation.

4 Conclusions

It was concluded that rigorous, bottoms up and student centered participatory action research approaches to education that address identified social needs (Fig.1) can be formulated in a highly customizable fashion. These approaches are proposed with sustainability principles in mind to focus on graduate education central to the science.

4.1 Acknowledgments

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Attitudes towards curriculum integration of sustainable development among program directors in engineering education

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Abstract

Among engineering degree programmes, learning objectives that relate to sustainable development may be very different and there are different approaches to understanding and embracing the concept of sustainable development. Some engineering programmes teach only introductory material on global issues in a way that is tangential to the core curriculum; others integrate sustainability issues through several courses. Some educators believe that ethics and equality issues constitute core topics in sustainability education, whereas others focus more on ‘hard topics’ such as the ecological foundations of sustainability.

This study reports on the results from a survey and interviews with programme directors at Swedish universities and engineering colleges. Core questions that have been evaluated are: (i) To what extent do programme directors possess a deep understanding of the subject of sustainable development? (ii) Which are the core competencies in sustainable development that programme directors identify as important for their engineering students to acquire during their basic training? (iii) To what extent are those competencies integrated into engineering education today?

In Sweden, the Higher Education Ordinance from 2006 state explicitly that for any university or university college to issue engineering degrees, it is mandatory they integrate competencies relating to a sustainable development into the education programmes. In a recent (2017) national evaluation on the integration of sustainable development in higher education in Sweden, the Swedish Higher Education Authority found three quarters of all higher education institutions to be lacking in their integration of sustainable development in the curriculum. The criticized institutions include many that issue engineering degrees.

This study takes a starting point in the national evaluation performed in Sweden in 2017 but addresses the core questions in such a way to make the findings interesting to a wider audience. In a subsequent study a similar survey may be performed with participants in higher education institutions from a range of countries. This paper reports on findings on how programme directors interpret the concept of sustainability; how they reason about the relationship between sustainability competencies and ‘traditional’ core competencies associated with their programme; and their view on factors that have an effect on integrating the concept into the programme, i.e. merging competencies associated with a sustainable development with traditional programme competencies.
1 Introduction

As the engineering profession evolves over time, so does the evolution of engineering educations and their curricula. Twenty years ago, ‘soft skills’ were being recognized as important components in an engineering education, along with core technology courses (Nguyen, 1998). There is a huge demand for engineers that can contribute in building long-term sustainable societies. However, as with earlier changes to engineering study programmes, it is not clear exactly how this should or will translate into changes at the study programme or course level. Directors of engineering study programmes need to navigate external influences as well as apply their own domain expertise in devising long-term strategies for their programmes. They must be mindful of how changes to the programme affect the existing curriculum layout and balance.

Our hypothesis is that there exists a general lack in adequate teaching resources and competences in many institutions for delivering effective engineering education for sustainable development. In this study, we asked all programme directors in Master of Science in Engineering programmes in Sweden a range of questions relating to their own conception of the subject; the extent to which sustainability is integrated in their programmes; and their view on major challenges that they perceive for making the change towards deep integration of sustainable development into the course material of the programme. The aim of the study was to evaluate whether there is a set of general challenges, with the objective of identifying concrete suggestions that would be reasonably general for which actions to make on the programme level.

The study follows up on a national evaluation performed in Sweden in 2017 by the Swedish Higher Education Authority (UKÄ), which assessed all higher education institutions on how they meet the requirements on integrating sustainable development in all higher education. In engineering education, sustainable development must be integrated into all degree rewarding educations due to two separate regulations: (i) the Higher Education Act (2005, HEA) which stipulates how higher education in general is organized; and (ii) the Higher Education Ordinance (2006, HEO) which states explicitly that for any university or university college to issue engineering degrees, it is mandatory they integrate competencies relating to sustainable development into all engineering education programmes. In the national evaluation in 2017, it was found that three quarters of all higher education institutions lack in their integration of sustainable development in the curriculum. The criticized institutions include many that issue engineering degrees. The review was based on self-assessments made by each university, which were critically reviewed by the Swedish Higher Education Authority (UKÄ). When making their assessment, they reviewed the central university strategies, competencies, collaborations, and specific activities.

To our knowledge, the current study is the first national and complete study that aims to chart the range of challenges that programme directors perceive regarding integrating sustainable development in engineering programmes. We explicitly refer to the national evaluation performed by UKÄ, which in itself is also unique, and elaborate on the reasons why such a vast majority of the institutes of higher education in Sweden actually break a more than ten-year-old law in failing to meet the required level of sustainability curriculum integration.

In contrast to earlier requirements for changes in engineering curricula, learning for a sustainable development does not mean that students will learn how to apply known solutions to well-defined problems. Sustainability challenges are notorious for being wicked, complex, cross-disciplinary problems with no obvious, optimal solutions. To learn for a sustainable development may involve such competences as understanding norms and values, developing a deeper sense of ethics, and improved communication skills (Segalàs et al., 2009). Ashford (2004) suggested that systems thinking and the ability to transcend
disciplinary boundaries will be essential abilities. Although frameworks for competences for sustainable development have been proposed (Wiek, Withycombe, & Redman, 2011), there is still no universal consensus on what competencies should be included in an engineering curriculum (Mulder, 2017). In some institutions for engineering education, teaching sustainability is limited to a basic orientation around sustainable development as a concept whereas in other institutions students acquire both specific skills training in methods such as life-cycle assessment and sustainable product development as well as broad experiences in simulated cross-disciplinary decision making exercises for example by playing educational games and role plays around normative discussions, system dynamics or multiple-stakeholder scenarios.

Transforming engineering education can in many ways be seen as a similar problem to transforming other societal systems. There are sources of inertia in large organizations, barriers to communication between different disciplines, departments and faculties and a lack of incentives for fundamental change. Some of these barriers are social and cultural, others economic or even physical due to distances between staff from different backgrounds. In an overview by O’Brien in 2013, they note incentives and reward structures that create disincentives for working over disciplinary boundaries as an important issue to overcome when transforming higher education institutions to promote learning for a sustainable development (O’Brien et al., 2013). Barth and Rieckmann (2012) point to training of academic staff as an important factor for meaningful curriculum transformation. Frameworks for assessing sustainability aspects in higher education often seem focused on governance of campus facilities rather than the collaboration between educators, researchers and the surrounding community and may thus fail to act as an efficient tool for strategic management tool for integrating sustainability in higher education (Yarime, M, Tanaka, Y, 2012).

2 Method
The scope of this study was to investigate how directors of engineering study programmes in Sweden, and in particular five-year Master of Science in Engineering degree programmes, reason about their responsibilities, incentives and challenges. An online survey form was distributed to all programme directors of five-year Master of Science in Engineering degree programmes in Sweden (N=100), with follow-up, short interviews for clarifications of their written answers in the survey.

The survey included questions on four themes, and included both multiple-choice questions, Likert-scale evaluations and open free text questions. Most questions included an option for free text clarification.

As a follow-up to the survey, a number of respondents were called for short follow-up interviews after they had provided their answers in the online survey. Interview questions related specifically to their responses.

3 Results
Here we present the core findings and discuss our view of their meaning.

4.1 Background knowledge and motivation
We asked what respondents associated with the term “sustainable development”. The most frequent association (86%) was the definition in the Brundtland report (Fig. 1). Significantly fewer mentioned preservation of biodiversity, assessing the triple bottom line of businesses or striving for the Agenda 2030 goals. The associated free text responses also indicate that a sustainable development focusing on human needs dominates the respondents’ world view, thus implying they adopt an anthropocentric.
4.2 Agenda 2030 Goals

In the national evaluation of degree programmes, Agenda 2030 was suggested as a framework for more concrete definitions of sustainability (Fors et al., 2017). Therefore, we wanted to know to which extent programme directors were using that framework actively. Only slightly more than half of the programme directors associated the concept of sustainable development with striving for the 17 Sustainable Development Goals (SDGs) of Agenda 2030 (Fig. 1). When asked specifically which, if any, of the goals that students could be expected to contribute to after their studies, the responses were centered on the goals that more clearly relate to resource management (Fig. 2). As a general tendency, programme directors view goals that are oriented towards efficient resource management as more central to engineering students.

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**Fig 1.** Numbers correspond to respectively: I – “Meeting the needs of the present without compromising the ability of future generations to meet their own needs”; II – “Long term management of human and natural resources”; III – “Conserving biological diversity”; IV – “Environmental, social and economic systems are in balance”; V – “Striving for fulfilment of the UN's Sustainable Development Goals of Agenda 2030”; and VI – “Business should be evaluated against social, economic and environmental factors (triple bottom line)”.

**Fig 2.** Programme Directors response to which, if any, of the UN’s stated Sustainable Development Goals they believe that graduates from their programme will have skills to address.
4.3 Progression of learning objectives

The respondents were asked about how the progression of learning objectives in sustainable development is organised within their programmes in terms of the stated competence goals. As seen in Fig 3., there is a clear tendency towards the adoption of introduction courses in sustainable development. One interpretation of the answers is that the adoption of introduction courses is considered the easiest route to achieve at least some sustainability education in the programme, considering that programme directors in general regard the integration and progression of sustainable development constituting a challenging undertaking to achieve.

A minority of the respondents state a more thorough progression through several or all years within the programme. Only 18% of the programmes include assessed subparts in courses throughout all years in the programme. However, a not so small proportion of the programmes (35%) state a considerable level of progression, with assessed subparts in at least three mandatory courses throughout the programme.

As has been stressed by Enelund (2015) and others, the integration of education for sustainable development with progression through the programme should emphasise deep connection between sustainability and the core engineering skills of the programme. Such approach should emphasise employability, an integration of general engineering skills, and authentic engineering experiences with a focus on a holistic view of the complete lifecycle of products and systems. Merely introducing sustainability as a concept does little in terms of integration, and merely working with sustainability issues once or twice within the space of a whole programme is not enough for acquiring any progression.

![Fig 3.](image)

Fig 3. Numbers correspond to respectively the following replies: I – “Introduction courses in sustainable development”; II – “Through assessed subparts in courses throughout all years in the programme”; III – “Through assessed subparts in at least three mandatory courses throughout the programme”; IV – “Through assessed subparts in at least one mandatory course throughout the programme”; and V – “Through introductory, non-assessed course activities”.

4.4 Learning activities that are currently integrated

The respondents were asked which learning activities they utilize in order to achieve the learning objectives for sustainable development stated earlier. As seen in Fig. 4., traditional learning activities such as lectures, writing assignments and project work dominate. Even though those indeed can be delivered in a non-traditional manner, the free text answers confirm that most teaching methods that are actually used are
traditional classroom teaching. In contrast, learning methods that are intrinsically based on active learning pedagogy such as laboratory exercises and educational games, are much more sparsely represented. The exception is seminar discussions, which may indeed represent an active learning activity.

In contrast, papers highlighting good examples for education practices for sustainability education often emphasise innovative and active learning approaches. For example, in a study by Palme (2010), a set of 29 inspirational examples were collected throughout a range of engineering programmes at Chalmers University of Technology in Gothenburg. Those includes peer-discussions, role plays, group work, reflective writing, and interactive lectures among others. In another study by Dahlin (2016), active learning in education for sustainable development in the form of board games were shown to be more efficient than traditional teaching activities. Those results were achieved in a flipped-classroom setting with board games constituting an active learning classroom activity that emphasised student reflection, interactivity and a starting point for peer-discussions and teacher-moderated discussions.

Also seen in Fig. 4., student projects with participation with non-academic partners is relatively unusual. This result is interesting especially because of the intrinsically multidisciplinary aspects of sustainable development as a subject, and since stakeholder-involvement is often argued for as an important strategy in real life strategies for sustainable development.

![What learning activities are utilised within the programme in order to achieve the learning objectives for sustainable development?](image)

**Fig 4.** Programme Directors response to what learning activities are utilised within their programme in order to achieve the learning objectives for sustainable development.

4.5 **Potential challenges**

In Fig. 5., potential challenges associated with the introduction of a progression scheme for learning objectives in sustainable development is addressed. The most obvious challenge for programme directors is the allocation of academic credits for new content, which is considered a prerequisite for adding material into courses relating to sustainability. The teacher’s competence (or lack thereof) in teaching for sustainable development is also stated as an important challenge, and to some extent there is also a confusion about terms and definitions. All these three aspects may be related to the strongly disciplinary characteristic of natural science traditions. Interestingly though, there is a strong perception of connection between sustainability and the core subject in the view of most of the programme directors in the study.
Conclusions and recommendations

Effective education in engineering for sustainable development involves more than merely introducing the concept of sustainable development to engineering students. In addition to doing so, there is also the need to educate for the use of relevant tools and methods; and to prepare engineering students for working in contexts where interdisciplinary, normative driven, multi-stakeholder and system dynamics aspects are present. The results suggest that those latter skills and abilities are often looked over. The results suggest a number of general challenges for those who plan, organise and deliver engineering education:

The responses in this study indicate that in cases when sustainable development is presently integrated into engineering education, this is often done at a rather rudimentary level. Most programme directors in the study point out that climate change and strategies for sustainable energy is currently addressed in their programmes. However, learning objectives relating to more complex issues, such as systems thinking and the ability to perceive other perspectives – which relate more to the interdisciplinary, complex, wicked problem related or normative aspects of sustainable development – are much more rarely integrated in the programmes. The literature suggests that many aspects of sustainable development may effectively be integrated into current education by performing non-conventional forms of education (such as active learning, role plays, educational games etc.). Such techniques have shown good results and this has been reported in many studies. Our recommendation on how to address this issue is to make an effort to increase the general awareness among teachers in the programme on the more advanced aspects of education for sustainable development, since the misunderstanding on what this involves seems to be rather widespread.

One of the most important obstacles against making the change towards deeper integration of sustainable development relate to a perceived lack of competence among teachers in educating for sustainable development. This is especially interesting since this may actually be dealt with rather straightforwardly: there are several organisations worldwide with a good record on training teachers to educate for sustainable development. Since the results suggest this to be a very commonly perceived challenge it is our recommendation to seek out cross-university and inter-university networks and teacher training courses that would benefit the general build-up of skills for education for sustainable development at the institution.
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Teaching Engineers to Think Appropriately by Thinking Holistically

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Abstract

In an Appropriate Technology course designed to explore both the technical and humanitarian proficiency necessary to positively increase quality of life and promote innovation in the developing world, students designed and built a water filtration system appropriate for a developing community. Our goal was to prepare students to effectively participate in humanitarian work in developing countries and demonstrate their ability to do so at our Sustainability Garden on campus.

The concept of “Do No Harm” was woven throughout the course by exposing students to international case studies. Approximately one class per week was dedicated to considering success of humanitarian engineering projects and the unfortunate frequency of failed – though well-intended – projects. Assignments forced students to reflect upon positives and negatives and incorporate the best in their plans.

In previous iterations of the course, students all worked to develop different solutions to the same problem. For example, students were tasked with lifting water 15 ft out of a creek. Most recently, we challenged students to design and implement an off-grid system for producing drinking water from pond water. The system used a solar powered pump to collect the water and a biosand filter to remove turbidity and pathogens. A drip chlorinator provided an extra layer of safety. The system used inexpensive and widely available 55 gallon plastic drums for water storage, sand filter containment, and chlorine exposure time.

As a result of this holistic project, students learned valuable lessons not only related to considering appropriateness in terms of cost and availability, but also in terms of working with the other teams to achieve a larger goal. We measured our effectiveness in teaching the “Do No Harm” concept and engineering in the context of the developing world. We evaluated our success using pre- and post-course surveys and final team interviews. Survey data showed that project approaches changed students’ perceptions about the importance of social considerations and the positive and negative impact that engineers can have in working with developing communities. Surveys and final interviews suggested that students struggled with the holistic nature of the cooperative project. However, the students’ struggles served a purpose and moved us toward achieving our learning objective of preparing students to effectively participate in humanitarian engineering work. These findings can serve as a reference to other instructors considering incorporating appropriate technology into new or existing courses.

1 Introduction and Background

Difficult, real-world problems can motivate students to learn. Projects that require sustainable designs not only challenge students to learn, but provide opportunities for students to innovate and create value. For these reasons, we developed and implemented a technical elective focused on providing students the tools
to be successful in bringing engineering solutions to developing communities. Courses with a focus on humanitarian development, service learning, or appropriate technology have been developed and implemented in various ways at many institutions. With the founding of Engineers Without Borders (EWB), the University of Colorado-Boulder has been a leader in incorporating technical service into the campus experience in and out of the classroom (Amadei and Sandekian, 2010). To support EWB undertakings, many universities have also introduced humanitarian-focused courses, curricula and degrees. Students generally view these programs favourably with the benefits of diversity, inclusion and critical thinking (Bosscher et al., 2005; Colledge, 2012; Bixler, 2014).

1.1 Overall course history, structure and goals

For the past three years, we have taught an Appropriate Technology for Developing Countries course at Rose-Hulman Institute of Technology. This course was originally developed and taught by a multidisciplinary team of three engineering educators with some experience in international development work, and a practitioner with extensive experience with EWB (Marincel Payne et al., 2016). In recent years, the course has been co-taught by the electrical engineering and environmental engineering faculty members.

The overarching goal of the course is to prepare students to effectively participate in humanitarian engineering work. We aim to emphasize the importance of cross-cultural communication, community support and involvement, long-term maintenance, and minimizing harmful side-effects. The course introduces multidisciplinary technical topics important in areas with limited infrastructure such as water, sanitation, agriculture, energy, communication and transportation. A key aspect of the course is a design project to demonstrate a practical and appropriate system from the course material.

We used the textbook entitled Engineering and Sustainable Community Development by Lucena, Schneider, and Leydens along with various case studies. These case studies were especially crucial in highlighting the importance of the integration of humanitarian considerations into the design of engineering solutions. Coupled with reflective exercises, we used these case studies to emphasize the concept of “Do No Harm”. One class per week was dedicated to considering the success of humanitarian engineering projects and the unfortunate frequency of failed – though well-intended – projects. These cases highlighted possible cultural, lingual, experiential and educational differences between the community members and outside engineers. Care was taken to weave the “Do No Harm” concept through all topics and activities in the course.

The course was comprised of engineering and math majors: mostly electrical engineering or mechanical engineering majors (Table 1). The course attracted more women (39-58%) than the overall institute level of 22%. Most engineering majors require two to three technical electives which this course fulfils. These electives are typically taken as upperclassmen, and as such, the course was primarily populated with seniors. The prerequisites excluded freshmen. Although development work is related to civil engineering, it hasn’t been taken by these students, likely because of the electrical and computer engineering (ECE) course prefix.

Table 8. Demographics for the Appropriate Technology course (EE: electrical engineering, ME: mechanical engineering, CPE: computer engineering, BE: biomedical engineering, CE: civil engineering)
1.2 Course project approaches

In the first two years of teaching the course, the project challenged teams of two to three students to design and prototype a means to pump water three feet above the campus creek bank elevation on a $150 budget. The teams were encouraged to minimize cost and time to fill a five gallon bucket while maximizing ease of use and robustness of their design. Teams competed for the lowest cost per flow in final demonstrations (Marincel Payne et al., 2016).

In the third offering of the course, the project still challenged students to deliver safe drinking water, but in a way that required cooperation across the class. Instead of having five teams working on separate projects, the five teams were tasked with various aspects of the overall water delivery and treatment system. The separate pieces designed by each team needed to fit together for the final demonstration. This integration proved to be somewhat difficult for the students, but extremely relevant in teaching the practical nature and challenges of real design projects. The system was required to include

- a pumping mechanism to pump water out of the pond
- a biosand filter
- a chlorinator
- raw and clean water storage
- water quality testing protocol

All students were involved in building and carrying out the necessary actions to get the system working. Each design team determined the labor requirements for their component, and each student was responsible for volunteering to help on several aspects of the project as a whole. Students reported their project hours on the honor system, and were held accountable through peer evaluations. Similar to previous project iterations, team progress was documented via memos (Table 9).

Table 9. Required content for incremental project components in year three (40 total percentage points)

<table>
<thead>
<tr>
<th>Project component</th>
<th>Minimum required content</th>
<th>Week</th>
<th>Points (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Design memo 1</td>
<td>Summary of three possible options, table of advantages and disadvantages for each option with discussion, discussion about the role and importance of team’s component in larger system</td>
<td>3</td>
<td>5</td>
</tr>
<tr>
<td>Design presentation 1</td>
<td>Plausible options identified through research, advantages and disadvantages, Q&amp;A</td>
<td>3</td>
<td>5</td>
</tr>
<tr>
<td>Design memo 2</td>
<td>Justification of design option including appropriateness, cost, safety, performance, service life, materials transportation, tear-down, storage</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>Design memo 3</td>
<td>Design, cost in terms of hours/people to build, building schedule, parts list with itemized cost</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>Design presentation 2 &amp; demonstration</td>
<td>Working operation of each component and system, highlight important features, and justify decisions made based on appropriateness, cost, safety, service life, materials transportation, tear-down, storage</td>
<td>7</td>
<td>10</td>
</tr>
<tr>
<td>Training plan memo</td>
<td>Plans for training community members to operate, maintain, repair design</td>
<td>11</td>
<td>5</td>
</tr>
</tbody>
</table>

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Because biosand filters require a minimum of three weeks to become active, to allow for ripening of the biosand filter, the project demonstration was scheduled for week eight of the eleven weeks in the term. This schedule allowed students to demonstrate the ripening process in their water quality monitoring. This constraint set the course timeline and required a quick project startup. This time, the project made up 40% of the total course points, the rest of which were accounted for by homework (15%), participation (5%), and two exams (40%). In summary, the key differences between the project in the third teaching of the course compared to the first two iterations stem from the differences in the project approach (Table 10).

Table 10. Key project differences between the first two years and year three

<table>
<thead>
<tr>
<th>Project component</th>
<th>Years 1 &amp; 2</th>
<th>Year 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Project statement</td>
<td>Single component of a water delivery and treatment system</td>
<td>Complete water delivery and treatment system</td>
</tr>
<tr>
<td>Relationship between teams</td>
<td>Competitive</td>
<td>Cooperative</td>
</tr>
<tr>
<td>Approximate number of class meetings dedicated to project work</td>
<td>2-3</td>
<td>6</td>
</tr>
<tr>
<td>Start of project</td>
<td>Week 5</td>
<td>Week 3</td>
</tr>
</tbody>
</table>

1.3 Project prototypes

In the first two years of teaching the course, common prototypes included bicycle powered pumps, hand pumps, rope pumps and solar pumps (Figure 11). The hand and solar pumps tended to perform most reliably and efficiently, and the hand pumps won out in terms of cost/flowrate.

![Figure 11. Water pumping mechanisms in year 2; A) Hand-powered pump, B and C) Rope pump, D) bicycle-powered pump](image1)

In the third iteration of the course, students used a solar powered pump to collect water, a biosand filter to remove turbidity and some pathogens, and a drip chlorinator for additional pathogen removal. The system used inexpensive and widely available 55 gallon plastic drums for water storage, sand filter containment,
and chlorine exposure (Figure 12). For water quality testing, students used Petrifilm® plates to measure coliform, an indicator bacteria for pathogens, and a Secchi disk to measure turbidity. Figure 12. Water treatment system in year three; the first basin is raw water storage, the second basin is the biosand filter, the third basin is the chlorination basin, and the fourth basin is finished water storage (not pictured is the drip chlorinator which belongs above basin three)

2 Methods

We evaluated the effectiveness of the Appropriate Technology course using surveys and final team interviews. Previously, we used a post-then-pre (retrospective pre) survey to evaluate our first teaching of the course (Marincel Payne et al., 2016). Subsequently in years two and three, we used pre- and post-course surveys to understand the skills and perceptions students gained as a result of the course. We were particularly interested in students’ understanding of the “Do No Harm” concept and ability to design sustainable engineering solutions in the context of the developing world. We were curious if one project provided a stronger experience for students. The surveys were administered by a third party at our university and the results were reported in aggregate. Following internal review board requirements, informed consent was obtained from each participant prior to participation.

3 Results and Discussion

Both project approaches changed students’ perceptions about their understanding of the importance of delivering appropriate solutions, and their ability to discern those appropriate solutions for developing communities. For both project approaches, there was a substantial increase in students’ abilities to provide examples of ways well-intentioned engineering solutions can be harmful as a result of the course (Table 11).

Table 11. Results for a survey question related to students’ abilities to provide examples of harmful “help”

<table>
<thead>
<tr>
<th>Question: I can give several examples of ways well-intentioned engineering can do more harm than good.</th>
<th>Year 2</th>
<th>Year 3</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Pre</td>
<td>Post</td>
</tr>
<tr>
<td>N</td>
<td>%</td>
<td>N</td>
</tr>
<tr>
<td>Strongly Disagree</td>
<td>0</td>
<td>0.0</td>
</tr>
<tr>
<td>Disagree</td>
<td>1</td>
<td>14.3</td>
</tr>
<tr>
<td>Neither</td>
<td>2</td>
<td>28.6</td>
</tr>
<tr>
<td>Agree</td>
<td>2</td>
<td>28.6</td>
</tr>
<tr>
<td>Strongly Agree</td>
<td>2</td>
<td>28.6</td>
</tr>
</tbody>
</table>

Similarly, as a result of the course, students were better able to determine appropriate alternative design solutions (Error! Not a valid bookmark self-reference.). In year two when teams were all working on different solutions to one component of a water treatment system, students may have been more able to determine alternatives (post-course 75% strongly agree, 25% agree). Instead, in year three where teams worked on different components of one complete system, they may not have had as much exposure to
alternatives since other teams were working on different components (post-course 37.5% strongly agree, 67.5% agree).

We attempted to correct for this difference in the cooperative project approach by including an initial design presentation where students described the alternative plausible options they had researched for their component of the larger system (Table 9). Overall, all post-course responses were either in the “agree” or “strongly agree” categories, indicating that we were able to sustain students’ confidence to determine appropriate solutions with both project approaches.

Table 12. Results for a survey question related to students’ abilities to determine alternative solutions

<table>
<thead>
<tr>
<th>Question: If I find a project to be inappropriate after evaluating it against a community’s needs, resources and environment I am able to determine what alternatives might be more appropriate.</th>
<th>Year 2</th>
<th>Year 3</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Pre</td>
<td>Post</td>
</tr>
<tr>
<td></td>
<td>N</td>
<td>%</td>
</tr>
<tr>
<td>Strongly Disagree</td>
<td>0</td>
<td>0.0</td>
</tr>
<tr>
<td>Disagree</td>
<td>1</td>
<td>14.3</td>
</tr>
<tr>
<td>Neither</td>
<td>4</td>
<td>57.1</td>
</tr>
<tr>
<td>Agree</td>
<td>1</td>
<td>14.3</td>
</tr>
<tr>
<td>Strongly Agree</td>
<td>1</td>
<td>14.3</td>
</tr>
</tbody>
</table>

Finally, in terms of the practical benefit of our course, students felt more prepared technically to participate in humanitarian engineering work as a result of the course (Error! Not a valid bookmark self-reference.). While the differences are not significant, these data indicate that year two students felt a stronger resolve in their preparedness to technically tackle humanitarian problems.

However, it may be that students simply struggled more in year three because of the extra requirements of stitching the whole system together, and as a result, actually felt less prepared. These students struggled with communicating and working across the teams towards one goal, however, we do not think it was needless stress.

Table 13. Results for a survey question related to students’ feeling of preparedness.

<table>
<thead>
<tr>
<th>Question: I feel prepared to participate technically in humanitarian work.</th>
<th>Year 2</th>
<th>Year 3</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Pre</td>
<td>Post</td>
</tr>
<tr>
<td></td>
<td>N</td>
<td>%</td>
</tr>
<tr>
<td>Strongly Disagree</td>
<td>0</td>
<td>0.0</td>
</tr>
<tr>
<td>Disagree</td>
<td>4</td>
<td>57.1</td>
</tr>
<tr>
<td>Neither</td>
<td>1</td>
<td>14.3</td>
</tr>
<tr>
<td>Agree</td>
<td>2</td>
<td>28.6</td>
</tr>
<tr>
<td>Strongly Agree</td>
<td>1</td>
<td>14.3</td>
</tr>
</tbody>
</table>
In fact, in final meetings with student teams, students commonly expressed that they were challenged by having to make sure that the whole system worked together and meeting constraints of other teams while advocating for their own. However, they also noted that they learned a lot through the process. Mistakes were made, so leaders came forward and students learned to check and critique each other’s work. As instructors for all three iterations of the course, we observed that students learned during all three scenarios, however, we found that the messy, changing constraints of having to prototype a whole system provided excellent real-world lessons about communication, responsibility and resiliency. These outcomes aligned well with our “appropriateness” learning objectives. While students from year three may not feel as prepared as students did in year two, students in year three may in fact, be better prepared.

4 Future Considerations

We envision continuing the cooperative, whole system approach to the course project. However, as instructors, we learned that we need to reserve more time for in-class all team discussions for the whole system project approach. The teams need to brainstorm, ask questions, and make decisions together. Additionally, we think students’ and the project’s success would benefit from more structured project building requirements such as a minimum number of volunteer hours. Finally, we are interested in developing a travel component to the course where students could get an immersive experience as part of the course. Even in the absence of the ideal international trip, there are communities in the United States that are off-grid or developing in certain ways that would provide context for students.

5 Conclusions

The Appropriate Technology for Developing Countries course was developed in the summer of 2015 and has been subsequently taught in the fall terms of 2015-2017. The course goal was to prepare students to effectively participate in humanitarian work in a variety of developing communities. We emphasized the non-technical aspects of development work alongside technical content in a holistic way uncommon in technical courses. We measured the effectiveness of the course on changes in students’ perceptions regarding how to engineer a successful solution in developing communities. For both project approaches, students were able to explain the importance and determine the appropriateness of a solution for its context as a result of the course. While our survey data did not reveal any pronounced differences in students’ understanding and ability with the complete system approach in year three, final interviews did reveal the learning that happened as a result of the necessary cooperation of all of the teams. Given our course goal of preparing students to effectively participate in humanitarian engineering work, the cooperative course project allowed students to achieve that goal.

References


Colledge, T.H. Convergence: Philosophies and Pedagogies for Developing the Next Generation

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Rethinking Curricula to Develop the Holistic Engineer

Salwa Beheiry

Abstract

The main purpose of this study is to develop a framework for revamping engineering curricula in light of the recently approved ABET criteria revisions. In addition to emphasis on applied learning, the latest ABET revisions are noticeably geared towards building a more holistic engineer. They highlight serving societal needs, having a global perspective, communicating effectively, functioning in teams, and understanding the ethical implications of one’s actions on the economy, the environment, and humanity’s cause. This proposed study will address the essentials to meticulously craft a well-rounded engineer in classical and relatively novel engineering disciplines. In effect, the different engineering curricula will be examined to consistently diffuse the innovation and sustainability dimensions in the pedagogy. Furthermore, the study will examine the path to transform the process of shaping our future engineers and the deep-rooted obstacles to the progression of change. The expected deliverables of the analysis will include an interrelated course plan for six engineering disciplines, Chemical, Civil, Electrical, Computer, Mechanical and Industrial. The deliverables will also encompass a thorough analysis of the planning approach, the benchmarking of the programs, the cultural dimensions, and the student body particulars.
Incorporating a Holistic Approach to Senior Capstone Design

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Abstract

Year after year, we have found that the senior capstone design students in the Civil and Environmental Engineering Department excel at the technical design of project components. However, student teams often struggle with how to connect the various components into one cohesive system, especially when addressing the relationships among technical, social, environmental, and economic aspects of their project. In order to address this, we have incorporated an approach into the senior capstone design course to help student teams better understand the purpose and need for their project, develop guiding principles to drive project decision-making, and determine design objectives that connect components of their project into a whole system. This approach is a regenerative design framework, known as Living Environments in Natural, Social, and Economic Systems (LENSES). The LENSES framework provides guidance in early stages of design concept development by inspiring creativity and a whole systems perspective of a project.

Student projects are community-based and typically involve land development that includes various civil engineering sub-disciplines. Students were first introduced to LENSES after getting their team project assignments, but before developing conceptual design options. After working through the LENSES framework, students described five or six “big ideas” or strategies to bring their project vision to reality. These strategies, or key initiatives, later became the design objectives for each project. After teams generated their conceptual design options, they utilized their design objectives to determine a final conceptual design recommendation that was rooted in their guiding principles and the LENSES approach.

When moving into the technical design phase of the project, students routinely reported on how their design was meeting the project-level design objectives that were formulated from a systems perspective through the LENSES framework. Indirect assessment was conducted via student surveys after the concept development phase of the project to assess student perception on the benefit of using LENSES to develop a more holistic understanding of their project and identify how technical social, environmental, and economic aspects of the project fit together as a whole system. Direct assessment was conducted when reviewing team report submissions of their final conceptual design recommendation and individual design report submissions.

1 Introduction

For 10 years, students in the senior capstone design course in the Civil and Environmental Engineering (CE) Department at Rose-Hulman Institute of Technology (RHIT) have been formally assessed on whether or not they’ve incorporated sustainability principles in the design of their project and if they can explain the impact of engineering solutions on the economy, environment, and society. In this way, we have been formally addressing sustainability in senior design projects for a decade. What we often realize, though, is
that students seem to address sustainability at the end of their project, as opposed to it being a driving force for decision making at the initiation and throughout the design process. Furthermore, students seem to view sustainability as an ancillary piece to their technical design work, as opposed to being integrated throughout the entire process.

During the current academic year, we have incorporated a framework to guide decision-making throughout the design process in the senior capstone design course. This approach is a regenerative design framework, known as Living Environments in Natural, Social, and Economic Systems (LENSES). The LENSES framework provides guidance in early stages of design concept development by inspiring creativity and a whole systems perspective of a project (CLEAR 2017).

2 Course Structure

Senior capstone design is a year-long collection of courses in the CE Department at RHIT, which operates on three 10-week quarters. Student projects are community-based and typically involve land development that includes various civil engineering sub-disciplines. Projects are submitted by corporate and governmental sponsors, and project work is carried out by teams of four to five students, typically. During the Fall Quarter, students take CE486 Civil Engineering Design & Synthesis I, which involves project planning, data collection, site visits, feasibility studies, and concept development. During this phase, students address economic, environmental, and social considerations for their project as part of their desk study. In the Winter Quarter, students are enrolled in both CE487 Technical System Design & Synthesis and CE488 Civil Engineering Design & Synthesis II. In CE487, students work individually on the particular subdiscipline technical design aspect of their project, which is designated as environmental, geotechnical, structural, transportation, water resources, or general civil site design. In CE488, student teams work to coordinate their individual design efforts to continue making progress to keep the project, as a whole, on schedule. They also submit a report to describe how they addressed sustainability in their technical design. In the Spring Quarter, students take CE489 Civil Engineering Design & Syntheses III, wherein student teams address constructability and cost of their designs and provide final recommendations to their client sponsors through written reports and public presentations.

3 Incorporation of LENSES Framework

To better integrate sustainable design principles throughout the design process, we have incorporated the LENSES framework into the senior capstone design course sequence to help student teams better understand the purpose and need for their project, develop guiding principles to drive project decision-making, and determine design objectives that connect components of their project into a whole system. The LENSES framework is built upon regenerative development. Regenerative development involves a collaborative design process to consider interactions among design aspects to produce a benefit, such as a synergistic effects of interrelationships or self-renewing system (Lyle 1994), as opposed to minimizing negative impacts. Regenerative development is based on principles of being aligned with nature, being of service, working as a whole system rather than in parts, and focusing on abundance rather than scarcity (CLEAR 2017). The LENSES framework is composed of three lenses: the Vitality Lens, the Flow Lens, and the Foundation Lens (Figure 1). The intent of each lens is to help the team think of their project as a whole system.

During the first half of Fall Quarter, the feasibility and desk study phases of their project work in CE486,
students were introduced to LENSES through a collection of in-class activities. The intent was to instill a mindset of regenerative development and whole systems thinking at the forefront of the concept development of their project. First, students utilized the Vitality Lens to understand degenerative vs. regenerative aspects of their projects as a measure of value created. In their project teams, students were asked to brainstorm words or phrases that they associate with development practices that describe each of the following terms: degenerative, sustaining, and regenerative. Then students identified both potential degenerative and regenerative outcomes from implementation of any aspect of their project. The purpose of this activity was to have students explore ideas of degenerative vs. regenerative development and attain a better understanding of concept of regenerative development. Students were encouraged to think of the Vitality Lens as having a fulcrum where the degenerative circle meets the regenerative circle, so that they can balance degenerative project aspects with regenerative project aspects. Although all aspects of project implementation will not produce regenerative outcomes, it is important to strive for an overall balance or push towards an overall beneficial outcome with the balance tipping to the regenerative side.

Figure 1: Representation of the three lenses in the LENSES framework: Vitality Lens (smallest circle), Flows Lens (medium-sized flower), and Foundation Lens (largest circle) (CLEAR 2017)

Then, students were asked to identify various entities, or “flows,” that entered, interacted with, and left their
project space by using the Flows Lens (Figure 1). Thinking of the physical footprint of their project site as the system boundary, students were asked to identify input and output fluxes of this system. Individually, each student identified three flows from petals of the Flow Lens, or they could add their own in the blank petal, that stood out as most important to their project. For each identified flow, they determined where it was coming from, how it interacted in their project space, and what happened when if left that space. For example, student teams often chose the flow of “nutrients” and analyzed water entering as drinking water or rainwater, interacting with the project space through consumption and stormwater runoff, and leaving through stormwater management and wastewater treatment or conveyance. Each student then considered combinations of two or three flows at a time to explore relationships that exist among these flows. As a team, students then revisited these questions and synthesized their thoughts to focus on three flows and any relationships among them.

Incorporation of the Foundation Lens called for students to develop guiding principles upon which project decisions would be based. Individually, students considered how each guiding principle noted around the perimeter of the Foundation Lens (Figure 1) related to their project. As a group, students synthesized their thoughts and chose three or four guiding principles that were most relevant to their project. They described how each related to their project and how each would influence project decisions.

After going through these exercises, students then looked for common themes that arose. This helped them to better dictate a purpose and vision statement for their project. Often when students are given a project assignment and meet with their client to determine the scope of their project, they conclude that they need to build a bridge, for example, as opposed to concluding that they need to find a means of getting access to one side of a waterway from the other. In this way, they are not fully understanding the underlying need for the project. Students explored the purpose of their project by brainstorming responses to the following questions: what need is being fulfilled by the project, how will you fulfill the purpose, and what is the significance of achieving the desired outcome. Students then developed their purpose statement in the following format: To . . . (purpose) . . . in a way . . . (transformation) . . . so that . . . (impact) (CLEAR 2017). This exercise helped project teams to determine the actual intentions for their project development and promote specificity in identifying the need that is being fulfilled by the project.

Another activity was to develop the project vision statement. As a group, students brainstormed responses to the following questions:

- What is the desired future state of this project? What do you envision happening with this project?
- What is the current state of this project? What is currently right, wrong, missing, or confused about the project?
- What resources exist to help achieve the vision? What strategies will help the project move forward?

They wrote a statement that included their vision the project (where they are heading), the current reality of the project (where they stand now), and how they will get from the current reality to their reach their vision.

The culmination of these activities resulted in determining the key initiatives needed to bring their vision to reality. Key initiatives were identified as strategies to achieve their project vision. These were built upon
their identified flows, guiding principles, purpose statement, and vision statement, as they should have begun to see common themes emerging after reflecting on flows, guiding principles, purpose statement, and vision statement. Students selected six to eight key initiatives for their project and described the concrete strategies that must be achieved to accomplish each initiative. Students consolidated this responses from process in the format of the LENSES Dashboard (Figure 2), which allowed each team to have a guiding document upon which to refer as they continue to work through the design process and make decisions on their final design.

Later in the Fall Quarter when students were developing their conceptual design options in CE486, project teams began with their key initiatives that were rooted in the three lenses, purpose statement, and vision statement; and they developed the initiatives into specific project-level design objectives. Students worked to develop SMART objectives that were specific, measurable, achievable, relevant, and time-bound (Frey & Osterich 2002). Students measured how well each design option, or hybrid of several options, fulfilled their design objectives. These objectives were the basis of their decision-making when evaluating their design options and determining a final conceptual design. They included these design objectives in their client memo with the final recommendation of their conceptual design for their project.

Figure 2: LENSES Dashboard Template (CLEAR 2017)
During the Winter Quarter in CE487, students worked individually on their particular technical design aspect of their project. Throughout this technical design process, students were asked to go back to the basis of their design objectives, which are the guiding principles and flows, and note how their technical designs were addressing or aligned with their guiding principles and flows. This was administered through bi-weekly assignments in CE488. After each technical design progress report was submitted for CE487, students had to complete a Project Design Objectives Form (Figure 3) to address how their technical design decisions and outcomes were aligned with their key initiatives and meeting their design objectives.

Figure 3: Project Design Objectives Form for addressing LENSES principles in technical design work

<table>
<thead>
<tr>
<th>Name:</th>
<th>Project:</th>
<th>Sub Discipline:</th>
<th>Date:</th>
</tr>
</thead>
</table>

### Guiding Principles

- From LENSES Dashboard (list all below)
- How did the Guiding Principles guide the design decisions for the Key Initiative(s) addressed in your CE487 Submittal last week, and why did you give the rating to the right?
- I rate this work mostly:
  - Regenerative
  - Regenerative-Sustaining
  - Sustaining
  - Degenerative-Sustaining
  - Degenerative

### Flows

- From LENSES Dashboard (list all below)
- How did the Flows guide the design decisions for the Key Initiative(s) addressed in your CE487 Submittal last week, and why did you give the rating to the right?
- I rate this work mostly:
  - Regenerative
  - Regenerative-Sustaining
  - Sustaining
  - Degenerative-Sustaining
  - Degenerative

* Insert as many rows as needed to accommodate all of the Guiding Principles and Flows.
* All members of a specific project team should be using an identical form.
* Name your file `<last name>_<week>_<project name>.docx` and use the abbreviated project names identified by the instructors.

4 Survey Results

Students enrolled in the senior capstone design course took a survey at the end of Fall Quarter to assess their perceptions of the usefulness of incorporating the LENSES framework into the design process for the purpose of developing design objectives and a final conceptual design recommendation. Twenty-four students participated in the study. The first part of the survey measured students’ perspectives as to how well applying the LENSES framework to their senior design project helped them to meet the listed learning outcomes (Table 1). Students rated how well they agreed with the statements on a 1-5 scale (1 = strongly disagree; 5 = strongly agree).

The largest percentage of student responses for each statement, as shown in bold in Table 1, was in the “Agree” category, and mean rating scores fell between “Agree” and “Neutral.” For each statement, over 50% of students responded that they agreed or strongly agreed with the statement. This shows that most students viewed this process as beneficial to the development of their conceptual design and to their holistic
understanding of the project.
Students were also asked to explain ways in which LENSES impacted and/or did not impact their design decisions. Table 2 shows a sampling of responses to the given prompts.

Table 1: Responses of student perspectives of applying LENSES framework (n=24)

<table>
<thead>
<tr>
<th>Applying the LENSES framework to my senior design project helped me to:</th>
<th>Strongly Agree (1)</th>
<th>Agree (2)</th>
<th>Neutral (3)</th>
<th>Disagree (4)</th>
<th>Strongly Disagree (5)</th>
<th>Mean Rating Score</th>
<th>Standard Deviation of Scores</th>
</tr>
</thead>
<tbody>
<tr>
<td>Better identify the real need of the project.</td>
<td>4%</td>
<td>58%</td>
<td>17%</td>
<td>13%</td>
<td>8%</td>
<td>2.6</td>
<td>1.1</td>
</tr>
<tr>
<td>Understand a broader perspective of the project beyond merely facilitating the client’s intended outcome.</td>
<td>21%</td>
<td>38%</td>
<td>33%</td>
<td>4%</td>
<td>4%</td>
<td>2.3</td>
<td>1.0</td>
</tr>
<tr>
<td>Incorporate regenerative design in my project.</td>
<td>13%</td>
<td>42%</td>
<td>33%</td>
<td>13%</td>
<td>0%</td>
<td>2.5</td>
<td>0.9</td>
</tr>
<tr>
<td>Develop a more holistic understanding of the project.</td>
<td>13%</td>
<td>46%</td>
<td>29%</td>
<td>8%</td>
<td>4%</td>
<td>2.5</td>
<td>1.0</td>
</tr>
<tr>
<td>Develop a better solution that meets an existing need in the community.</td>
<td>13%</td>
<td>38%</td>
<td>38%</td>
<td>13%</td>
<td>0%</td>
<td>2.5</td>
<td>0.9</td>
</tr>
<tr>
<td>Identify how technical, social, environmental, and economic aspects of the project fit together as a whole system.</td>
<td>13%</td>
<td>50%</td>
<td>25%</td>
<td>8%</td>
<td>4%</td>
<td>2.4</td>
<td>1.0</td>
</tr>
<tr>
<td>Develop design objectives to assess conceptual design options.</td>
<td>17%</td>
<td>50%</td>
<td>21%</td>
<td>8%</td>
<td>4%</td>
<td>2.3</td>
<td>1.0</td>
</tr>
</tbody>
</table>
Table 2: Sample student responses about applying the LENSES framework

<table>
<thead>
<tr>
<th></th>
<th>Explain ways in which LENSES was helpful and/or not helpful in developing your conceptual design.</th>
<th>Explain ways in which LENSES was helpful and/or not helpful in assessing design options to provide a final recommendation.</th>
<th>Explain ways in which LENSES impacted and/or did not impact your design decisions.</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Student A</strong></td>
<td>It was helpful in finding out the most important aspects to each team member.</td>
<td>It was helpful to get the design objectives. This really helped to know what the most important items where for our team.</td>
<td>It helped with the final decision.</td>
</tr>
<tr>
<td><strong>Student B</strong></td>
<td>It didn't truly help give any sort of new insight or benefit to our project</td>
<td>It didn't give any sort of benefit or tell us anything we didn't already know</td>
<td>See above</td>
</tr>
<tr>
<td><strong>Student C</strong></td>
<td>It helped me and my group look past the basic needs of the project and look at other needs that weren’t the obvious client needs. Helped us come up with a more creative design and incorporate natural lighting and a more aesthetic design.</td>
<td>It helped us in choosing the most sustainable options and combine them to create the best design option possible.</td>
<td>They were basically a guideline to follow when picking out our final design. It is always helpful to have the goals written out.</td>
</tr>
</tbody>
</table>

5 Conclusion

As this was a pilot study for incorporating LENSES in the capstone senior design process, there is still much progress that can be made in how the process is facilitated to be most impactful for the student teams. Based on the survey results, some students saw the benefit of using LENSES in their design process, while others did not. We plan to begin incorporating LENSES principles earlier in the curriculum, such as in the freshman design course, and will facilitate the brainstorming activities, as described in Section 3, in smaller installments throughout the quarter, as opposed to in just two sessions. In this way, students will begin to see this framework as just part of the design process. From an educator’s point of view, the LENSES framework is a model way of approaching project development from a more holistic, whole-system perspective, which is necessary for students to experience when working with open-ended engineering problems.

References


Student Approaches to Ambiguity while Working on a Community-Based Design Problem

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Abstract

Community-based design can be a powerful tool for engaging students in the design process while providing them the means to have active involvement and communication with stakeholders. The use of community-based design can be seen throughout engineering including the EPICS program at Purdue University and the Community-Engagement Based Design course at Harvey Mudd College. These approaches have the following benefits: supporting the retention of students, increasing diversity within programs, and preparing students for leadership roles in industry. Another feature of community-based design projects is that they are ill-defined and often open-ended, similar to problems students will face in industry. Exposure to this type of problem early in engineering programs can help students develop their problem solving and communication skills; however, many students struggle with the ambiguity and uncertainty associated with them.

In this pilot study, a sophomore level engineering design class at a mid-sized, public institution was redesigned to incorporate a user-oriented, community-based design project modeled after a course structure from Olin College of Engineering. Each team of 4-5 students identified campus problems and selected one to focus on. They then completed ethnographic observations and stakeholder interviews to create a customer persona, which helped them identify possible solutions to their customer’s problem.

Finally, teams selected one of those solutions and developed a minimum viable product or prototype. This pilot study sought to explore how students deal with ambiguity associated with a community-based design problem. To do so, students were invited to complete a survey to determine their comfort level with ambiguity and participate in a focus group to further elucidate how they approached their design problem.

Survey results demonstrated that students fell into four main statistically determined clusters defined by their level of closed-mindedness, discomfort with ambiguity, resistance to ambiguity in engineering, and resistance to multiple perspectives in engineering. Student clusters ranged from those students which clearly struggled with ambiguity and were closed-minded in nature to students that were more accepting of this ill-defined environment and were willing to keep an open mind about how to approach problems. The focus group results further supported these categorizations with students commenting on the difficulty of getting started with the project due to the ill-defined nature of the problem and what they perceived as too broad of a scope. Despite these observed behaviors, students were aware of the importance of open-ended problems in their professional development and encouraged their use within the course.

1 Introduction

Engineers will be increasingly asked to tackle ill-defined and open-ended problems throughout their professional practice. For this reason, teaching students to be able to cope with the ambiguity associated with these types of problems is critical (Atman et al., 2007; Dym, 2006). However, our current educational system
is not well equipped to teach these skills outside of engineering design based courses. Engineering design presents good opportunities to incorporate this line of thinking as it emphasizes the need to spend time with scoping or formulating the problem before proceeding with creating a solution.

Dym (2006) outlines that successful designers must possess several attributes including the ability to deal with ambiguity and maintain a view of the entire picture that they are trying to solve. However, this is often an area where students have been shown to struggle and need additional support (Abell and Devore, 2017; Mohammed et al., 2006). For instance, studies performed that compare senior engineering students with expert practitioners have shown that the area where students differ the most from practitioners is in the amount of time that they spend on problem scoping and gathering information (Atman et al., 2007) which tend to be the most ambiguous phases of the design process. Further, freshman engineering students in general spend less time on problem scoping than their senior engineering student counterparts showing that this is a skill that can be learned through the engineering curriculum (Atman et al., 1999).

In an effort to better understand students’ ability to deal with ambiguity, a second-year engineering course was re-designed to focus on the front-end portion of the design process using a community-based-design model. The selection of a community-based design context was made as it has been shown to be beneficial in developing engineering students broader skill sets such as leadership, teamwork, communication skills and knowledge of the design process (EPICS, 2018). This type of design project also provides students with the opportunity to learn more about the role that engineering can serve in their local community through interaction with the intended customers (Cardenas, 2013).

2 Methods

The following section provides an overview of the study design that was employed, the survey selection and data analysis undertaken as well as the focus group that was conducted as part of this pilot study.

• Study Design

In the Fall 2017 semester, we completed a pilot study within a second-year engineering design course to begin to understand the different dispositions of engineering students towards ambiguity and multiple perspectives in the context of engineering design. The pilot study involved three sections of a 17-section course and was taught by two faculty members. This course is co-instructed by faculty members in both writing arts and engineering, since it is focused on enhancing the written communication skill sets of engineering students; however the two faculty members involved with this study are both in engineering. Each section had 18-19 students and met for one 165-minute lab period each week. The students in this course represented five different engineering majors: biomedical, chemical, civil and environmental, electrical and computer, and mechanical.

In this course, students generated a list of problems that they or someone they knew had experienced on campus. They then consolidated their ideas to generate a list of key stakeholders that would have input on the identified problems. The problems that they focused upon included internet, parking, food services, fire alarms and academic issues. In teams of 4-5, students performed ethnographic observations and stakeholder interviews to gain a broader perspective of the problem and challenges the stakeholders were experiencing. Students used this information to generate customer personas that would assist their design process. In the second half of the semester, students generated a list of potential solutions to the specific problem that was identified through their work on the customer persona. Students then narrowed down their solution ideas to
a single solution that could be used in the generation of a minimum viable product. They then sought feedback from their stakeholders to allow them to finalize their concept.

To understand how students deal with ambiguity associated with a community-based design problem in our redesigned course, students were invited to complete a survey and participate in focus groups.

• **Survey**

Fifty-three students completed the 36-item survey (see Appendix 1) that included items from the Need for Cognitive Closure Scale (Kruglanski et al., 2013) and the Dringenberg & Wertz (2016) Instrument. Items were five point, anchored Likert-type ranging from 1-strongly disagree to 5-strongly agree. Theoretically, the items on the survey can be grouped into four constructs: resistance to ambiguity in an engineering context, resistance to multiple perspectives in an engineering context, closed-mindedness, and discomfort with ambiguity. The first two constructs are from the Dringenberg & Wertz (2016) Instrument and are situated within the context of engineering, while the last two constructs are from the Need for Cognitive Closure Scale (Kruglanski et al., 2013) and are domain general.

<table>
<thead>
<tr>
<th>Source of items</th>
<th>Survey construct</th>
<th>Number of items</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dringenberg &amp; Wertz (2016) Instrument</td>
<td>Resistance to ambiguity</td>
<td>7</td>
</tr>
<tr>
<td></td>
<td>Resistance to multiple perspectives</td>
<td>14</td>
</tr>
<tr>
<td>Need for Cognitive Closure Scale (Kruglanski, et al., 2013)</td>
<td>Closed-mindedness</td>
<td>7</td>
</tr>
<tr>
<td></td>
<td>Discomfort with ambiguity</td>
<td>8</td>
</tr>
</tbody>
</table>

• **Cronbach’s Alpha**

Cronbach’s alpha is a measure of the internal consistency of items within a single construct or how well items within the same construct deliver similar responses. We calculated Cronbach’s alpha for each of the four constructs in our survey to assess the items’ internal consistency reliability (Nunnally & Bernstein, 1994). For constructs that had an alpha below 0.6, we assessed the convergent validity by calculating the correlations between each item in the construct. Items within a single construct should be highly correlated with one another because they were designed to measure similar concepts (Trochim & Donnelly, 2007). As such, we removed items, one by one, that had low correlations with other items in the construct. This was done until the alpha value for the construct was at least 0.6, at which point the construct was considered acceptable for this pilot study.
• **K-Means Cluster Analysis**

We used a k-means cluster analysis to identify homogeneous subgroups based on the four constructs of our survey. This statistical analysis minimizes the variance in a cluster while maximizing the variance between clusters (Fraley & Raftery, 1998). The number of clusters was defined by the researcher by creating plots of the percent variance explained as a function of the number of clusters and the principal component analysis. Based on this scree plot, we determined the optimal number of clusters to be four by looking at the point at which the first big change in slopes occurs. After obtaining our clustering solution, we compared the mean of each construct across the clusters using an ANOVA followed by Tukey’s HSD post-hoc test. All quantitative analyses were performed in R, a statistical analysis platform (Team, 2012). The cluster analysis was performed using the cluster package for R (Maechler et al., 2015).

• **Focus Group**

Students that participated in the community-based design project were given the opportunity to participate in a voluntary focus group to discuss their impressions of the newly re-designed course and how the ambiguity surrounding the nature of their design problem influenced their experiences. In total, sixteen students consented to participate in the focus group. The focus group was led by an independent researcher that was not involved in the course delivery to provide students a forum where they could freely discuss their experiences without concerns about how this would be perceived by course instructors.

The focus group was semi-structured and led with a set of guiding questions that included:

3.1.2 Did you struggle to get started on the design project? If so, why?
3.1.3 How comfortable were you accepting input from your other team members when working on the design project?
3.1.4 Was it more difficult to work with your team members when you all didn’t agree about direction the project should go? Why or why not?
3.1.5 Do you struggle working on design problems when you encounter hurdles? What approach did you and your team take to overcome these hurdles?
3.1.6 Do you feel that everyone on your team had something valuable to contribute to the design process? Why or why not?
3.1.7 What part of the design process did you spend the most time on? Why?
3.1.8 How important was the instructor’s opinion on the goals and outcomes of the project to your team’s design process?
3.1.9 Do you prefer to work on design problems that have a clear solution? Why or why not?
3.1.10 How important do you think it is for an engineer to be able to approach open-ended design problems?
3.1.11 How did you seek input during your design process?

Students were given the opportunity to express their opinions which included being able to agree or disagree with their peers. The researcher leading the focus group confirmed before proceeding to the next question that all students had the opportunity to share their input on the question being discussed. This was particularly important as some questions led to very passionate discussions.
3 Results and Discussion

This study sought to provide initial insight into how students experienced ambiguity within the context of a community-based design problem. The results that were obtained from the survey administered and the focus group are highlighted below along with a brief discussion of the insight gained from this pilot study.

3.1.4 Survey Results

To begin to establish internal consistency reliability we determined the Cronbach’s alpha score for each survey construct. For each construct, we also looked at the correlation matrix to identify any items with low correlations to the other items in the constructs. For items with low correlations to other items, we looked at the item to determine if it seemed different from the other items in the construct. For example the item, ‘Engineering designers should prioritize learning what people like or dislike about a design so they can make changes to improve it for the users’ asks what engineering designers should do while the other items in the construct focus on the student. Using this process, we removed seven items across the four constructs. The Cronbach’s alpha values for each construct suggest acceptable internal consistency reliability (see Table 2) (Nunnally & Bernstein, 1994).

<table>
<thead>
<tr>
<th>Survey construct</th>
<th>Cronbach’s alpha</th>
</tr>
</thead>
<tbody>
<tr>
<td>Closed-mindedness</td>
<td>0.602</td>
</tr>
<tr>
<td>Discomfort with ambiguity</td>
<td>0.615</td>
</tr>
<tr>
<td>Resistance to ambiguity in engineering</td>
<td>0.672</td>
</tr>
<tr>
<td>Resistance to multiple perspectives in engineering</td>
<td>0.662</td>
</tr>
</tbody>
</table>

We performed a k-means cluster analysis, setting the number of clusters to four. A summary of the mean scores for each cluster is in Table 3. Higher means correspond to increased agreement with each construct with 1 being Strongly Agree and 5 being Strongly Disagree. For example, in the closed-minded construct Cluster A is less closed-minded than Cluster C.

<table>
<thead>
<tr>
<th>Survey construct</th>
<th>Cluster A</th>
<th>Cluster B</th>
<th>Cluster C</th>
<th>Cluster D</th>
</tr>
</thead>
<tbody>
<tr>
<td>Closed-mindedness</td>
<td>3.69&lt;sup&gt;c&lt;/sup&gt;</td>
<td>4.13&lt;sup&gt;c&lt;/sup&gt;</td>
<td>4.52&lt;sup&gt;ab&lt;/sup&gt;</td>
<td>4.45&lt;sup&gt;c&lt;/sup&gt;</td>
</tr>
<tr>
<td>Discomfort with ambiguity</td>
<td>2.77&lt;sup&gt;bcd&lt;/sup&gt;</td>
<td>3.52&lt;sup&gt;a&lt;/sup&gt;</td>
<td>3.77&lt;sup&gt;ad&lt;/sup&gt;</td>
<td>2.92&lt;sup&gt;ac&lt;/sup&gt;</td>
</tr>
<tr>
<td>Resistance to ambiguity in engineering</td>
<td>3.35&lt;sup&gt;bc&lt;/sup&gt;</td>
<td>4.14&lt;sup&gt;ad&lt;/sup&gt;</td>
<td>4.29&lt;sup&gt;ad&lt;/sup&gt;</td>
<td>3.51&lt;sup&gt;bc&lt;/sup&gt;</td>
</tr>
<tr>
<td>Resistance to multiple perspectives in engineering</td>
<td>3.08&lt;sup&gt;c&lt;/sup&gt;</td>
<td>3.14&lt;sup&gt;c&lt;/sup&gt;</td>
<td>3.73&lt;sup&gt;ab&lt;/sup&gt;</td>
<td>3.60&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
</tbody>
</table>

Note: Lettered superscripts indicate significant difference between that cluster and the cluster letter. For example, superscript a means that cluster is significantly different than cluster A. For all significant differences p < 0.01. (Tukey’s HSD test, alpha = 0.05).
Unlike typical descriptive analysis (means and standard deviation of the whole sample), the cluster analysis, allowed us to identify groups of students with similar profiles in their dispositions towards ambiguity and multiple perspectives. The results showed an interesting spread in the types of students that participated in this community-based design problem with some students more open-minded and comfortable with the open-ended nature of the design problem (Clusters A, B, and D) whereas other students were very closed-minded and struggled with the ambiguous nature of the problems that they were assigned to complete (Cluster C). This result is not atypical to engineering design projects. For instance, Mohammed et al. (2006) observed that first-year engineering students demonstrated a range of tolerance for ambiguity with students that exhibited a higher tolerance for ambiguity demonstrating greater self-efficacy, and satisfaction when working on open-ended design problems.

Our results show that students in Clusters A and D had less discomfort with ambiguity than the other two clusters. Abell and DeVore (2017) found that students would struggle with ambiguity in the open-ended contexts associated with design problems but that they could be supported in their ability to contextualize ambiguity through the application of a framework that included “collaborate, overwhelm, mitigate, acknowledge, empathize, and reflect”. In this framework students are placed in teams when working on design problems (collaborate), they are faced with open-ended problems similar to the ones used in this course (overwhelm), and they are tasked with reaching specific actionable goals such as the customer persona in this context (mitigate). Students should also be supported in their process through assistance by the instructors (acknowledge) and inclusion of elements that will allow them to understand the customer experience (empathize). Finally, providing students the opportunity to reflect on their experiences can help them feel more comfortable with ambiguity. The reflection component on this project was achieved through the focus group that sought to provide students a forum to share their experiences on this community-based approach to engineering design.

3.1.4 Focus Group Results

An interesting theme that arose from the focus group was the choice of topic for the community-based design project. Although students were told by the course instructors that the topic they selected would be the focus of their design throughout the semester, students felt that they were not fully aware of this constraint when they were selecting their problem. One point brought up and agreed upon by the majority of the students was that the community-based design problems were too broad, vague or ambiguous to accurately determine potential customers that they would need to speak with. For instance, students that were working on the “internet” topic felt that the size and scope of the problem was too large which impacted their motivation and interest in working on the project. This result confirms observations made by other researchers when studying early stage engineering students. In work done by Atman et al. (1999), they found that some first-year students had a difficult time with the problem definition phase of the design process and then had a difficult time moving forward with other steps of the design process. It also supports observations made of junior engineering students working on open-ended problems where students have expressed difficulty in determining whether they are making appropriate assumptions and felt unsure about whether the way they were scoping the problem was making the problem too large or too narrow in scope (Mourtos, 2010).

Despite these hesitations about working on open-ended problems, the students acknowledged that being able to work on open-ended design problems was “very important” and “essential” to engineering
practice. Recognition of the importance of ambiguity in problems is important since it has been found that designers need to have the ability to tolerate ambiguity (Dym, 2006).

Students shared that they spent the most time in their design process focused on understanding their customer and performing a stakeholder analysis. This included reaching out to instructors for input, speaking with customers and getting input back from their fellow peers. They shared that they felt this stage of the process “dragged on” but they understood the importance of it in a final design. This finding shows students don’t necessarily fully appreciate the amount of time that is dedicated to problem scoping in professional practice as was also supported by the work of Atman et al. (2007).

Another point raised by the students was the difficulty in separating themselves from customers on the project. As many of the community-based design problems, such as food, internet, and fire alarms, directly pertained to problems experienced by students, they felt that it was difficult to remove themselves from the problem and avoid biases that they may have surrounding the situation. This near experience with the problem may have contributed to the students expressing difficulty with the problem scoping as outlined earlier in this section.

Finally, students discussed the role of teamwork as part of their design process. They felt that team performance differed based on the students that were in the group and decisions were made to allow the project to move ahead with the least amount of conflict. Their overall team performance was also influenced by the skill sets that the particular project required although they felt overall that most projects only required general engineering thinking and not a focus on any one specific discipline.

3.1.5 Limitations

This pilot study was conducted at a single institution with a total of three class sections, and, as such, the results are not yet generalizable or transferable to other contexts. This pilot study also had a small sample size for both the survey and focus group components of the study and hence further studies will be necessary to validate the results that were observed and ensure the validity of the survey instrument. In addition, future work will aim to integrate the qualitative and quantitative data to better understand the experiences of students with specific dispositions towards ambiguity and multiple perspectives.

4 Conclusions

Students need to develop the capability of tolerating ambiguity and being able to work on ill-defined problems to be successful in professional practice. This pilot study demonstrated that students that participated in a community-based design problem demonstrated a variety of profiles in terms of their comfort level with ambiguity in engineering and closed-mindedness with students on either end of the spectrum, those with higher tolerance for ambiguity and open-mindedness to those that were much more closed-minded and expressed resistance to ambiguity in engineering. This observation was reaffirmed in students’ expressions of difficulty surrounding the problem scoping portion of the design process and the ill-defined nature of the problem provided. However, all the students acknowledged the importance of exposure to these types of problems within their engineering training. Supporting students in their development of the ability to tolerate ambiguity through exposure to community-based design problems will enable them to be successful as they develop into engineering professionals.
5 References


Appendix 1 – Survey Instrument

Resistance to ambiguity – engineering context

Q2_1: I feel frustrated when I am given a problem that is ambiguous

Q2_2: When working on a design project, I find myself wishing the instructor would tell me what they want me to do

Q2_3: I prefer problems that have an established way to solve them

Q2_4: Problems that are ambiguous make me worry that I won’t get a good grade

Q2_5: I enjoy working on problems that have multiple solution (reverse-scored)

Q2_6: I feel comfortable when my instructor gives me a problem and it isn’t clear how to solve it (reverse-scored)

Q2_7: Engaging with problems with multiple possible solutions is an opportunity for me to use my creativity (reverse-scored)

Resistance to multiple perspectives

Q2_8: The most important opinion for a classroom design project is the opinion of the instructor

Q2_9: Other students who have solved a similar design problem already could help our team understand how to satisfy the requirements of the assignment

Q2_10: Decisions throughout the design project are best decided by asking someone who knows a lot about that particular subject or area

Q2_11: Engineering designers should prioritize learning what people like or dislike about a design so they can make changes to improve it for the users. (reverse-scored)

Q2_12: The way that people view design problems differently makes it hard to get anything done Q2_13: I feel frustrated when my teammates have different ideas about how to solve a problem than I do

Q2_14: It is important to listen to the ideas of others when solving a problem with multiple possible solutions (reverse-scored)

Q2_15: I prefer to proceed with my original ideas rather than spend time listening to my teammates

Q2_16: Everyone has something valuable to contribute to any engineering design problem (reverse-scored)

Q2_17: Learning how others see problems differently than I do makes me a better engineer (reverse-scored)
Q2_18: Working with others has revealed to me that I don’t always have the best ideas (reverse-scored)

Q2_19: After taking time to listen to the ideas of others, sometimes I change my own perspective (reverse-scored)

Q2_20: I prefer to work with others on design problem (reverse-scored)

Q2_21: In an engineering design team, all perspectives are important (reverse-scored)

Closed-mindedness

Q3_1: Even after I've made up my mind about something, I am always eager to consider a different opinion. (Reverse-scored)

Q3_6: In most social conflicts, I can easily see which side is right and which is wrong.

Q3_7: When considering most conflict situations, I can usually see how both sides could be right. (Reverse-scored)

Q3_8: When thinking about a problem, I consider as many different opinions on the issue as possible. (reverse-scored)

Q3_11: I prefer interacting with people whose opinions are very different from my own. (reverse-scored)

Q3_13: I always see many possible solutions to problems I face. (reverse-scored)

Q3_15: I do not usually consult many different opinions before forming my own view.

Discomfort with ambiguity

Q3_2: I don't like situations that are uncertain.

Q3_3: I dislike questions which could be answered in many different ways.

Q3_4: I feel uncomfortable when I don't understand the reason why an event occurred in my life.

Q3_5: When I am confused about an important issue, I feel very upset

Q3_9: I like to know what people are thinking all the time.

Q3_10: It's annoying to listen to someone who cannot seem to make up his or her mind.

Q3_12: I feel uncomfortable when someone's meaning or intention is unclear to me.

Q3_14: I'd rather know bad news than stay in a state of uncertainty.
Leveraging Experienced Graduate Students to Enhance International Service Learning Programming

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2 Director, Engineering Service Learning Program

Abstract

Formally established in 2011, the Villanova Engineering Service Learning (VESL) program provides opportunities for undergraduate and graduate engineering students to engage in partner efforts around the globe to develop local solutions to local problems (Ermilio, et. al., 2010). Also started in 2011, Villanova’s cross-cutting MS in Sustainable Engineering (MSSE) program prepares students to apply whole-systems, lifecycle thinking in problem solving. Synergies that have developed between the two programs, with MSSE students involved with international research projects in collaboration with VESL partners, helped to motivate the launch of a curricular track in Sustainable International Development (ID) in the MSSE program in September, 2016.

The advent of the ID track has helped facilitate the recruitment of graduate assistants (GAs) to the MSSE program with incoming international experience, such as Returned Peace Corps Volunteers (RPCVs), and participants in VESL’s Year of Service (YoS) program. These GAs then serve as team leaders for collaborative efforts VESL’s program partners Africa, Asia, and Central America. As project leaders, the GAs help to mentor undergraduate students involved with service projects and interface with international partners. In addition, they co-facilitate weekly seminars for students participating in international experiences ranging from week-long immersion trips to 8-week summer internships, and also lead student teams while in the field. Finally, the GAs focus their efforts on investigating development challenges related to sustainability adding value to program partner initiatives and providing further depth of opportunity to undergraduate students who can participate as field assistants. With prior experience working in a developing context, the graduate students are uniquely positioned to fill leadership roles, and help offset the need for greater faculty involvement as the scope of the VESL program grows.

Whereas, a pilot of this model was implemented from 2012 to 2016, the two-year anniversary of the official launch of the MSSE ID track and graduate leadership model (May 2018), provides an opportunity to evaluate early outcomes. As a result, this paper considers the impact that this model has had on the total number of students involved as well as the overall quality of the VESL program. The former was considered in terms of program expansion to new countries and partners, thus facilitating increased opportunity for student participation. Program quality was evaluated by compiling results from surveys administered on a periodic basis to gather feedback from students participating in service learning experiences, faculty and graduate student advisors, and representatives of project partner organizations. Finally, the paper offers further detail regarding the experience of integrating graduate student leadership into service learning programming, with the hope that it will offer insights to peers from other institutions.
1. Introduction and Background

1.1 Villanova Engineering Service Learning (VESL) Program

With Villanova University founded upon an Augustinian Catholic tradition, the institution and its College of Engineering (CoE) have a long tradition of engaging students in international service initiatives. The first international engineering service project started in 1991, when a group of students and faculty traveled to Panama to work with a Franciscan Priest to support water supply and other community infrastructure projects, a partnership that’s continued to the present (O’Brien, 2010). Later, in the mid-2000s, projects were initiated with partners in Nicaragua and the Philippines. The VESL program was formally established in 2011, when the Dean of Engineering created Director of Service Learning position for the College.

A foundational element of the VESL approach is establishing partnerships and providing technical assistance to organizations that have the capacity to implement projects. This latter point is key, as faculty and student teams do not operate in the critical path of project implementation, but rather support the ongoing programming of local partners through engineering design, innovation, capacity strengthening, and third-party evaluation and research. As such, partnerships are designed to extend beyond the lifecycle of a single project. At the time of writing, VESL is actively engaged in projects with 8 partner organizations in 7 countries, with pilot initiatives underway with prospective partners in 2 more countries (see Table 14).

Table 14 Active VESL Partnerships

<table>
<thead>
<tr>
<th>Partner and Location</th>
<th>Focus of Collaboration</th>
</tr>
</thead>
<tbody>
<tr>
<td>Caramanico Foundation, Cambodia (since 2012)</td>
<td>School infrastructure and STEM education.</td>
</tr>
<tr>
<td>Golden West Humanitarian Foundation, Cambodia (since 2012)</td>
<td>Humanitarian technologies for detection and disposal of unexploded ordinances (UXO).</td>
</tr>
<tr>
<td>Lifetime Wells International, Ghana (since 2014)</td>
<td>Sustainability of handpump water supply services.</td>
</tr>
<tr>
<td>Profugo, India (since 2013)</td>
<td>Biodisgetors and water resources management.</td>
</tr>
<tr>
<td>Himalaya Hope Charitable Foundation, India (since 2016)</td>
<td>STEM education.</td>
</tr>
<tr>
<td>Catholic Relief Services, Madagascar, Tanzania, &amp; Ghana (since 2011)</td>
<td>Sustainable Water, Sanitation and Hygiene (WaSH) services.</td>
</tr>
<tr>
<td>El Porvenir (formerly Water for Waslala), Nicaragua (since 2004)</td>
<td>Gravity-driven piped-water supply for rural communities.</td>
</tr>
<tr>
<td>Chepyo Bayano Mission, Tortí, Panama (since 1991)</td>
<td>Community infrastructure, piped water supply, water resources management.</td>
</tr>
</tbody>
</table>

The VESL program is horizontally and vertically integrated within CoE, interfacing with each of the College’s 4 departments, and offering avenues for involvement for students from freshman to graduate levels. Opportunities for involvement present a range of both breadth (number of students reached), and depth (level of interaction with partners and projects). These include projects embedded in engineering courses, 1-2 week field experiences, dedicated courses, summer internships, capstone design projects, year of service (YoS) assignments, and graduate research projects.
1.2 MS in Sustainable Engineering (MSSE) Program

Graduate courses in Sustainable Engineering have been offered in CoE since 2008 and a formal MS program was established in 2011. Villanova’s MSSE program is only one of a handful of graduate programs in the emerging field that exist in the US. The program is housed at the College level, enabling it to cut across different engineering disciplines.

Systems thinking is a core competency for students coming out of the MS program, and is embedded into the program’s core curriculum via the STEEP framework, first coined by the firm Arup (Schmidt, et. al., 2015, Arup, 2006). The conceptual framework prompts the engineer to consider the social, technological, economic, environmental, and political dimensions of sustainability problems. STEEP is integrated throughout the program’s core curriculum and provides an overarching framework for Sustainable Engineering research.

The MSSE degree requires 4 core courses (12 credits) to build a whole systems foundation, 4 courses (12 credits) selected from one of 6 tracks to provide depth in a discipline-specific area, and 2 courses equivalent (6 credits) in research and elective courses. The newest track, launched in the September of 2016 and relevant for the purposes of this paper, is Sustainable International Development.

Table 15 MSSE Core and Sustainable International Development Track Curriculum

<table>
<thead>
<tr>
<th>Core Courses (12 credits)</th>
<th>Sustainable International Development Track Courses</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sustainable Engineering Fundamentals</td>
<td>Intro to Sustainable Engineering for International Development</td>
</tr>
<tr>
<td>Lifecycle Assessment &amp; the Circular Economy</td>
<td>Sustainable Product Development for Low Resource Settings</td>
</tr>
<tr>
<td>Social and Economic Integrators</td>
<td>Sustainable WaSH &amp; Environmental Engineering for Development</td>
</tr>
<tr>
<td>Sustainable Materials &amp; Design</td>
<td>Information, Communications, and Energy Technologies for Development (for Spring 2019)</td>
</tr>
</tbody>
</table>

1.3 MSSE and VESL Integration

The first experience with MSSE students engaging in research projects with VESL partners dates back to 2012. In 2013, these efforts were further formalized as the CoE began supporting an annual graduate assistantship earmarked for candidates with at least one year of prior international field experience, including Returned Peace Corps Volunteers (RPCVs), VESL YoS alumni, and employees of partner organizations. Contributing to an emerging Sustainable WaSH research initiative, three fellows worked with VESL partners from 2013-16 on research projects to monitor the technical performance of water supply infrastructure and evaluate the sustainability of water supply services in Panama, Nicaragua, and Madagascar. These research projects served as conduit for undergraduate student involvement, with break trip participants and summer interns serving as field research assistants. The graduate fellows assisted in advising undergraduate student teams, providing pre-travel orientation, leadership in the field, and helping to mentor capstone design teams.

As these collaborations gained momentum along with interest among MSSE students in sustainable development issues in developing communities, the Sustainable International Development (ID) curricular track in the MSSE program was rolled out in Fall 2016. Recognizing that the application of engineering and technology to sustainable livelihoods and the provision of services in low resource settings poses multi-
dimensional problems, the track aims to apply the whole-systems approaches embedded in the MSSE program to this context. The track’s introductory course provides a survey of development practice fundamentals including project management frameworks, participatory appraisal methods, and monitoring, evaluation, accountability & learning (MEAL) tools.

With a complimentary curricular option to the already established research initiative, along with increased financial aid opportunities, recruitment of experienced GAs has risen. With the addition of 3 graduate assistance annually, the leadership team has a total of 6 team leaders with 4 RPCVs, 1 VESL YoS alumnus, and 1 partner organization represented. Each GA serves as a country leader, and works with the VESL Program Director and CoE faculty in mentoring undergraduate student teams and interfacing with program partners. Undergraduate students participating in break trips or summer internships are required to attend a 1-credit seminar course to facilitate orientation and preparation prior to travel, and the completion of project deliverables and reporting back to partners after travel. As part of their leadership role, GAs act as teaching assistants for the seminars, facilitating small group sessions for each country program as well as collaborating to plan and facilitate plenary sessions. As experienced practitioners, GAs are able to draw upon their own prior experience, as well as Sustainable International Development coursework in mentoring student teams. Also, being accustomed to operating in cross-cultural and low-resource settings, the have appropriate skillsets to lead teams in the field and serve as a bridge between students and international partners. Having an experience leadership team has enabled VESL and its partners to improve the overall quality of their respective programs while creating unique opportunities for participants (students, faculty, communities and local staff) to engage in immersive learning experiences that reinforce culture and values with a global perspective.

2. Results and Discussion

2.1 Growth and Expansion of VESL Program

One of VESL’s three strategic objectives is to create service learning opportunities for every engineering student. While these opportunities may sometimes take the form of class projects or other on-campus activities, there is a demand for and unique value to facilitating international field experiences for students. As these field experiences entail special logistical considerations, and the direct interaction with partners and communities in a cross-cultural setting requires mentorship that may be distinct from that needed for other academic projects, the role of experienced GA advisors is most direct in the area of facilitating field experiences. Table 16, below, considers VESL program growth since the 2013-14 academic year expressed in terms of number of projects active during the academic year, number of Fall/Winter/Spring Break trips, and number of students participating in break trips. Students participating in break trips more than one semester are intentionally being double counted as student participation is used as a measure of program bandwidth, rather than of unique students reached.

6 The term “project” here refers to activity with a given project in a given country. For the 2017-18 academic year, this number exceeds the number of partners listed in Table 14 because activities with CRS in Madagascar, Tanzania, and Ghana are each counted individually, and prospective new partnerships that have entailed student travel as a pilot effort in Costa Rica and Indonesia are also counted.
Table 16 VESL Program Growth AY 2013-14 to AY 2017-18

<table>
<thead>
<tr>
<th>Year</th>
<th>No. Projects</th>
<th>No. Grad. Fellow Leaders</th>
<th>No. Break Trips</th>
<th>No. Student Participants</th>
</tr>
</thead>
<tbody>
<tr>
<td>2013-14</td>
<td>7</td>
<td>2</td>
<td>9</td>
<td>69</td>
</tr>
<tr>
<td>2014-15</td>
<td>8</td>
<td>2</td>
<td>9</td>
<td>59</td>
</tr>
<tr>
<td>2015-16</td>
<td>7</td>
<td>1</td>
<td>8</td>
<td>46</td>
</tr>
<tr>
<td>2016-17</td>
<td>9</td>
<td>3</td>
<td>9</td>
<td>52</td>
</tr>
<tr>
<td>2017-18</td>
<td>12</td>
<td>6</td>
<td>12</td>
<td>75</td>
</tr>
</tbody>
</table>

While the VESL program has grown since its inception (the program only had 3 project partners in 2011), its scale remained relatively steady in terms of projects and trips between the 2013-14 and 2016-17 academic years, with new projects replacing ones that had been discontinued in some cases. The 2017-18 academic year, however, shows greater net growth, though some of projects counted entail new partnerships, with longer-term possibilities still being explored. The summer of 2017 also marked a program high in terms of number of VESL summer interns, with 17 students participating. With 2017-18 as Year 2 of the MSSE Sustainable International Development track, the number of experienced graduate student leaders doubled as compared with the previous year. The program has grown independently of recruiting experienced GAs through the MSSE ID track, and integrating these students as VESL project leaders may be considered as much a growth management strategy as a driver of growth. However, graduate research projects do offer an avenue to increase the depth of the experience for undergraduate student teams. For example, having a graduate student who had recently returned from a Peace Corps assignment in Tanzania enabled the establishment of a research project considering the use of pre-paid metering for water fetching points in rural areas. In October 2017, the GA led a team of undergraduate students to Tanzania for the first time as field research assistants.

2.2 VESL Program Quality: Student Perspective

Considering program growth and constraints on CoE faculty/staff bandwidth, the intention of integrating experienced graduate student leadership has to be to at least maintain, if not improve, program quality. Following break trips and summer internship experiences, participating students are asked to evaluate the experience using a Likert Scale across the following categories: application process, orientation and preparation, logistics, housing, project partner, project impact, engineering advisors, professional growth, and personal growth. In Table 17, a summary of student responses from AY2013-14 through AY2017-18 is provided, wherein any rating of 3 or below is considered an area of weakness, and any rating of 4 or above is considered an area of strength. In order to compare the experience with and without experienced graduate fellow leadership, the data was delineated according trips/internships where experienced GA leaders were involved and those where they were not. In the case of the latter, a combination of faculty, alumni, external professional advisors, and less-experienced graduate or undergraduate students (such as students who have previously completed summer internships) lead the respective projects/trips.
Table 17 Student Feedback on VESL Break Trips and Summer Internships

<table>
<thead>
<tr>
<th></th>
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<th></th>
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<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Trips Without Experienced GA Leadership (n=69)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Strength</td>
<td>86.8%</td>
<td>72.1%</td>
<td>81.2%</td>
<td>82.6%</td>
<td>91.3%</td>
<td>81.2%</td>
<td>82.1%</td>
<td>89.9%</td>
<td>89.9%</td>
</tr>
<tr>
<td>Weakness</td>
<td>13.2%</td>
<td>27.9%</td>
<td>18.8%</td>
<td>17.4%</td>
<td>8.7%</td>
<td>18.8%</td>
<td>17.9%</td>
<td>10.1%</td>
<td>10.1%</td>
</tr>
<tr>
<td>Trips With Experienced GA Leadership (n=94)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Strength</td>
<td>91.4%</td>
<td>73.1%</td>
<td>84.0%</td>
<td>93.6%</td>
<td>94.6%</td>
<td>79.8%</td>
<td>93.6%</td>
<td>92.6%</td>
<td>96.8%</td>
</tr>
<tr>
<td>Weakness</td>
<td>8.6%</td>
<td>26.9%</td>
<td>16.0%</td>
<td>6.4%</td>
<td>5.4%</td>
<td>20.2%</td>
<td>6.4%</td>
<td>7.4%</td>
<td>3.2%</td>
</tr>
<tr>
<td>All Responses (n=163)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Strength</td>
<td>88.9%</td>
<td>72.2%</td>
<td>82.8%</td>
<td>89.0%</td>
<td>93.2%</td>
<td>80.4%</td>
<td>88.8%</td>
<td>91.4%</td>
<td>93.8%</td>
</tr>
<tr>
<td>Weakness</td>
<td>11.1%</td>
<td>27.8%</td>
<td>17.2%</td>
<td>11.0%</td>
<td>6.8%</td>
<td>19.6%</td>
<td>11.2%</td>
<td>8.6%</td>
<td>6.2%</td>
</tr>
</tbody>
</table>

The only category that showed even a modest drop in student ratings with experienced GA leadership involved was perceived project impact. The area that showed the sharpest increase (at 11.5%) was engineering advisors, the most direct measure of leadership quality. Personal growth also showed a significant increase, at 6.9%. Considering all student responses since AY2013-14, areas that may be considered program strengths include personal growth and professional growth – two areas relevant to the impact of service learning on students – as well as the application process (all with over 90% of respondents rating these areas as strengths). However, the effectiveness of the orientation process in preparing students for international field experiences remains the area most in need of improvement according to student feedback, with student ratings virtually unchanged between trips with and without experienced GA leadership.

2.3 VESL Program Quality: Advisor Perspective

In the spring of 2018, 14 graduate student, faculty, and alumni advisors provided feedback on the VESL program through an anonymous survey, with some thematic areas covered coinciding with those from student break trip surveys. In summary, the areas covered were the VESL framework for providing both a breadth and depth of service learning opportunities to students, student interest and participation in service learning initiatives, faculty interest and participation, equal student and faculty participation among all VESL projects and partners, horizontal integration across all engineering disciplines, vertical integration across all academic levels from freshman to graduate students, the application process for break trips and internships, travel logistics, and the quality of deliverables to project partners. As was the case with student feedback, responses of 4 or greater on a 1-5 scale are considered strengths, while responses of 3 or below are considered weaknesses.

Table 18 Advisor Feedback on VESL Programming (n=14)

|-----------------|---------------|--------------|---------------|---------------|--------------|------------|-------------|--------------|-------------|

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Based on advisor feedback, the areas identified as the biggest program strengths were student participation and integration across all academic levels, with over 90% of respondents identifying each as strengths. Areas identified as needing improvement were equal participation among projects, deliverables to project partners, travel logistics, and integration across all engineering disciplines. While some of these issues exist at a program level, independent of individual project leadership, ensuring high quality deliverables and effectively facilitating travel logistics are key areas where experienced graduate student leaders can play a role in making improvements. An open ended question was also included in the survey to identify program strengths, with common responses being partnerships (cited 7 times) and having experienced leadership (cited 6 times).

2.4 VESL Program Quality: Partner Perspective

As part of the same spring 2018 VESL program evaluation, a survey of program partners, was conducted, with 13 responses collected (10 from overseas staff and 3 from US-based representatives). Areas covered in the partner survey included the level of technical assistance from VESL teams throughout the project cycle, timeliness of project deliverables, preparation of students with respect to cultural awareness, preparation of students with respect to technical knowledge, travel logistics, and effectiveness of Villanova team leaders. While the sample size was limited, responses from program partners were shown to be more favorable than those of students and advisors in similar categories. 100% of respondents rated technical assistance from VESL teams, cultural awareness, and effectiveness of team leaders as strengths. The area that may be singled out as needing the most improvement is timeliness of project deliverables, an area also shown in need of improvement according to the advisors survey.

A 2014 evaluation of the VESL program involved a survey of 7 partner representatives (Ermilio, et. al., 2014), and included two of the same questions used in the 2018 survey. In 2014, only 25% of respondents rated the level of technical assistance across the project cycle a strength, compared to 100% in 2018. While project deliverables remains the area most in need of improvement according to the 2018 partner survey, this area has also improved, with only 50% of respondents rating the area as a strength in 2014. The level of technical assistance provided to partners and timeliness of deliverables are closely connected areas, and arguably ones where team leadership is key.

The work of Reynolds (2014), considering community and partner views on Villanova’s partnerships in Nicaragua, serves as a reminder that local perspectives in host communities may go overlooked in research around international service learning initiatives. While the data reported here does provide some external
viewpoints, some limitations should be acknowledged with respect to representing perspectives of local stakeholders in host communities, due not only to sample size, but also to the data collection method (online surveys) and potential power differentials between university and local NGO partners.

3. Preliminary Conclusions

The VESL program has grown since its inception, with the 2017-18 academic year marking the highest number of project collaborations, experiential break trips, and students participating in those break trips to date. The incorporation of graduate fellows with prior international experience as project leaders has helped augment the program’s bandwidth to manage this growth. As the program has grown, program quality, as measured by stakeholder feedback, seems to have improved in several areas. According to feedback from students, incorporating experienced graduate student leaders was shown to at least moderately improve program quality in every area but perceived project impact. Feedback from project partners also revealed improvements in key program areas, technical assistance and project deliverables. However, in spite of apparent improvements, stakeholder feedback also identified room for further improvement in some key program areas including the quality and timeliness of project deliverables, travel logistics, and the orientation process. Hence, experienced graduate fellows appear to have a valuable role to play in facilitating service learning experiences for undergraduate engineering students, but maintaining program quality in the context of growth seems to require more than increasing bandwidth through these leaders. A key upcoming challenge with the leadership model described here will be continuity, as the first ID track cohort will be graduating, necessitating a transition of leadership.

References


Ethics in Sustainability and Engineering

Deborah Grubbe

Abstract

Ms. Grubbe will discuss, using case studies and prior papers, the role of ethics in support of sustainable engineering practice, in industry, government and academia. She will share a detailed, multi-year curriculum for ethics in undergraduate programs, and will outline how universities may easily address this subject for their students. A force behind the creation of the AIChE Credential for a Sustainability Professional, she will offer a viewpoint around the credential and the subject matter that underpins a holistic definition of sustainability.
Embedding sustainability to produce an award winning chemical engineering programme: some challenges and learnings

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e.byrne@ucc.ie

Abstract

Since writing about the ‘the need to embed sustainability’ into chemical engineering programmes in a 2009 paper (Byrne & Fitzpatrick, 2009), the authors have endeavoured to walk the walk by helping embed sustainability into the Process & Chemical Engineering undergraduate degree programme at University College Cork. This has been achieved both through the development of ‘primary’ bespoke modules with explicit sustainability related foci, as well as through the development of a coherent sustainability related context right throughout the programme, and across modules more generally. Nearly a decade on, this approach yielded international recognition, with a successful submission by the authors on behalf of their programme, which resulted in the award of the 2016 Teaching Sustainability Award by the Institution of Chemical Engineers (IChemE), an award given with the purpose of ‘encouraging the development of better approaches to integrating sustainability principles and values into undergraduate teaching’ among IChemE accredited programmes globally.

This paper provides a reflective account of the evolution (in thinking and practice) made to the Process & Chemical Engineering degree at University College Cork over the past number of years on its sustainability journey, from the perspective of the authors who have championed this journey, and demonstrates how a confluences of various environmental factors, operating at various levels, can help facilitate iterative change and development.

1 Introduction

“Dedicated modules and elective streams alone are not in themselves sufficient to demonstrate how sustainability should be the context through which 21st Century chemical engineering must be practiced. To do this programmes must inherently and consistently demonstrate the need for sustainable practice.”

The above citation, taken from a paper entitled ‘Chemical engineering in an unsustainable world; obligations and opportunities’, in the IChemE journal Education for Chemical Engineers, (Byrne & Fitzpatrick, 2009) represented both an expression of belief and a statement of intent by the authors of this paper. Over the following decade, along with colleagues on the Process & Chemical Engineering degree at University College Cork, the authors have sought to develop a programme with sustainability as both core and the context through which process and chemical engineering is both taught and practiced. This is both in line with contemporary drivers within the discipline, for example, as articulated by the Institution of Chemical Engineers 2007 Roadmap for the profession through the 21st Century (IChemE, 2007), as indeed across other disciplines and within (higher) education more generally (UNESCO, 2015, 2017; Byrne et al., 2016). Research and associated publications around embedding sustainability into contemporary
engineering education has also been a focus of the authors in the intervening period (e.g. Byrne, 2012; Byrne et al., 2013; Byrne & Mullally, 2014; Byrne, 2014; Fitzpatrick et al., 2015; Fitzpatrick, 2016, Byrne & Mullally, 2016; Fitzpatrick, 2017).

2 The Journey
Both of the authors were educated on conventional chemical/engineering programmes in Ireland (both at University College Dublin) through the nineteen eighties and nineties. These programmes reflected engineering programmes across Europe at this time, with a limited amount of (emerging) environmental engineering content (typically included to complement safety aspects on the programme), which were incorporated to support ‘core’ topics. Both authors had a general interest in, and empathy with protecting the environment, but in line with their education, saw this as chiefly a matter from a professional and educational perspective as largely amounting to reducing pollution as far as is technically and economically practicable, while maintaining site emissions below safe and legal operating standards. Essentially, process and chemical engineers produced a range of great processes and products for society, so once we kept our bibs clean and operated within evolving legal environmental and safety standards, then all would be well.

Throughout the nineteen nineties and around the turn of the century, issues around climate change, while seen as being potentially problematic, and potentially impacting on chemical engineering (given that manufacturing and the process industries were responsible for carbon emissions), these were not understood to be much more problematic than say, issues around the hole in ozone layer (which was seen to be eminently fixable). At any rate, it was seen as an intergenerational issue that would be something that maybe our grandchildren might have to face up to.

However, a tipping point came for Edmond Byrne in the case of Al Gore’s powerful Academy winning movie ‘An Inconvenient Truth’, which emanated from the book of the same name (Gore, 2006). The movie was being shown in a local arthouse cinema in Cork, and resonated profoundly with me, as it did with much of society more generally, since it exposed the sheer scale, immediacy and impact of climate change. Indeed, it precipitated a self-awareness by revealing the starkness of the situation, while highlighting the deeply ethical nature of this environmental issue, in a way that resonated deeply for me, both as a citizen and as an engineer and educator.

At this time, I was also teaching a first year introductory module on Process & Chemical Engineering, a sort of catch all introductory module which, among other things (e.g. material and energy balances, process control, introduction to unit operations), incorporated sections on environmental engineering and engineering ethics. Up to that point I considered environmental engineering as a sort of end of pipe activity which enabled process companies maintain their emissions levels within regulatory frameworks. Better still if new and innovative processes or solutions could be engineered to reduce or eliminate such waste. Meanwhile, I had considered teaching of engineering ethics to be a largely separate and orthogonal activity, which called upon personal integrity and moral standing and which might sometimes involve ethical dilemmas for individuals, up to and including potential considerations around whistleblowing. Engaging with the latter, in particular involved in-class ethical fictional case studies, where students might be asked to discuss, debate and identify optimal courses of action for unfortunate engineers, as has been the standard practice in much engineering ethics teaching (e.g. see Shallcross & Parkinson, 2006). This approach
however, always still left me feeling a bit cold and unfulfilled in my attempts to teach this topic; somehow engineering ethics must be more than just about students moralising about notional personal ethical dilemmas.

Gore’s movie however resonated deeply with me. Not only did it open my eyes to the vast scale and urgent immediacy of climate change, it, perhaps more importantly, facilitated me in making a number of connections. First of all, that we as engineers, as key players in the construction of many of society’s physical manifestations, processes and products, need to raise our heads up and consider our impact on society around us, rather than just concentrating on that which is going on inside the perimeter (system boundaries) of our plants. For what goes on respectively within and without the (open) system boundary of the plant are deeply and intrinsically connected. Thus the agonising micro-ethical personal moralistic dilemmas of individual engineers (as taught in the engineering ethics class) could only be (an incomplete) part of the picture; engineers also work in and contribute to broader societal workings, and thus we are both implicated and responsible for macro-ethical issues such as those around climate change, and can (and are ethically obliged) to contribute to addressing these (alongside others). As Gore put it in his corresponding book; ‘Our capacity for analysis sometimes leads us to an arrogant illusion: that we are so special and unique that nature isn’t connected to us. But the fact is, we’re inextricably tied.’ (Gore, 2006). Indeed it became apparent to me that the connections were not just on the micro (individual) versus macro (societal level) ethical spectrum (operating iteratively as recursive drivers of societal cultural change and personal behaviour), but also that climate change was really just one manifestation of an unsustainable societal construct (along with biodiversity loss, environmental degradation of oceans, air and land, etc.) which are themselves deeply interconnected with societal issues around water, energy, food and material flows. Moreover, it soon became baldly apparent to me that the pillars of environmental engineering and engineering ethics were also closely linked, for as Gore put it as his academy speech ‘we need to solve the climate crisis: It's not a political issue; it's a moral issue.’

This movie moved me to the extent that I brought the whole first year class to watch the movie at the nearby cinema that was showing it in Cork as part of their engineering ethics class. Thereafter, stimulated and informed by contemporary work of researchers on engineering ethics such as Herkert (2005), Bucciarelli (2008) and Conlon (2010) my outlook on the role of engineering ethics evolved and broadened, to more deeply and explicitly incorporate the corresponding macro-ethical responsibilities of engineers to society and environment. This precipitated the development of a personal research interest and corresponding outputs in this area (e.g. Byrne, 2012; Byrne & Mullally, 2014) and thereby a recognition of the value and necessity of more explicitly transdisciplinary approaches in addressing emerging complex contemporary challenges (Byrne at al., 2016; Byrne & Mullally, 2016)). I was also undertaking an MA in Teaching and Learning in Higher Education at the time (graduating in 2008), which helped facilitate the development of a personal understanding of learning in terms of constructivist approaches, something which is alien to the traditional modernistic worldview as espoused by classical engineering education, but which is essential to effectively engaging with sustainability issues and associated narratives, including education for sustainable development (UNESCO, 2015, p. 15).

The second author of this paper, John Fitzpatrick, has been teaching chemical / process engineering students since 1995 in mainly technical subjects. Around 2003, he started teaching two half modules in environmental protection. These focused mainly on management and technical aspects from a process
industry perspective, including waste treatment & disposal, environmental legislation, waste minimisation, life cycle assessment, cleaner process technology and cleaner energy. Over time, he had the niggling feeling that the big challenges to moving humanity towards a sustainable paradigm lay in broader global societal challenges, such as climate change and the food-energy-water nexus. Furthermore, he developed the feeling that the economic and social domains have a major role to play and are possibly the “game-changers” (Fitzpatrick, 2017). This is not to say that the technological innovation and challenges are not important; yes they are but the critical levers to moving humanity towards a sustainable paradigm may exist in the economic and social domains. He also had the niggling feeling that he was complicit in producing ‘technically competent barbarians’ (see Barry, 2012, p.126), who were not truly fit-for-purpose for the sustainability challenges of the 21st century.

3 A Process of Directed Chance

As colleagues in a small tight knit department, and each with an active (research) interest in engineering education as well as broader issues of sustainability, both authors inevitably discussed how and to what extent sustainability related issues should be incorporated into the engineering curriculum. An opportunity arose to host an international conference on engineering education in 2010, the 3rd International Symposium for Engineering Education (Byrne, 2010), where the authors comprised the majority of academics on the local organising committee (including the conference Chair). A theme which reflected a particular interest of ours was selected, specifically on engineering education for sustainability/sustainable development. Thus the chosen conference theme was ‘Educating engineers for a changing world – Leading transformation from an unsustainable global society’. We worked hard to make this a successful conference which would attract academics interested in this area and incorporated, among other things, a delegate workshop on the theme of ‘Accreditation and Sustainable Engineering,’ with a corresponding delegate primer paper which looked at state of the art regarding the sustainability requirements of engineering accreditation bodies globally (Byrne et al., 2010). Outputs from this workshop provided material for a subsequent paper published in the International Journal of Sustainability in Higher Education (Byrne et al., 2013). The symposium was very successful, attracting a number of like-minded academics among the 135 participants from 16 countries across all continents. Among them were some from the EESD conference series. It was this pioneering community that the UCC academics engaged with, were inspired by and learned from, from the 2010 conference in Gothenburg (Chalmers University of Technology) to the present series and beyond (the 11th EESD is scheduled for Cork in 2020).

This engagement led to discussions among the authors about the possibility of jointly developing a new core bespoke module on ‘Sustainability in Process Engineering’ (PE3011). Having discussed it with and received the support of colleagues and our local curriculum committee, the green light was given for this new module which began in Spring 2011. This module provided a focus for sustainability on the programme, and took a broad view of the topic at hand, not just covering socio-technical aspects such as life cycle analysis, but also making explicit the underlying values and paradigms around sustainability narratives and the nature of complex non deterministic systems; essentially aiming to develop the generic competencies, including integrative approaches and critical thinking skills necessary for and that correspond with education for sustainable development (ESD) more generally (Bourne & Neal, 2008; UN, 2012; Byrne, 2014).
Neither was our earlier call for ‘the need to embed sustainability’ (Byrne & Fitzpatrick, 2009) forgotten, and other modules on the programme were, with the support of colleagues, developed to help deliver this aim. This is an important point; while colleagues were not perhaps as enthused or as interested in issues around EESD, they nevertheless were generally supportive of our endeavours, while also willing to incorporate sustainability elements and indeed contexts of sustainability into their respective modules and to engage with us, where appropriate, as they generally saw the greater value of this endeavour. Moreover, the macro environment as facilitated both by the likes of professional accreditation bodies such as the IChemE and Engineers Ireland, as espoused through their accreditation requirements and other drivers such as the IChemE Roadmap (IChemE, 2007) and their associated sustainability related prizes and initiatives, or Engineers Ireland Code of Ethics (Engineers Ireland, 2018) certainly provided useful top down professional body leadership and a broader context for facilitating and promoting this approach. Moreover, a positive sustainability ethos and leadership across our university also helped provide a positively oriented context.

Sustainability embeddedness was achieved through the programme via a number of modules at each stage; these included the obvious ones such as the first year module on Professional Engineering Ethics (see Byrne & Mullally, 2014) and the two Safety and Environmental Protection modules, but also, with support of colleagues on the programme, a sustainability ethos and applications found their way into other less obvious modules also, such as for example, Introduction to Biochemical Engineering and Advanced Process Design (Table 1). Perhaps the biggest achievement (and challenge) of all, was the evolution of the capstone final year design project from an initial point where ‘sustainability’ was treated as, at best an end of pipe add-on, to the point whereby sustainability thinking is an inherent part of the module as students are encouraged to integrate it, in particular at the early scoping and key decision making stages of the project. Moreover, students are also encouraged to view the broader societal context of their design, including the consideration of socio-economic aspects and frameworks, which in terms of eliciting transformative change, may be have a bigger and more fundamental role to play than the development of technological artefacts and processes (Fitzpatrick, 2017). However, while many of the big economic and social sustainability issues are at the macro-societal level, and thus may be considered too broad in scope for inclusion in the design project, students are nevertheless challenged to at least reflect on their sustainability education and exhorted to consider framing the boundaries of the broader social and economic environment from a sustainability perspective within the context of their respective designs. This approach can thus help students ‘explicitly reflect on how they envisage the scope of their project and to what extent they might engage with and incorporate sustainability issues in a meaningful way which recognises how socio-economic and political factors interact with technical ones within the open system that the design problem is actually situated’. (Fitzpatrick & Byrne, 2017).

To this end, both authors provide some guidance on the sustainability requirements of the group design project, in support of the module coordinator and academic delivery team. Moreover, the effective required output for the groups is a proposed entry into the IChemE’s Macnab-Lacey final year sustainability design prize, which is a prize awarded annually by IChemE to the undergraduate student design project team whose design project submission best shows how chemical engineering practice can contribute to a more sustainable world’, among other things in order to ‘influence chemical engineering departments to position sustainable development at the heart of the curriculum’ (IChemE, 2018). One entry is allowed per third level institution, so our academic design team confer to choose a UCC entry each year.
Table 1 Modules designed to embed sustainability on UCC’s programme

<table>
<thead>
<tr>
<th>‘Primary’ Sustainability Modules</th>
<th>‘Secondary’ Sustainability Modules</th>
</tr>
</thead>
<tbody>
<tr>
<td>PE1006 Professional Engineering Communication &amp; Ethics</td>
<td>PE1003 Intro. to Process &amp; Chemical Engineering</td>
</tr>
<tr>
<td><strong>Objective:</strong> develop appreciation of professional ethics through</td>
<td><strong>Objective:</strong> understand the role and responsibilities of</td>
</tr>
<tr>
<td>application in complex problems and case studies.</td>
<td>chemical process engineers. selecting process alternatives,</td>
</tr>
<tr>
<td><strong>Learning Outcome:</strong> Relate professional engineering practice to</td>
<td>constructing process diagrams, performing mass and energy</td>
</tr>
<tr>
<td>the ethics and ethos of the profession and the role of engineering</td>
<td>balances.</td>
</tr>
<tr>
<td>in society. Understand the nature of complex wicked problems and</td>
<td><strong>Learning Outcome:</strong> Discuss the role of process</td>
</tr>
<tr>
<td>apply appropriate strategies for resolving such problems.</td>
<td>engineering with respect to production efficiency, safety</td>
</tr>
<tr>
<td></td>
<td>and the environment.</td>
</tr>
<tr>
<td>PE2005 Introduction to Biochemical Engineering</td>
<td></td>
</tr>
<tr>
<td><strong>Learning Outcome:</strong> Apply an engineering approach to development</td>
<td></td>
</tr>
<tr>
<td>of sustainable industrial biochemical systems.</td>
<td></td>
</tr>
<tr>
<td>PE2011 Plant Design and Commissioning</td>
<td></td>
</tr>
<tr>
<td><strong>Learning Outcome:</strong> Appraise the design and operation of process</td>
<td></td>
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<tr>
<td>facilities with specific reference to sustainability, plant safety</td>
<td></td>
</tr>
<tr>
<td>and plant management.</td>
<td></td>
</tr>
<tr>
<td>PE3011 Sustainability in Process Engineering</td>
<td>PE3001 Applied Thermodynamics and Fluid Mechanics</td>
</tr>
<tr>
<td><strong>Objective:</strong> Examine concepts, constructs, models and values</td>
<td><strong>Learning Outcome:</strong> Employ a whole system design approach</td>
</tr>
<tr>
<td>relating to sustainability and sustainable development. Examine</td>
<td>to optimise pump-pipeline system design.</td>
</tr>
<tr>
<td>relationships between complex systems, thermodynamics and sustainability</td>
<td></td>
</tr>
<tr>
<td>and how these relate to post-normal engineering roles,</td>
<td></td>
</tr>
<tr>
<td>responsibilities and practice. examine environmental management</td>
<td></td>
</tr>
<tr>
<td>systems and clean/green concepts &amp; technologies and how they can be</td>
<td></td>
</tr>
<tr>
<td>applied to sustainably produced products from process industries.</td>
<td></td>
</tr>
<tr>
<td>PE3008 Safety &amp; Environmental Protection I</td>
<td></td>
</tr>
<tr>
<td><strong>Content:</strong> Environmental protection: Human impact on the</td>
<td></td>
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<tr>
<td>environment; Ecological limits; Water and waste water treatment;</td>
<td></td>
</tr>
<tr>
<td>Hazardous waste treatment/disposal; Air pollution control.</td>
<td></td>
</tr>
<tr>
<td>PE4004 Safety &amp; Environmental Protection II</td>
<td>PE4001 Advanced Process Design</td>
</tr>
<tr>
<td><strong>Objective:</strong> Understanding of Process Safety and Environmental</td>
<td><strong>Objective:</strong> developing, designing and scaling up innovative,</td>
</tr>
<tr>
<td>Protection/Sustainability. <strong>Content:</strong> Legislation; Solid waste</td>
<td>sustainable and creative chemical engineering products and</td>
</tr>
<tr>
<td>treatment and energy from waste plants. Cleaner process technology</td>
<td>processes.</td>
</tr>
<tr>
<td>and cleaner energy in the process industries. Corporate environmental</td>
<td><strong>Learning Outcome:</strong> Assess the opportunity for green engineering</td>
</tr>
<tr>
<td>sustainability. Ecological economics.</td>
<td>and sustainable chemical product design.</td>
</tr>
<tr>
<td>PE4006 Design Project</td>
<td></td>
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<tr>
<td><strong>Learning Outcome:</strong> Design a process with a sustainability</td>
<td></td>
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<tr>
<td>perspective.</td>
<td></td>
</tr>
</tbody>
</table>

Apart from engaging with the broader EESD community on a European and global stage, as well as with chemical engineering academics in our own institution, we have also engaged over this period to a far greater extent in our local university with colleagues of like mind right across the disciplines. ESD competencies naturally call for inter and transdisciplinary engagement, something which can be far easier to recognise than enact. However, this was assisted by an environment at UCC which encouraged environmental engagement right across the university (University College Cork was the first university in the world to receive the Green Flag for environmental friendliness (2010) and reached a high point of overall number two in the global UI Green Metric Universities rankings list in 2014 (Byrne et al., 2016a)), guided by the pioneering leadership of current Registrar and Deputy President (and Professor of Zoology)
John O’Halloran, alongside a cohort of like-minded and committed staff and academics. In this context, Ed Byrne reached out to a lecturer in Sociology, Dr Ger Mullally, and forged a relationship which facilitated the development of a transdisciplinary group sustainability assignment on the third year *Sustainability in Process Engineering* module, by also incorporating the assignment on a third year *Sociology of the Environment* module. Thus undergraduate engineers were brought into collaborative contact with sociology and government students. After all, there’s hardly any point in us exhorting our graduates to go out and work with other disciplines in the workforce for good, if we are not prepared to *walk the walk* and prepare them for that within the confines of the uni-versity! This journey also led to coming into contact with other like-minded colleagues, such as the food geographer Dr Colin Sage, who instigated the UCC supported transdisciplinary Environmental Citizenship Research Priority Area (‘Sustainability in Society’) in 2011 (Mullally et al., 2016), which sought to (re)consider sustainability in a way which both draws from disciplinary contexts and knowledge but also transcends and builds on new contexts.

Disciplinary imperatives were also tended too across the programme. The sustainability ethos of the programme was developed and refined, drawing on research from Imperial College, London which showed that the desire to ‘*make a difference to the world*’ (Alpay et al., 2008) in their careers was a key driver in enthusiastic idealistic young school leavers (in many cases ahead of making money, designing new things and travelling), in particular among females. This too was our experience; students generally were overwhelming positive about both the ethos and the respective modules around the programme, indeed even, and especially some of the more novel aspects, such as working with sociology students on a sustainability assignment. For example, the following represents (anonymously collected) feedback from a number Process & Chemical Engineering students on their experience of this assignment as part of the Sustainability in Process Engineering module:

- ‘Completing an interdisciplinary [assignment] gave me a more all round view on sustainability as it made us look at sustainability from more than just an engineering point of view.’
- ‘A major learning point of this was taking on board alternative perspectives of problems, outside of engineering solutions.’
- ‘[The] transdisciplinary approach was enlightening – an engineering solution isn’t always the only option.’
- ‘Greater understanding and appreciation of perspectives [from those] which don’t work on “hard science”’
- ‘Working in a team with vastly different opinions is hugely valuable to our careers in the future.’

The positive feedback from our students, allied to the aforementioned research on the attraction of making a positive difference, encouraged us to explore the value of using the broader sustainability ethos of the programme as a soft marketing tool to attract potential students to the programme. Inspired by the IChemE’s visionary 2007 ‘Roadmap’, a strategic plan for the profession for the century ahead, and its associated cover image (IChemE, 2007), Ed Byrne worked with colleagues to develop a forward looking ‘journey ahead’ image which seeks to convey both the essence of the UCC programme (and the profession), while also highlighting the role and opportunity that chemical engineers have in both facilitating and helping to lead transformational societal change (alongside others) when practiced through a sustainability lens (Figure 1).
4 International recognition; A Staging post

In 2015, the Institution of Chemical Engineers instigated a Sustainability Teaching Award, organised and promoted by the Sustainability Interest Group in conjunction with its Education Interest Group. It was developed in order to encourage ‘the development of better approaches to integrating sustainability principles and values into undergraduate teaching’. The authors of this paper decided to submit an entry to this award on behalf of the UCC Process & Chemical Engineering programme for the second iteration of the award in 2016. To our delight our entry was deemed the winner on the first attempt, beating off highly commended competition from top universities across the globe, with the judging panel noting that they ‘were particularly impressed by your integration of sustainability teaching across the curriculum, with good examples of interdisciplinary projects and varied assessment with student comments indicating their appreciation of the approach.’ (UCC, 2017). In making the award, the IChemE also noted that “University College Cork demonstrated that they could integrate sustainability teaching principles across the curriculum, which will provide their chemical engineering students with a set of values to apply to their future careers.” (IChemE, 2017). The award was presented at the IChemE’s AGM in Birmingham, England in May 2017 by the incoming IChemE President John McGagh. In presenting our case for the award, we highlighted a number of modules from across the programme, which we indicatively labelled ‘primary’ and ‘secondary’ modules, with respect to the degree to which they aim to embed sustainability across the four years of the degree programme (see Table 1). The secondary modules highlighted are indicative; others modules also incorporate a sustainability ethic.

5 Conclusion and Learnings

We have found the journey to be both fascinating and rewarding as we’ve sought to help transition our programme from a more traditional one programme whereby sustainability is envisaged in a narrow way, that is, concerned with simply boosting efficiencies and improving environmental emissions, to one whereby it explicitly seeks to add value (and values) to contemporary chemical engineering education, through recognising that ‘the key ingredient required .is an aspiration to enable and empower learners to meet their full potential by developing the necessary skills and aptitudes (critical, reflective and complex thinking, self-awareness and empathy, teamwork, listening and communication skills) to be fit-for-purpose’ (Byrne, 2014) contemporary chemical engineers. Indeed, as we’ve attempted to push various doors (via our students, colleagues, accreditation bodies, industry, peers), we have found that not only have they generally swung open with surprising ease, but that they’ve often opened altogether new and exciting vistas. We offer this account as one which can hopefully help and inspire others on similar pathways, while also offering a perspective on what and how we see as ‘core’ chemical engineering, to educate fit- for-purpose graduates in addressing contemporary and emergent 21st century challenges, in a way that can contribute meaningfully towards authentic societal sustainability and human flourishing.
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Process, Improvisation, Holarchic Learning Loops and all that Jazz: Experiences in Transdisciplinary Education for Sustainable Development

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Abstract

This paper explores the experiences of an ‘Interdisciplinary Sustainability Assessment Laboratory’ (‘ISA Lab’) workshop, which took place over a week at Universitat Politècnica de València during April 2017. The workshop drew together students from a range of disciplines from across engineering and science, law and the social sciences and from a range of countries and backgrounds, including North and South America, Europe and Asia. It also facilitated a rich co-creative learning environment as it was led by (engineering) academic faculty from across Europe (Spain, UK, Netherlands and Ireland) as well as North America (Canada), as well as local experts who helped provide participants with appropriate context and guidance. The workshops culminated with a number of presentations from respective student groups, where they outlined an integrated development plan for a selected real life local project.

A necessary constraint of the workshop involved the fact that faculty came from several geographic locations, and thus had an incomplete understanding of the local project descriptions in advance, while the students had even less so. Nor did the six faculty members have a clear idea of the workshop structure or format for the week ahead, except for having produced a bespoke presentation based on their own backgrounds and expertise. Indeed, the faculty team were licenced to essentially develop a five day workshop plan from an outline concept. Nevertheless (or perhaps because of these contextual circumstances), the resultant contingency, allied to a highly motivated group of faculty, students and local experts actually led to a highly creative and productive week of co-created learning opportunities and ultimately inspiring emergent outcomes at a number of levels. From faculty developing and improving on workshop structure and delivery collaboratively and ‘just in time’, to students who initially struggled with concepts and roles, the week culminated in the formulation and presentation of a number of socially sensitive and comprehensively elaborated development plans. Like a piece of harmoniously improvised jazz, this was a collective journey laced with creativity, improvisation and inspiration, which surpassed even our most ambitious goals. This paper describes the process and provides reflections (from both faculty and students) through a number of strands which permeated the workshop. It also speculates on the wider learnings gained from this exercise in project based learning which both facilitated and required innovation, reflection, connection and improvisation amid an ethos and setting of open transdisciplinarity.

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Introduction and Background

This paper emanates from and is inspired by an ‘Interdisciplinary Sustainability Assessment Laboratory’ (‘ISA Lab’) workshop which took place from 10-14th April 2017 at Universitat Politècnica de València (UPV), Spain. The workshop was overseen by a team of six faculty (the listed authors) from a number of European and North American institutions, all of whom are involved in Engineering Education for Sustainable Development (EESD) related scholarship. They were joined by Masters students from a range of disciplines, mainly engineering and architecture related programmes (in Engineering for Sustainable Development, Chemical Engineering, Energy, Built Environment, Architecture, Green Infrastructure) but also from Law. Diversity was further enhanced by the fact that students had various cultural and linguistic backgrounds ranging from across Europe, North and South America and Asia. Local experts were at hand too from the Valencia region, who helped guide and advise students (some of whom were studying locally at UPV) on the respective projects covered. The week culminated in student groups presenting their respective proposals concerning a sustainability informed plan for the development of a designated site or area in the Valencian Community which had been outlined to the groups at the start of the week. The work of the student groups was also underpinned by a series of lectures, given by both faculty and by invited experts, which were aimed at helping contextualise, inform and stimulate the students in their work.

The projects outlined to students were identified in advance by the workshop host and leader Javier Orozco-Messana, who had also assembled a team of local experts who could be used as consultants by the students throughout the week. These were, respectively, the neighbourhood of Benicalap, a relatively low income neighbourhood in the north of Valencia which is bounded by a busy highway, but which also includes a historic building (Casino del Americano) and adjacent public park/gardens which had potential as a local amenity, park and recreational area (for locals and visitors alike). The other project was for the island of Taberca, a Mediterranean island located about 4 km offshore and 18 km due south of Alicante. The island is very popular with day trippers during the summer who take a boat out to it for lunch, but is far less frequented during the winter months. Nevertheless, only the western peninsula of the island is developed with restaurants and houses, while the remainder of it has a number of walkways as well as an old lighthouse and building. The task of the project teams was to see how these could be sensitively developed as an amenity, perhaps for cultural or educational purposes, within an overall ‘sustainability’ ethos, while considering a mix of environmental, social, economic and technical dimensions. Essentially, the projects encapsulated the essence of the kind of challenges we wish to prepare engineers for; i.e., they are current, real life, open ended problems with no obvious solutions, requiring multi–actor engagement and inter– and transdisciplinary approaches, while reflecting the kind of messy problems they are likely to encounter in their professional careers. Furthermore, such inter– and transdisciplinary approaches and opportunities are recognised as critical for sustainability teaching and learning (Coops et al., 2015; Byrne & Mullally, 2016).

Development of workshop structure – a co-created learning journey

Apart from some project descriptions for the projects outlined above, and a requirement for each of the faculty to bring with them a presentation on an agreed area of their own personal expertise which would help guide the students over the course of the week (to be delivered on consecutive mornings), the structure of the week was largely left open and was not predetermined. It was largely up to the faculty team to help develop and create the programme ‘on the run’. The impending task of improvisation appeared both
daunting and exhilarating, though mainly the former! While the largely blank sheet presented to us facilitated a lot of creativity, it also necessitated a high degree of cohesion and at times negotiated consent, and a willingness to be receptive to, incorporate and build upon differing perspectives and ideas. The fact that this team was assembled from all corners of the globe, from varying disciplines, backgrounds and areas of expertise and outlook, and who had previously known each other to varying degrees (or in some cases, not at all!) simply added to the mix.

Figure 1 Holarchic learning and interacting relationships during workshop week

So, while we had the common objective of delivering a programme which aimed to give student volunteers from each of our own Institutions an inter and transdisciplinary experience in finding sustainability oriented solutions to real problems across the Valencia Community over the course of a week, we had no rigid pre-planned structure for doing this. Moreover, we agreed that in seeking out possible courses of action and in developing proposals, we were at one in agreeing that for the students, there were no pre-planned solutions or uniquely correct answers, as we sought to provide guidance and interventions alongside an outline brief and a general direction of travel, asking how might any developments proposed be more sustainable ones. As ever, there was also the consideration that no development might be the best option! Thus as we engaged with this process, the idea of a holarchic learning loop (inspired by the holarchic ecosystems model proposed by Kay et al. (1999) and the panarchic model developed by Holling et al. (2002), which considered system evolution in terms of multi-level adaptive recursive change and positive and negative feedback processes, as opposed to being governed by linear deterministic causal change) emerged in our minds over the course of the week. As faculty leads, we were just a step or two (at most!) ahead of the students in creating a guiding structure which we hoped was sufficiently open and stimulating to provide the scope and time for creative endeavours, while at the same time provide sufficient guidance to produce a meaningful plan. We were improvising and playing off each other(s ideas) in designing the week, while also being
influenced by how the students were reacting to the programme and what they were producing. Meanwhile
the students, in their respective groups, and between groups were learning from each other (with their
diverse backgrounds) and from the faculty leading and structuring the week as well as from invited local
experts. The overall result was a rich network of co-created and co-dependent mode of iterative learning
(Figure 1) (see Roxa et al., 2013; Williams et al., 2013; Roxa & Martensson, 2015; Verwoord & Poole,
2016). The ‘plan’ description which follows is an output of this iterative process and thus emerged largely
throughout the week.

<table>
<thead>
<tr>
<th>Daily Objective:</th>
<th>9–11am</th>
<th>11.30am–1pm Working Session A</th>
<th>3–5pm Working Session B</th>
<th>Evening exercise</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Mon.</strong></td>
<td>Meet, greet, &amp; settling in</td>
<td>Faculty convene to discuss mechanics of workshop week.</td>
<td>Opening introductory session with students; Outline case studies and group selection.</td>
<td>Short personal reflective exercise on day’s work.</td>
</tr>
<tr>
<td><strong>Tues.</strong></td>
<td>Blue skies – Creative possibilities</td>
<td>‘Setting the scene’ lectures from faculty, plus Q&amp;A.</td>
<td>Ice breaker session – group exercise(s) aimed at developing teamwork, trust.</td>
<td>Group exercises: Identify possible criteria for achieving ‘sustainability’, and how can we determine (project) success?</td>
</tr>
<tr>
<td><strong>Wed.</strong></td>
<td>Setting the goals and identifying the “best” conceptual design</td>
<td>‘Setting the scene’ lectures from faculty, plus Q&amp;A.</td>
<td>Local experts/ faculty present detailed account of respective case studies, plus Q&amp;A. Group brainstorming.</td>
<td>Groups identify clusters of ideas/interventions around common themes, and add more in iterative process. Present outline of outputs (as a mind map) to all.</td>
</tr>
<tr>
<td><strong>Thur.</strong></td>
<td>Refining &amp; Preparing your design</td>
<td>‘Setting the scene’ lectures from faculty, plus Q&amp;A.</td>
<td>Group working session.</td>
<td>Develop selected ideas/innovations, including presentation.</td>
</tr>
<tr>
<td><strong>Fri.</strong></td>
<td>Final Preparations &amp; Presentations</td>
<td>Groups work on presentations.</td>
<td>Group Presentations to peers/faculty. Personal reflective feedback on week’s work: what worked, what could be enhanced.</td>
<td></td>
</tr>
</tbody>
</table>

Figure 2 Outline timetable for workshop week.

In addition, the exact structure of the actual workshop emerged as an iterative process. While the lead
faculty provided a conceptual overarching super structure (i.e. a lecture based session each day followed
by two working sessions) and some general guidance, it was up to the faculty team to collectively come up
with a detailed structure for the week. To this end, an outline agenda (incorporating daily themes, staging
points, respective session themes and guiding questions) was developed at an initial kick off meeting by
the faculty team on the first morning before being presented to the students that afternoon for the students’
first session. This agenda was further developed, finessed and enhanced by the faculty as the week went
on, as they were iteratively influenced by progress of the students and the direction of the programme. This
was done in parallel with the student working sessions each afternoon, where faculty worked in the same
room (alongside the students and just a step ahead of them (Figure 4 b)), while also being available to interact with the students on their respective projects. Figure 2 represents the actual workshop structure for the week which emerged and accompanying daily themes. Evening social gatherings also helped provide a useful gel for the group. These included students and faculty working together to develop a fresh, healthy vegan meal, walking tours of Valencia and evening social meals. These gatherings helped break down barriers in the early part of the week, but as the week progressed, they provided a space for collaborative reflection, free thinking and exchange of ideas as the projects came to fruition.

Each day began with a pair of ‘setting the scene’ lectures given by the faculty team (Figure 4 a)), where faculty presented on aspects of sustainability drawn from their own disciplinary perspective and expertise. This covered a wide range of areas from carbon capture and storage, problem framing, integrated design process (at product, process and building level), energy systems, creativity and planning for green infrastructure (Figure 3), and was followed by an open question and answer/discussion session. Faculty subsequently recorded abridged versions of their lectures for public consumption on the UPV website.

<table>
<thead>
<tr>
<th>Academic/Institution</th>
<th>‘Setting the scene’ lecture title</th>
<th>Online URL (where available):</th>
</tr>
</thead>
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<tr>
<td>Javier Orozco Messana, UPV</td>
<td>ISA lab challenge; Workshop on Sustainability</td>
<td><a href="https://media.upv.es/#/portal/video/a53d11f0-04c9-11e7-b987-ab956caf10fc">https://media.upv.es/#/portal/video/a53d11f0-04c9-11e7-b987-ab956caf10fc</a></td>
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<tr>
<td>Edmond Byrne, UCC</td>
<td>Context, Framing, Risk, Uncertainty, and Integrative Approaches to Complex Sustainability problems</td>
<td><a href="https://media.upv.es/#/portal/video/a7bf5210-1eca-11e7-abe0-251981d50228">https://media.upv.es/#/portal/video/a7bf5210-1eca-11e7-abe0-251981d50228</a></td>
</tr>
<tr>
<td>Naoko Ellis, UBC</td>
<td>Campus as a living lab</td>
<td><a href="https://media.upv.es/#/portal/video/eb342660-1eca-11e7-abe0-251981d50228">https://media.upv.es/#/portal/video/eb342660-1eca-11e7-abe0-251981d50228</a></td>
</tr>
<tr>
<td>Susan Nesbit, UBC</td>
<td>The Seven Questions to Sustainability</td>
<td></td>
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<tr>
<td>Kas Hemmes, TU Delft</td>
<td>How to improve energy systems to become more sustainable?</td>
<td><a href="https://media.upv.es/#/portal/video/22bf8190-1f9a-11e7-abe0-251981d50228">https://media.upv.es/#/portal/video/22bf8190-1f9a-11e7-abe0-251981d50228</a></td>
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</table>

Figure 3 Workshop ‘Setting the scene’ lectures.

Morning lectures were followed by two working sessions which allowed students to work in their teams and discuss aspects of their respective projects with local experts and faculty. These session had various themes and were primed by various guiding questions which the faculty developed. For example, for the first session on day two, groups were asked to consider the following: ’What is our design process? What problems might we encounter? – Teams discuss the steps they will follow to create their preliminary conceptual design. Submit a graphic of the process.’ Corresponding overarching guiding questions for this session included: ‘What are sustainability design criteria? What are the important contextual issues for your project? What are some blue-sky design ideas?’

A feature of these sessions that helped provide structure was a short focus piece delivered at the beginning of the first working session each day by one of the faculty or local experts to help prime or stimulate the group ahead of their designated session task. These included an insightful presentation by architect and urban planning expert, Arancha Muñoz-Criado of Harvard University Graduate School of Design, who drew on her wide international experience in speaking about strategic green infrastructure planning and the need to design urban infrastructure around natural systems and to make physical connections/greenways between larger green areas. She also pointed out that in communicating with people, they need a story or
narrative to relate to, and while the populace don’t necessarily always understand ecology, they do readily identify with and understand (narratives around) cultural heritage and family.

3  The Jazz influence; listening and improvising

One of the session introductory pieces, which was proposed during the initial faculty brainstorming session, involved playing part of a TED talk/performance by jazz artist Stefan Harris, entitled ‘There are no mistakes on the bandstand’ (Harris, 2011). This largely self-explanatory piece on the value of jazz improvisation (essentially every ‘mistake’ is an opportunity in jazz; thus the only mistake is when no one accepts/reacts to a note) seemed a useful way to help get the creative juices flowing among the student groups from the start, while also encouraging the establishment of an ethos throughout the workshop which encouraged cohesion, innovation, creativity and exploration among the students. As Davies suggests: ‘We don’t micromanage in jazz. ..if I want the music to get to a certain level of intensity, ..the best way for me to it is to listen’ and in doing this ‘you engage and inspire the other musicians – and they give you more and gradually it builds’ and thus naturally evolves.

Listening, collaborative development and improvisation were thus explicitly privileged over the course of the week, rather than competition and trying to dominate with the best ideas, by force of personality or inflexible plans. That said, the dissenting voice - or the metaphorical bum note, i.e., one which perhaps didn't chime with the preceding melody or set of ideas - was also welcomed to challenge the status quo and ensure that group think didn't take hold.

This seemed to chime very well among the students, though as the week went on, the faculty could increasingly identify with the metaphor too, in particular with the interactive and iterative process of engagement we ourselves experienced both in developing the programme session details ‘on the hoof’, in a way that required the faculty to listen and learn from each other and from our students (as graphically described in Figure 1). While challenging at times, this was ultimately hugely fruitful and rewarding. As this was the first time we had come together as a group, we also each discovered we needed patience and a willingness and capacity to adjust so as to harmonize with the rhythms of our colleagues and the group. This relied heavily on listening and creativity to develop an agreed evolving plan for the week as it progressed, while modifying and developing our presentations and advice to students during the project sessions to better fit the needs of the workshop. This meant staying present, active and engaged throughout.

Moreover, it was also quite obvious how this also strongly resonated as a valuable metaphor for engaging with sustainability issues themselves: “Jazz musicians obviously improvise [because..] their assumption is ..that we can collaboratively create through the interaction of constraints and possibilities rather than either order or disorder.” (Montuori, 2003). And it is that ‘structure’ versus ‘creativity’ dialectic that lies at the heart of many sustainability narratives and conceptions (Byrne, 2017). Jazz improvisation (and the inherent listening involved) therefore worked well as a metaphor on a number of levels (indeed it can be applied to learning more generally (Montuori, 1996)), and thus continued to resonate throughout the workshop as a whole. This was aided too by the lecture content, which included introducing de Bono’s creative six hats concept (de Bono, 1985) for example, as students were encouraged to put on their ‘creative’ and ‘feeling’ hats to drive the ideation process, as these were often the ones that come less easily.
The music

Following on from the jazz metaphor - the output of jazz is spontaneous music, so what music did our groups make? Right up to the final day, the faculty guiding the workshop were never quite sure how this might play out in terms of ultimate output and presentations. Would there be evidence that the group had become more than the sum of their (disciplinary and individual) parts? Three of the four groups worked on the same project (the Benicalap district) and, as a result, there were concerns amongst faculty and students alike that the solutions might look very similar and could make for a rather repetitive afternoon.

Those fears proved wholly unfounded, with each group presenting a distinct take on the problem and a unique approach to telling their story. Whether developing a systems map to understand and illustrate the different dynamics which influenced the problem or drawing inspiration from the lectures to frame the problem in terms of green infrastructure at multiple scales - the presentations used a range of themes and techniques to organise their individual and collective contributions.

There was some evidence of students disciplinary background in the presentations and a technical underpinning to some of the proposed concepts (the projects of course needed to be feasible, cost-effective and safe!); however, there was also evidence that they had stepped beyond their own (chiefly technical) disciplines as a group to come up with a more holistic approach, benefiting from building on each other's ideas and strengths to address multiple dimensions of performance in an integrated way.
Whilst all the projects acknowledged the principle of stakeholder engagement as being essential in assessing and progressing the concepts developed, one group brought that notion into their mechanism of delivery, presenting their concept from the point of view of an individual stakeholder, a fictional local thirty year old woman named Pilar (Figure 5), who took it upon herself to engage her local community in a social regenerative project, and whose enthusiasm and leadership helped draw down funds and support from the city’s municipal budget and a visit from the mayor.

![Figure 5 ‘Pilar’ and the associated group presentation](image)

This storytelling approach provided a unique perspective on the development and went beyond intellectual and technical engagement, towards a more empathetic approach to the solution and its potential beneficiaries, and made for a truly inspirational presentation. Other groups took different approaches, but all came up with excellent ideas, including for example, proposing a local community garden, vertical urban food production system and local farmer’s market, developing multifunctional, educational and arts and craft spaces (which could help develop ‘Falles’ festival materials), a greywater sustainable urban drainage system, enhanced local transportation options and mounting of PV solar panels on public buildings.

5 The learning

Overall the workshop, like a wonderful piece of improvised jazz came together for a terrific final crescendo of creativity and innovation. The journey however, was none less thrilling, in part because of the open ended and uncertain nature of the project, for students and faculty alike. Formal and informal student feedback was generally universally positive (while containing some useful feedback suggestions), and the feedback of the following student reflected the general tone:

“We did not have a single team leader. We were all leaders at different stages of the workshop and that worked very well for me. I also think that the faculty did a good job of supervising our team work without narrowing down the scope of our brainstorming sessions.

The TED talk video played during one of the afternoon sessions resonated strongly with me and I thought that it was very useful in helping us build on top of each other’s ideas instead of simply discarding them as ‘wrong’ or ‘outlandish’.”
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A New Program in Sustainable Energy Engineering - Balancing subject matter with transformative pedagogies to produce Global Citizens

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Abstract

Responding to an identified need at the institutional, regional and global levels, the Faculty of Applied Sciences (FAS) at Simon Fraser University recently developed a new undergraduate program in Sustainable Energy Engineering (SEE). The program, developed in concert with an expansion to SFU’s Surrey campus, aims to address the growing need for engineers who are globally-minded critical thinkers, able to provide sustainable energy solutions and technical leadership in interdisciplinary environments.

This paper describes the process used to develop the SEE curriculum, including approaches to address the numerous constraints, specifications, and resource challenges. High-level program and curriculum objectives included the following:

- Leveraging disciplinary strengths in existing FAS programs to provide a foundation upon which the specialized curriculum could be built.
- Offering elective focus areas in Smart Cities, Clean Transportation Systems, Sustainable Manufacturing, and Environmental Systems.
- Developing a unique portfolio of mandatory and elective courses that provide technical depth and disciplinary breadth while integrating business, social, ecological, and economic models into sustainable engineering design.
- Integrating throughout the program a rich set of experiential, transformative pedagogies, including problem-based learning, research, reflective learning, and real-world interdisciplinary projects.

To begin the curriculum development process, a committee was struck, led by an education specialist from the SFU Teaching & Learning Centre (TLC) and with representation from each of the existing academic and administrative units in FAS. Draft program level learning outcomes provided a framework for curriculum design, course planning and consultations with various disciplinary experts. The committee took a pan-university approach, working with experts in FAS and in collaboration with other SFU Faculties, and convened a full day facilitated curriculum discussion with outside experts who have experience in both industry and academia. Finally, robustness in regard to eventual program accreditation with the Canadian Engineering Accreditation Board (CEAB) was addressed through detailed Accreditation Unit (AU) calculations and iterative mapping of Graduate Attributes (GAs).

Throughout the process many discussions focused on balancing the need for considerable technical skills with the need for the acumen for managing real world, complex interdisciplinary problems with integrity.
and professionalism. To encourage adoption of experiential pedagogies, the TLC will offer faculty members a series of corresponding supports, resources, and materials.

1 Introduction and Background

The need to integrate sustainability engineering content and pedagogies into engineering curricula has been advocated in numerous studies in recent years (Byrne & Mullally, 2016; Hawkey et al., 2012; Nicolaou & Conlon, 2016; Salvotore et al., 2016). In concert with this, the substantial and quickly growing clean technology (cleantech) sector is generating the need for technical professionals with the skills and perspectives to design effective and sustainable solutions (The Delphi Group, 2016). In response, SFU developed an initiative to educate engineers who will become leaders in the utilization, transmission, and management of energy and environmental resources through the development of sustainable engineering solutions. While several opportunities were identified to leverage, and harmonize with, strengths of the existing Applied Sciences programs at SFU, it was also recognized that much of the technical and conceptual foundation required for a strong education in energy systems, particularly in the area of sustainable energy, would be quite distinct. As such, the initiative was positioned as a new and complete program. The Sustainable Energy Engineering (SEE) program aims to educate students in engineering principles and design practices, current technologies, economics and policies, and ecological implications related to the cleantech sector. Engineers need the knowledge, skills, and attributes to work with complex engineering problems in an uncertain future. This requires multidisciplinary and interdisciplinary skills, change agency skills, and the self-efficacy to be leaders on the cleantech stage both nationally and internationally.

At full capacity, the program will have approximately 320 undergraduate and 120 graduate students. We expect the first students to enter the program in the Fall of 2019. Up to this time, the focus has been on gearing up for the first and second cohorts of undergraduates. Going forward, the planning will shift to the graduate research program which will include specialty areas within sustainable energy engineering and will, in turn, afford research opportunities for undergraduate students.

A new five-storey 15,000 square metre building, located at the SFU Surrey campus, will provide the teaching space for this program including state-of-the-art, custom-designed, laboratory facilities. The building will be certified to a high standard, Leadership in Energy and Environmental Design (LEED) Gold, and will provide an opportunity to be used as a living lab for research and instruction.

2 Assessing Student Interest and Industry Needs

A survey of 96 cleantech and sustainable energy technology companies in Canada (The Delphi Group, 2016) identified the following cleantech segments as those expected to see the highest global growth over the next decade:

1. Energy storage and battery technology;
2. Clean power generation;
3. Smart grid, transmission, and distribution;
4. Clean transportation technology;
5. Energy efficiency, conservation, and demand-side management;
6. Green building design and construction; and
7. Water and wastewater management.

For the market opportunities in British Columbia, BC-based companies identified green building design and construction, clean transportation technology, and energy efficiency, conservation, and demand-side management as the top growth segments over the next decade.

Survey respondents suggested that a program offering a more “broad-based” energy systems focus that includes techno-economics and a specialization in certain areas of environmental or clean technology (such as energy storage and smart grid, a broad range of renewable energy technologies, alternative fuels and technologies, and resource optimization solutions) would add value to the industry and fill a current gap in the market. Findings from the market research suggest that the program should be global in outlook, multidisciplinary in nature, be grounded in solid engineering fundamentals, and include hands-on, practical experience (such as a co-operative education program).

In terms of non-technical skills, survey respondents look for Bachelor’s level engineering graduates with: strong creative thinking and problem-solving capabilities, interpersonal / teamwork skills, strong communication and presentation skills, and project management skills.

A student survey was also undertaken to assess demand for both the content and structure of the proposed SEE program. FAS students were asked about the importance associated with certain characteristics relevant to the SEE program. The survey received 167 responses in 1 week. When considering the specific content, students clearly supported the Clean Technology, Energy and Transportation industry focus. Generally speaking, the students also indicated that they prefer industry engagement through co-op or other industry interaction over other types of learning experiences.

3. The Process of Curriculum Design

SEE program planning began in the summer of 2016 with the appointment of a Task Force to initiate and oversee the various elements of the project including consulting on the new building, student recruitment, stakeholder consultations and curriculum design. From this, a curriculum committee was struck, led by an educational specialist from the SFU Teaching & Learning Centre (TLC), with a faculty member representing each of the three existing FAS Schools, the Manager of FAS Student Affairs, the Task Force chair, and two research assistants. The faculty representatives were selected partly for their subject matter expertise and partly for their role within their respective Schools.

The curriculum committee’s first task was to draft program level learning outcomes to provide a framework to develop the curriculum structure and individual courses, and to be used for consultations with various parties involved in the program development and approvals process. As courses were planned, the program design went through much iteration, and the program level learning outcomes were iteratively mapped against the course level learning outcomes to ensure that the collection of courses was aligned with the original educational intentions of the program.

3.1 Balancing and Integrating Technical Subject Matter with Transformative Learning Activities

Many curriculum committee discussions focused on balancing the need for considerable technical skills and knowledge with the need for other education for sustainable development, including competencies related to interdisciplinarity, change agency skills, and self-efficacy (University of British Columbia, 2018; Goldberg & Somerville, 2016). These conversations often took the form of “how do we ‘cover’ important
technical subjects” and still incorporate learning methods that will foster these attributes. We prioritized experiential pedagogies to enhance critical and creative thinking, and leadership skills. In addition, we included multiple disciplinary models - economic, political, ecological, and technical - at each level of the program. Students will use and integrate these models to solve interdisciplinary problems that are intentionally ill-defined. The program integrates at least one interdisciplinary experience in each academic term, increasing in amount and intensity over the four-year curriculum.

In our attempt to include these experiences and also ensure that students gain considerable technical content, we found at one point that the curriculum plan had grown such that the total number of credit hours included was approximately 25% more than what was reasonable for an undergraduate engineering program. That is, we were essentially trying to fit five years of study into four. To address this, we had to make some hard decisions about what was really important, keeping in mind the overall program goals, the learning outcomes, and other institutional constraints.

3.2 Consultation with Subject Matter Experts

Over 35 new courses were developed and the course outlines written (using a standard SFU template) by subject matter experts, and reviewed by either another subject matter expert or curriculum committee member with some expertise in the area. Several of the first and second year courses were relatively straightforward to plan because they shared similarities with existing courses in the other two SFU engineering programs. In addition, foundational subjects in mathematics, physics, chemistry and computing science, will be taught as service courses by other SFU departments. For some other courses, the subject matter experts were also curriculum committee members, which made the coordination of course development more streamlined. This process of writing course outlines was iterative and some courses were substantially revised, combined or removed, as the process proceeded.

The committee worked closely with experts in FAS, in collaboration with other SFU faculties, and also with disciplinary experts outside of SFU. As the process evolved, it became clear that we needed to hold a deeper discussion with experts outside of SFU. We convened a full day facilitated curriculum discussion with disciplinary experts from across the region who had experience in both industry and academia.

Finally, robustness regarding eventual program accreditation with the Canadian Engineering Accreditation Board (CEAB) was addressed through detailed Accreditation Unit (AU) calculations and mapping of Graduate Attributes (GA). For each substantial revision, we revised the AU and GA mapping, which allowed us to have confidence that the program will ultimately be eligible for CEAB accreditation.

4 The Curriculum

4.1 Program Learning Outcomes

Seven learning outcomes frame the program and provide the curricular context within which the program will be implemented. These outcomes are consistent with the CEAB Graduate Attribute requirements, serve to provide students with a description of what they will gain by studying in the program, and will also serve to guide future revisions and updates to the program. The learning outcomes are:

1. Integrate energy, social and environmental factors with the principles of energy conversion, utilization, and systems for engineering design.
2. Analyze and design energy components and systems using scientific and engineering principles
and tools with reference to a sustainable energy industry, including smart city energy and environmental systems, clean transportation systems, and sustainable manufacturing systems.

3. Use foundational and specialized knowledge to design and implement sustainable energy solutions, from generation to utilization.

4. Analyze and investigate global economic, environmental, societal, regulatory, health and safety factors in the context of energy systems.

5. Analyze and apply business and entrepreneurship principles, and economic models, to the development and implementation of sustainable energy systems.

6. Demonstrate adaptability, ability to work individually and in teams, and the skills to communicate effectively in multidisciplinary and interdisciplinary settings, using a variety of media and forums.

7. Serve the public interest through competency in engineering practice and commitment to environmental stewardship using ethical conduct, professionalism and application of life-long learning skills.

4.2 Sustainability Pedagogies

Learning to solve complex, real-world problems requires an interdisciplinary, embedded, experiential approach (Cotton & Winter, 2010). Projects and real world problems require students to integrate factors and specifications from multiple sources, and often from multiple disciplinary perspectives, to carry out their learning and assessment tasks. This means creating a sustainability mindset through which students approach and think through engineering problems. In addition to an appreciation of the importance of sustainability in their own discipline, engineers need an awareness of different disciplinary worldviews to understand how knowledge is created and communicated. To gain these attributes, a pedagogy of praxis, thinking with engaged action such as authentic learning and assessment, will support students to take ownership of their learning and their future engineering practice. Pedagogies consistent with education for sustainable development are embedded in the program plan, and include:

- Real-world scenarios and problem solving to simulate engineering practice.
- Co-op work experience, or alternative co-op such as service or community work.
- Project-based and problem-based learning, including solving ill-defined problems, and partnerships with industry.
- Solving problems using multiple disciplinary perspectives, in particular, business, societal and environmental.
- Teamwork, including peer teaching and assessment; collaboration and cooperation enhance self-efficacy and engender change agency skills (University of British Columbia, 2018; Franzen & Gröndahl, 2016; Goldberg & Somerville, 2017; Salvatore et al., 2016).
- Meaningful engagement with the larger world to deepen critical thinking.

4.3 Program Structure and Components

The program learning outcomes are achieved through a variety of program components, including specialized design courses that culminate in an eight-month capstone project; elective focus areas; engagement with multiple disciplinary models and perspectives including environmental, societal, regulatory, business; co-op and alternative experience; and communication skills.

Traditional lectures, laboratories, and midterm and final exams will comprise a significant portion of the learning activities and assessment methods. However, to anchor the classroom knowledge in engineering practice, experiential learning methodologies, authentic learning and assessment are also extensively incorporated throughout the curriculum.
Students will engage in increasingly complex learning experiences over the four years of the program. In years one and two, the courses provide fundamental science and engineering knowledge and skills with some exposure to experiential learning activities in sustainable energy engineering. Years three and four provide increasingly specialized and complex applications of engineering science and engineering design, specialized electives, the capstone project experience, complementary (not engineering related) electives, and a choice of elective focus areas.

First Year, Third Year and Capstone Design Courses: Students are exposed to design theory and practice in a first year project course. In years three and four, students start to specialize in three additional project courses, two of which constitute the capstone experience. These allow a deep investigation of a real-world engineering problem in partnership with industry or an academic laboratory.

Elective Focus Areas: Three elective focus areas, Smart City Energy and Environmental Systems, Clean Transportation Systems, and Sustainable Manufacturing Systems, provide deeper knowledge and engagement with specialized engineering knowledge and practices. Students can choose to take all of their electives in one focus area, or select courses across more than one to create their own specialization.

Co-op and Co-op Alternative Experience: Three terms during the undergraduate degree are devoted to a co-op experience working alongside practicing engineers in technical roles, in many cases having the opportunity to design and build real products. One of the work terms may be an Alternative Experience, which could include a self-directed project (e.g., sustainable community-engaged project), service (e.g., an internship with Engineers Without Borders), entrepreneurial, or research term. We are currently working with SFU’s Work Integrated Learning team to define the Alternative Experience.

The Building as a Living Lab: The benefits of engaging with the campus as a living lab have been advocated in the ESD literature (Winter et al., 2015; Cotton, 2015.) The authentic learning opportunities afforded by the new LEED certified building involves engagement with the building systems, components, engineers, and occupants. Faculty members will have the opportunity to use the building as a real-world experimental space, a living lab, to help students appreciate the broader context of their discipline and future professional engineering practice through the application of subject specialisms in the context of their immediate surroundings. More specifically, in most buildings the energy consumption, efficiencies and sources, are invisible to the occupants; making these transparent allows students to be involved and take ownership of energy debates, decisions, analyses and designs. The building and its operations can be thought of as a microcosm of the wider society: an experimental space for innovating, taking risks, and experimenting through inquiry-based and authentic learning.

4.4 CEAB AUs and GAs

All CEAB accredited engineering programs in Canada are assessed at least every six years and must meet stringent standards to maintain their accreditation status. At several stages during the SEE curriculum development process, the committee mapped the courses and content against CEAB’s AUs and GAs to ensure it would meet the accreditation criteria.

5 Consultation/Collaborations
Given the intended interdisciplinary nature of the program, substantial pan-university consultation was pursued. This included specifically deep dialogue with SFU’s Faculty of Science, Faculty of Environment, and Beedie School of Business.

The Faculty of Science (SCI) was engaged in the program and curriculum design process in establishing a set of foundational courses in mathematics, physics and chemistry that will provide a foundation in the natural sciences upon which subsequent engineering fundamentals and ultimately specialized courses in Sustainable Energy Engineering will be built. The corresponding set of service courses has been built into the SEE curriculum and reflects the experience that has been gained in establishing Engineering curricula at SFU that meets all CEAB accreditation requirements.

The Faculty of Environment (FENV) was engaged in the program and curriculum design process in identifying a unique set of inter-disciplinary courses that will provide a genuine and broad perspective on ecological, environmental, urban planning and industrial issues that will be necessary for the broad based education that is intended in delivering the SEE program. To this end the curriculum includes the a service course in ecological economics, as well as a series of identified complementary electives that align with the program’s focus areas in smart cities, clean transportation and sustainable manufacturing.

The Beedie School of Business (BUS) was engaged in the program and curriculum design process in developing an approach to embed a rich inter-disciplinary entrepreneurial experience; to this end a mandatory service course to be delivered by Beedie has been included in the SEE curriculum.

Internal and external consultation was also carried out with Energy Systems domain experts, notably including a substantial critical review of the proposed program and its specific curricular design by the Canada Research Chair in Energy System Design and Computational Modelling (at the University of Victoria), with resulting refinements incorporated.

6 Support for Faculty Development

A variety of resources, services, and learning opportunities will be made available to support faculty to develop their courses, teaching materials and teaching practices, and become familiar with approaches to education for sustainable development. Not all faculty members have experience using sustainability pedagogies and therefore might need support to enhance their teaching practice. In fact, some of the most engaging and deep student learning is a result of experiential activities such as field trips, group projects and real-world research that can be very time-intensive for faculty to plan (Simon Fraser University, 2018).

“Perhaps the most palpable challenge of engaging in such an innovative approach to teaching about global issues and lifelong skills is the struggle with time…. Developing authentic learning experiences takes time. Without clear commitment to the collaboration from the institutions, faculty may find it hard to dedicate the required amount of time” (Matias & Aguilar-González, p. 122, 2017). Support for faculty and course development could involve:

- Support for the creation or sourcing of lesson modules that integrate sustainability into engineering topics, for example developing authentic learning activities or engaging students with the energy systems in the new building.
- Stories and case studies shared by colleagues or guests at brown bag seminars and workshops about how they have integrated sustainability into assignments, courses, assessments, etc.
Access to literature about sustainability principles and frameworks, or news stories or engineering education cases about integrating sustainability into learning activities.

7 Next Steps

This paper described our experiences of the process and challenges of creating a new engineering program at SFU with the goal of graduating globally-minded, critical thinking technical leaders who can tackle complex, interdisciplinary sustainable energy engineering problems. Though the curriculum is designed, the building is almost completed, and there is commitment at the institutional and provincial levels, we still have many hurdles ahead. We are looking forward to receiving the first cohort of undergraduates in 2019, bringing on staff and faculty, and growing the program to include leading-edge knowledge development and transfer through faculty research and graduate programs.

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Comparing Point-of-Use Water Treatment Technologies for Emergency Response

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Abstract

According to the World Health Organization there are 3-5 million cholera cases and 100,000 - 120,000 deaths due to cholera every year. In this study, we use naturally occurring hydrogen sulfide-producing bacteria measured in Pathoscreen™ tests as an indicator of disinfection effectiveness. The feasibility and effectiveness of on-site chlorine generation using the CDC recommended Safe-Water-System, a commercially available and portable mixed oxidant (MIOX) system, and solid oxidant tablets (AquaTabs) are compared. In tap water, the electrochemical chlorine generator yielded a concentration of up to 6.05 mg/L of chlorine, with stainless steel electrodes and a contact time of 30 minutes. The amount of free chlorine produced by electrochemical chlorine generator was between 2.26 and 4.11 mg/L in pond water which contained bacteria and organic matter, well below the desired CDC and WHO level of 5 mg/L.

Disinfection chlorine tablets were inexpensive for treating small amounts of water, they are also easily distributed and were found to be an effective method of short-term water treatment. Commercially available personal chlorine and oxidant generators are easy to transport and will purify a small amount of contaminated water but are extremely expensive to purchase and operate and are not a viable long-term option in a flooding scenario in Sub-Saharan Africa. Small chlorine generation systems lie the CDC’s Safe Water System can be fabricated quickly on site and utilized to purify drinking water however detailed construction instructions and operating instructions are required for safe operation and effective use. A detailed training and operation manual is needed for implementation in an emergency response scenario.

Keywords

Chlorination, Point-of-use, Safe Water System, Disinfection

Introduction

Water quality is a major issue in sub-Saharan Africa, specifically Benin. According to the World health organization there are 3-5 million cholera cases and 100,000 - 120,000 deaths due to cholera every year (WHO, 2014). The World Health Organization, WHO, solution to an outbreak is to “control the spread of the disease by providing safe water, proper sanitation and health education for improved hygiene and safe food handling practices by the community” (WHO, 2014). Currently 25% of the population of Benin lack access to a clean water source of drinking water (WHO, 2012).

In 2001 a major cholera outbreak occurred in Benin, Africa located in western sub-Saharan Africa there were 3,943 cases and 71 deaths due to cholera in the water (WHO, 2012). The goal of the project is to create a point of use hypochlorite water treatment device to be implemented for flooding disaster scenarios in rural communities in Sub-Saharan Africa. These communities have open water sources used for drinking water, as well as open defecation. Flooding disasters cause water sources to be contaminated with fecal matter, and bacteria that cause Cholera and other waterborne diseases.
With over 17,000 cases that suffer from cholera, and 567 that die and suffer from Cholera strains spreading through water, there is a need in Sub-Saharan Africa for an emergency response water treatment system that eliminates water borne disease and Cholera strains (WHO, 2011).

Historically there is a high failure rate of water devices in developing countries, with 30-60% critical failure rates of existing water supply devices (Henriques, Louis, 2011). In sub-Saharan Africa 35% of rural water devices are not functioning. The failure rates can be due to operational malfunction, and that locals lack the knowledge to fix water treatment devices (Henriques, Louis, 2011).

The United States Centers for Disease Control and Prevention (CDC) recommends several point-of-use (POU) water treatment devices for water purification. The CDC developed the Safe Water System (SWS) in response to epidemic cholera in South America (Center for Disease Control, 2012). The SWS process involves the electrolysis of a salt-water solution to create hypochlorite (and other mixed oxidants) that may disinfect drinking water. The CDC reports that the SWS inactivates most bacteria and viruses and decreased diarrheal disease by 22 – 84% in studies where the system has been deployed. Currently, the system has been used in Uganda and Kenya to, reportedly, supply citizens, with HIV, a means for safe drinking water to reduce the chance of contracting opportunistic diarrheal diseases (Center for Disease Control, 2012).

Other researchers have developed a solar powered Chlorine system (Baginski, Et al, 2012). The system was tested by Auburn University researchers in field tests in Uganda, Africa. The system involved using water along with salt in a brine solution with power from a solar energy pack to produce bleach. The article provides an excellent source for initial research into bleach creation from just salt and water combined (Baginski, Et al, 2012). A downside to the system is that it requires the purchase of a solar panel energy pack costing approximately $99.00 USD. The solar pack would have to be purchased by an individual with the income almost twice as much as a citizen of Benin makes yearly. The solar pack if broken or not placed in the proper orientation to the sun it will not work as efficient as a direct power source like a battery. The paper does show that with 2mL of salt would be need to add to 0.5L water to produce 0.5L of chlorine (Baginski, Et al, 2012).

The Center for Disease Control, CDC, states there is the potential of full cost recovery from the implementation of a household chlorination device by charging the user the full cost of product, marketing, distribution and education (CDC, 2014). The design of the chlorination device will aim to produce a product with low material and assembly cost to strive for full cost recovery. While developing the system, complete instruction and materials supply list are not available. Most POU chlorination systems reported in the literature use a zirconium rod for electrode materials, which is cost prohibitive for many families in areas in sub-Saharan Africa. The optimal cost range of the device will need to cost less than 14000 CFA, or 30 USD. Which allows the device to be similar in cost to the ceramic filtration device already in Benin (Striebig, et al. 2010). Which will allow for an effective disinfection device to be used not only with the NGO’s in Benin but anywhere in sub-Saharan Africa where an outbreak occurs.

Due to the potential of harmful byproduct formation, a chlorine generation device will require the education to safely handle the chemicals created and used. The WHO guidelines state, that when using the chlorine generator for water treatment purposes, hypochlorite levels should be below 5 mg/L (WHO, et al. 2011). The 5 mg/L standard is set when only one chlorination method is present, and only where one byproduct is found. With the CDC’s and WHO guidelines for 5mg/L of chlorine, finding a working model of the chlorine generation device would allow for further experimentation to be done.

The device must be portable, easy to use, and be able to treat the average household use of drinking water: 80L of water per day (Striebig, et al. 2010). The project will span two years, and by the end of the two years the chlorine generation device should be able to be brought to the Songhai Center in Porto
Novo, Benin. The chlorine generator would be used in disaster relief scenarios in rural communities in Sub-Saharan Africa that have open water sources used for drinking. The average person in Benin uses 20 liters of drinking water per day. (Striebig, et al. 2010) With an average household size of 4, the household use of water per day is approximately 80L per day. The output of treated water that comes from the device must be equal to or greater than the total water consumption per family per day within the free hypochlorite.

The device that was defined in the scope of the project uses electrolysis to create hypochlorite, the active disinfection chemical. Variations in the setup include changing the time duration of electrolysis and changing the salt concentrations will be done. Steel Electrodes were chosen because of steels availability in Benin along with data collected that shows steel created the highest concentration of Hypochlorite.

**Approach**

The project focuses on the development of a chlorination water treatment system for use in rural communities in Sub-Saharan Africa, that have open water sources used for drinking, that have been contaminated in flooding disaster scenarios. The chlorine generation device is set as a battery attached to 2 electrodes that allows for electrolysis to occur as shown in Figure 1. The project goals were to develop a system that can treat contaminated water with chlorine, and compare its results to that of alternative methods readily available in Sub-Saharan Africa. Two members of the team traveled to Benin, Africa, and were able to gather parts readily available in Benin to create the system. While in Benin, the project was discussed to determine if a chlorine generation device would be a method of water treatment that is found useful. The system has a constraint cost, which means it can cost up to 29.00 USD. The cost constraint is set by the client, by asking for the device to not cost more than the Ceramic Water Filters already found in Benin, Africa. Each CWF costs 14000 CFA, which is about 29.00 USD.

![Initial concept prototype](image)

**Figure 1: Initial concept prototype**

**Sustainability Approach and Challenges**

The project approaches sustainability by developing a chlorine generation device that can be analyzed by a feasibility study and collect quantified results that can be used to compare alternative devices and treatment methods. The technical challenge of sustainability in the project is not only finding the aspects of the chlorine generation system that generate the optimal output, minimize cost, and minimize pollutants, but also determining, if applicable, which of the alternatives that are being tested will be the optimal solution for the situation provided are.
The challenge will be met by comparing all of the possible electrodes, methods of power sources, and amount of chlorine generated along with those specific materials, as well as comparing the chlorine generated by the team’s device to the chlorine generated by the alternatives. The innovative portion of the project is the quantified results of the methods being tested. Many organizations using alternative methods for water treatment have a belief that their method is the only optimal solution, however, they should have access to quantified results of all alternatives so they can better educate themselves on their systems.

Concept Selection

In order to quantify a chosen method of purify water a house of quality in Figure 2 below comes the customer requirements to four different methods for treating water. The four methods are chlorine generation device created at JMU, Miox MSR water purifier, Ceramic water filter, and AquaTabs.

![House of quality of competing concepts](image)

Figure 2: House of quality of competing concepts

The house of quality above in figure 2 shows the important requirements given and the engineering parameter that accompany the requirements. When determining which given system would be an adequate solution to the rural disaster relief scenario. It was determined that the ceramic filter would not be a feasible because it does not eliminate pathogens in 2L of contaminated water. In addition the Miox MSR system does not meet the requirement of the cost, the manufacture retail cost of the system is $185 USD. Therefore the Miox MSR is not a feasible system to use for a rural disaster relief scenario due to the cost. This leaves just AquaTabs and the chlorine generation device as feasible solutions to a flooding scenario in a rural area.

The three experiments that are included this section are “Chlorine Generation of AquaTabs”, “Chlorine Generation and Dilution Factor Determination of JMU’s Chlorine Device”, and “Chlorine Generation of MSR Water Purifier.” The three experiments objective was to determine the level of free chlorine resulting from treatment. Determining the concentration of free chlorine is important because free chlorine is what inactivates coliform. The free chlorine concentrations of the experimental samples will be compared to the maximum of 5 mg/L and the minimum level of 0.02 mg/L (WHO, 2011).

Test Methods

The following general testing procedure applied to the MIOX, AquaTab methods, and JMU’s chlorine generator. Sample water was obtained using the MIOX, AquaTab methods, and JMU’s chlorine
generator. Then free chlorine concentrations were measured every ten minutes for both MIOX and JMU’s chlorine generator using HACH DR 2800, method 8021. Method 8021* is also used for AquaTabs, measuring the final concentration of total chlorine concentration of OCl- and HOCl that are the chemical compounds used in water treatment. (*Method 8021 measures total chlorine but because the test is taking place in DI water, free chlorine concentration and total chlorine concentration are the same.) Samples from the MIOX MSR and AquaTabs were diluted for the analysis due to the high concentrations of chlorine generated.

The JMU designed portable chlorine generator produced 0.21 to 0.84 mg of hypochlorite, with the chlorine mass increasing with increasing time. The exponential trend from Figure 3 of Salt concentration compared to chlorine generation was found to be equation (1) below. Where y in the equation represents the chlorine generated in milligrams and x represents the initial salt mass in grams.

\[ y = 1.14e^{0.715x} \] (1)

With this information, an individual trying to generate chlorine in a disaster it is possible to know, within the uncertainty of measurement, the amount of hypochlorite generated from the amount of salt added to the system. This way the risk of consuming high concentration of chlorine can be mitigated. This way the chlorine generator will be safe to use in the case of a disaster were water is contaminated with cholera.

Figure 3: Graph of same salt 10mg levels at different generation times
Equation predicts the hypochlorite generated in a given time of 1 minute using the JMU Chlorine Generator. The error and uncertainty in the experiment comes from the standard deviation of the mean along with the instrument error of 0.02 mg/L from the HACH 2800s. The cost of each system does not include any foreign taxes or shipping costs to send to Africa. That the chlorine generator will have a minimum life span of 30 days while producing 75L for 9 hours a day. In addition the MIOX MSR will also be run for a time period of 9 hours a day to produce 24L of purified water. The salt required to operate the chlorine generator and MIOX MSR are not supplied with the device itself would have to be bought locally.

**Cost Benefit Analysis**

**MIOX MSR**

This section includes the economic analysis, health risk associated with use, and social intangible risk associated with the MIOX MSR device. Each section concluded the team’s findings from the project for the MIOX MSR device. The MIOX MSR was found to cost 5.62 USD per person assuming a system would be able to treat enough water for 43 people. This cost take into account the cost of the initial system along with cost of buy extra batteries and extra salt that might be needed. From laboratory testing the MIOX MSR generated an initial average hypochlorite concentration of 0.786 mg/L in 1L water. This value falls below the WHO’s value of 5 mg/L which means the MIOX MSR chlorine generator is safe to use and consume. Therefore the MIOX MSR can be recommended as being safe to use and handle.

The MIOX MSR cost $120.99 USD (2014), this cost falls outside of the range most low income communities. In addition the MIOX MSR has been found in lab to be inconsistent in using the device. In order to purify a large amount of contaminated water the user would need to repeat the process steps many times.

**AquaTabs**
This section includes the economic analysis, health risk associated with use, and social intangible risk associated with the AquaTabs. The AquaTab system costs 0.47 USD per person for a month-long disaster scenario. This cost has no up-front investment like the MSR MIOX system or the chlorine generator system. Instead, the cost comes entirely from the purchase of Aquatabs to be added to water needing treatment. Within the dilution and free chlorine tests, the 1 L AquaTabs produced a chlorine level above the 5 mg/L of chlorine allowed for CDC and WHO standards. With this information, the 20L AquaTabs that are used in Sub-Saharan Africa could cause major health risks with continuous consumption of the treated water. Not only could the levels be a bit too high, but the packaging states it can treat up to 1 L, and 20 L, per packaging. If a 20 L tablet is put into less than 17.5 L of water that needs treated, as the instructions suggest, the chlorine levels that will be produced will be far above the WHO standard, and without knowing this, the water consumption could be dangerous. However, the high levels of chlorine release a very “bleachy” smell, which may prevent use due to the aesthetic taste preference, and this is supported by observations and communications in the field in Benin.

AquaTabs cost $0.63 USD for 10 tablets, which treats 20 L of water per tablet. Though, within the report, 1 L AquaTabs were used due to the EPA regulations on water treatment products, the dilution and free chlorine tests allow insight into the AquaTabs uses in Sub-Saharan Africa. The AquaTabs have an ease of use factor for emergency purposes in Sub-Saharan Africa because the rural communities have already been exposed to the tablets before, and the instructions for using the tablets are a part of the packaging.

**Portable Chlorine Generator**

This section includes the economic analysis, health risk associated with use, and social intangible risk associated with the Chlorine Generator. This chlorine generator is the second cheapest system to depend upon for a one month disaster scenario. It will cost approximately 0.46 USD to treat water for an individual each month. The vast majority of this cost comes from purchasing the system and not from operation and maintenance. The calculations can be found in the appendix 10 with economic analysis of cost per person.

The chlorine generator has behaved more consistently in laboratory experiments. This results in higher confidence of the total chlorine in water that has undergone treatment. If the system were to treat 6L at a time, a total chlorine concentration of 0.5 mg/L would result. Because free chlorine concentrations are always less than total chlorine concentrations, 0.5 mg/L falls well below the free chlorine concentration of 5 mg/L recommended by the WHO. If the chlorine demand is higher than 0.5 mg/L, the water will not be treated, so the user should identify that a chlorine odor can be identified in the treated water.

The chlorine generator will require that an individual be trained to operate the system because this technology is not currently one used in Benin. As such, if a disaster were to occur, a community would need to devote a person to preparing water for the community. This system’s consistency is dependent upon the user carefully following the water preparations method. The user would have to measure 500 mL of water, add 1 g of salt, operate the system for 1 minute, and then add what results to 5.5 L of untreated water. Whatever deviation is taken from this procedure will result in unexpected total chlorine concentrations. Each system was able to result in a bacteria concentration lower than 2.2 MPN/100mL, the minimum concentration the 5 tube method can detect.

**Recommendations**

The AquaTab tablets would be the recommended method of water treatment for ease of use, cost and portability. The recommendation would come with a warning of the use of tablets in small amounts of treatable water. If the user needs a small device that is easy to transport and will purify a small amount of contaminated water then the MIOX is suitable. However the MIOX MSR does not meet several
requirements that the clients requires, meaning that it is not a feasible device for generation hypochlorite in a flooding scenario in Sub-Saharan Africa. Previous reports of a locally made portable chlorine suitable for water treatment in developing communities could not be substantiated by this research. While modifications to previous portable generators helped make the technique more cost-effective, other technologies are better suited to emergency relief and use in most low income communities.

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GREET-based comparison of carbon emissions from locally and non-locally sourced food for a college dining hall

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**Abstract**

The concentration of carbon dioxide in the atmosphere continues to rise and the global food system is a significant contributor that often gets overlooked when it comes to solving the problem. In this study, emissions related to food transportation were studied to determine what impact getting local food instead of non-local food could make on the overall emissions of the food system. The dining service at James Madison University utilizes local food to varying extents when it is in season, and a life cycle assessment (LCA) was done on lettuce, tomatoes, strawberries, and chicken to compare the emissions associated with production of these foods. The transport-oriented GREET software was used for the LCA along with information from the sustainability coordinator at the university itself to get results. Given a lack of publicly available data regarding crop cultivation in certain areas of the U.S. some information had to be obtained from databases in Europe, but results suggest that produce coming from the west coast to the Virginia campus can have four to five times the emissions associated with production and produce from Florida can have roughly twice as many emissions associated with production. There is a relatively low number of LCAs done in America to compare this data to but it somewhat fits in with many European studies. Some LCAs do not factor in transportation processes but my results suggest that any American studies should factor in transportation since they can contribute greatly to the overall footprint of products. The current available software for LCAs lack consistency between programs, all having different strengths and weaknesses, and needs to be improved for quality results in the future.

**Introduction**

The push for sustainability and a ‘greener’ America in the food industry has been almost entirely carried out by the American public rather than legislative pressures. As a result, non-governmental organizations (NGOs) play a role in informing the public of what is in their food and how it was grown or raised. Food companies rely on third party certifications to inform consumers about food standards and criteria regarding the products’ growth and production. The emphasis of such standards, however, is more for marketing and product differentiation. Most of the certifications seen on products in the grocery store relate to the conditions in which the food was grown or raised, such as organic and fair trade certifications. Many of these are unrelated to food transportation and do not take into account from where the food comes.

The current structure of the global economy makes it cheaper in many cases to import food from across the country or across the world. The goal of this project is to learn to what extent JMU dining food acquisition is sustainable. With the knowledge that James Madison University (JMU) got some of its food from local sources when in season and from across the country when out of season, a comparison between the two systems was made to better understand the effects of each. Given the large transportation distance, it was hypothesized that the total emissions would show a significant difference when coming from
Many LCAs on tomatoes done are regarding those grown in greenhouses, which have a much larger indirect footprint due to the emissions related to construction and heating/lighting of the structure. It is worth noting that the location of the greenhouses plays an important role in their energy consumption, with colder climates requiring greater energy to maintain a suitable temperature for growing conditions (Torrellas et al. 2012). The same study showed the biggest contributor to global warming potential was the greenhouse structure itself and the energy put into its production. This study however, did not look at any post-production stages of the tomatoes and therefore transportation was not considered. Besides the structure, auxiliary equipment and the production and application of fertilizers were the other main contributors to global warming potential of tomato production in the greenhouse (Torrellas et al. 2012). A study that included storage and transport concluded that imports from Israel to Sweden resulted in lower emissions than local greenhouse production in the UK (Roy et al. 2008). However, in addition to variations in location and cultivation methods that make food production comparisons difficult, greenhouses also vary depending on type and construction of the structure. They also reported that certain packaging might reduce emissions compared to the classic box and cold chain distribution pathway (Roy et al. 2008). In total, tomato production is greatly dependent on where it is grown and the methods used. Values range greatly, with less than 300 g CO₂e emissions per kg of tomato in the study done by Torrellas et al. and nearly 1 kg CO₂e per kg of greenhouse-grown tomato in an Italian study done in 2010 that included transportation, packaging, and waste (Cellura et al. 2010). The different LCAs show that even when done thoroughly and in-depth, the estimated emissions can vary greatly.

Production of strawberries varies greatly depending on where they are grown. A study was done in Iran comparing open field strawberries and those grown in a greenhouse. In the study, transportation and post-harvest processes were not taken into account, only studying cradle to farm-gate. The yield per hectare was significantly lower in the open-field production but cost much less, with an overall benefit-cost ratio over four times higher than greenhouse growing (Khoshnevisan et al. 2013). The greenhouse used plastics and a greater diversity of fertilizers and pesticides, but the open field used a greater amount of chemicals on the crops overall while requiring just over half the amount of labor and almost no electricity resulting in a total global warming potential roughly 15% lower when compared to greenhouse production (Khoshnevisan et al. 2013). It should be noted that the area used for the open field study in Iran was especially well-suited for strawberry growth, meaning other areas may not have as substantial difference between the two methods. Another study that included strawberries was done in Australia, also focusing mostly on pre-farm and farming activities, only including some transportation in the analysis. This study cited agricultural machinery operation as the main contributor to emissions (58%) with the use of fertilizers (23%) and electricity (12%) rounding out the significant sources of CO₂ (Gunady et al. 2012). While not all aspects of transportation were included in the analysis, transportation was shown to contribute only 2% of CO₂ equivalents (CO₂e)/KJ (Gunady et al. 2012). The use of KJ as a functional unit is uncommon in LCAs but was done in this case to make the data comparable with other crops (lettuce and mushrooms) in the study. This data suggests that growing strawberries in greenhouses contributes more emissions than open field production, but requires much less space and productivity is less dependent on climate.

Like the other crops mentioned, growing lettuce produces varying amounts of emissions based on many different factors. Hall et al. paper reported on industrial production compared to civic production, of which they defined as urban or residential-rural areas in 2014. For lettuce production, the civic producers used less water and one of them produced far fewer emissions (0.08 kg CO₂e per kg lettuce) than the other civic producer (0.25 kg CO₂e per kg lettuce) and the industrial producer (0.32 kg CO₂e per kg lettuce) by using home chicken manure instead of fertilizers and minimized car transport (Hall et al. 2014). Fertilizers

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require fossil fuels to create, which is partly responsible for the increased footprint of large scale farming activities compared to small-scale agriculture. The study included transportation in its analysis and cited it as part of the main emission producers (fuel for both tractor and transport), ahead of fertilizers (Hall et al. 2014). However, the study concluded that the main emission contributions came during the growing phase, so fuel for transport may be a small portion of that. Additionally, the civic suppliers in the study saw educational value in their practices and enjoyed demonstrating the potential of backyard and community gardens, an added value that cannot be quantified. Gunady et al. evaluated lettuce and cited agricultural machinery operation and electricity as the two largest impact factors, followed by nitrogen fertilizers (Gunady et al. 2012). The transportation phase accounted for 7% of emissions per KJ of energy in this study but that could be partly attributed to the lack of caloric value in lettuce, which requires over 30% more mass to equal the energy of strawberries. While growing conditions in Australia may not translate to all locations, these studies are important in showing that when farming significant influence life cycle emissions.

Chicken is different than the other crops mentioned so far because it has additional processing steps and requires additional packaging and refrigeration. The growing of the chickens is still the most energy intensive (Katajajuuri 2007, Hall et al. 2014), but according to a study done in Finland on broiler chickens, the housing, packaging, and slaughtering rank as the third, fourth, and fifth most energy-demanding processes respectively (Katajajuuri 2007). In terms of emissions and global warming potential, slaughtering and packaging are less impactful but broiler housing creates roughly 80% of the CO₂ as the growing of chickens, with all other processes falling near or below 20% of growing the chickens (Katajajuuri 2007). Hall et al. compared small-scale versus industrial production of chicken. However, unlike lettuce production, the chicken industry turned out to be much more efficient in terms of emissions and land use, while having similar water consumption as one small-scale producer and nearly half the consumption of the other (Hall et al. 2014). Chicken farms hold so many chickens and are so efficient that practices like feeding small-scale chickens food scraps and using rain water instead of well water don’t reduce emissions enough to make the practices significantly reduce impacts.

A study done in Iowa took an in-depth look at the potential CO₂ emission reductions that are possible by utilizing non-conventional food transportation. It looked at a total of 28 different food items and defined three distinct food systems and their transportation methods. The conventional food system was simplified to only national sources, not international, and utilized large semi-trailer trucks for transport. An Iowa-based regional system was hypothesized and modeled after an existing regional infrastructure involving brokers and distributors to deliver Iowa-grown food from small and midsize farms to various markets such as supermarkets and restaurants. This system would use large semi-trailer trucks and midsized trucks over an estimated 82-mile average distance from farm to sale. A local system was modeled on the idea of farmers directly interacting with consumers and retailers through the use of light-duty vehicles that would run on gasoline (as opposed to diesel) and travel an estimated 38 miles from farm to sale on average. The results showed that the regional system was most efficient and greenhouse gas emissions could be reduced by 7 million pounds (Pirog et al. 2001). Although there are significant reductions with the local system as well, the smaller vehicles have to make a lot more trips in order to meet the consumption demands. Based purely on the transportation phase, Pirog et al. concluded transportation impacts could be reduced through centralized and localized planning, but they did not factor in the potential increase in production inputs in Iowa compared to other areas with warmer climates or the seasonality of crops grown in Iowa.

**Approach to Life Cycle Analysis of Food Delivery for University Dining Services**

GREET was used to conduct an LCA study on the difference between the carbon footprint of local and non-
local food. While other software is out there, such as SimaPro and ECO-it from PRé Consultants, GaBi from PE-International, and IDEMAT from Delft University of technology (Striebig et al. 2015), GREET was chosen because it is transportation-oriented, which is the main difference between local and non-local food in this study. For the basis of the analysis the functional unit was defined as 100 kg of each food item. While the use of KJ as a functional unit to compare different foods can be useful, a functional unit using mass was chosen in an effort to make this study more comparable with other LCAs, most of data came from various sources and in the case of inputs is not necessarily specific to the region from which foods are actually coming. The study therefore does not always demonstrate tradeoffs in local food production grown under less than optimal conditions and imported food grown in optimal or close to optimal conditions as was the original intent of the project, but still provides useful data about transportation emissions. The use of storage facilities and distribution centers for long distance transport was beyond the scope of this study based on the information available. Similarly, the variation in transport vehicles is acknowledged but specific information was unavailable and therefore generalized for simplification. Although not part of the information used in the study, GREET does not include temperature-controlled vehicles as an option for transportation. Some of the inputs such as electricity and plastic for packaging are rough estimations at best based both the Danish Government information for chicken and Ecoinvent data from a group of Swiss institutes within the SimaPro database since I was unable to find any specific numbers. The study is limited in the sense that it highlights only the transportation phase and assumptions were made in other aspects of the food chain.

Information regarding fertilizer inputs came from the USDA (USDA, ERS 2011; USDA, ERS 2013; USDA, ERS 2010) and all other inputs were taken from the Danish Government, within the SimaPro database. From this source there was specific information on tomatoes and chicken based on data from Europe. General fruit and vegetable farming was also within the SimaPro database but was in a unit of measurement that did not make the data useful without knowledge of how much JMU dining service spent on different food items.

Distances traveled by the vehicles was estimated using Google Maps. Local farms had addresses but non-local food was simply given a general area. Over half of the lettuce grown in California comes from Monterey County (Geisseler et al. 2013) and there is a large strawberry grower in Salinas, CA, also in Monterey County, so distances were estimated from the city of Monterey itself. Food production in Florida is common in the southern part of the state but not specific to one area like in California, so Belle Glade was used as a reference point and distances were approximated from there due to the large number of fields surrounding it on Google Earth and its roughly central location in Southern Florida. For Arizona production, Google Earth was used to find a large concentration of farms in the south-central area and distance was estimated based on where those farms were. While not precise, inaccuracies were likely inconsequential based on the overall distance between Arizona and JMU campus. Dodd’s Acres Farm was used as the source for local tomatoes approximately 130 miles from campus, Standard Produce Company was used as the local source for strawberries approximately 55 miles from campus, and Kirby Farms was used as the local source for lettuce approximately 130 miles from campus.

The GREET software is focused on emissions related to transportation, but the goods that are transported are also often related to fuels in some way. Farming processes were created and included inputs such as nitrogen and water per 100 kg of product. In order to determine the amount of chemicals used, data was found on yields to go with my USDA data on chemical applications. For example, tomato yields in Florida averaged 366 cwt per acre in 2009 (USDA 2010) and inputs included 173 lbs. per acre of nitrogen, 0 phosphate, 302 lbs. per acre of potash, and 181 lbs. per acre of sulfur in 2014 (USDA 2014) resulting in 4.22 g of nitrogen, 7.37 g potash, and 4.42 g sulfur per kg of tomatoes respectively (Figure 1). A similar
process was used for the other crops and locations. The USDA listed phosphorus, potash, and sulfur as inputs along with nitrogen, which were put into GREET as phosphoric acid, potassium oxide, and sulfuric acid respectively. Tomatoes were the only product found with yield information in Virginia (300 cwt/acre in 2009) but did not have chemical input data, so numbers from North Carolina were used to get a rough estimate of lbs./acre for fertilizer use in a relatively nearby area with similar climate and soil. Yields from 2009 were available for lettuce in California and Arizona along with Strawberries in California and Florida and were used with the 2014 data on chemical applications. For lettuce and strawberry local production, figures were not available from the USDA since overall production is minimal in the Virginia area. Chemical application was based on the “multi-state” figures in the USDA data and yields from the California data were used for the sake of simplicity.

Figure 1: Florida raised tomato inputs to the GREET model

A transportation process was then created using a medium heavy-duty vehicle for local crop transport and heavy heavy-duty vehicles for the long range transport, creating separate processes for local and non-local transport (Figure 2). A pathway was then made connecting the farming process and the transportation process with the output being that crop or food item (Figure 3). When a crop was received from more than one non-local state, separate farming and transportation processes were made for each. For the chicken, a chicken raising process and a separate chicken butchering process were made and coincided with a transportation process bringing the output of processed chicken to JMU campus. Upon completion of the pathway, the GREET program then provided emission outputs for the entire process.

Figure 2: GREET-based transportation process for farm to dining services
Inputs for growing tomatoes were assumed to be the same in Europe, where the data came from, as both Florida and the area surrounding Harrisonburg, Virginia. Although a majority of lettuce comes from Monterey County in California and that county happens to also have a large strawberry supplier, JMU strawberries and lettuce may not come from there, which would alter the distances traveled, though not a great deal most likely. The assumption was made that inputs for growing tomatoes is the same as inputs for growing lettuce and strawberries everywhere in the U.S. with the exception of fertilizers. Transportation was assumed to happen all in one trip without the use of storage facilities or distribution centers. Due to the campus of JMU being bisected by an interstate, it was assumed that there was no significant urban share to the transport miles involved in importing food. Crop production was assumed to take place in an open field rather than in a greenhouse. The vehicle payloads for crops were based off a study done on strawberry transportation, which stated 53-foot refrigerated trailers carried 29,568 lbs. of strawberries in corrugated containers and less in reusable plastic containers (CPA 2014). For simplicity, this was rounded to 15 tons and assumed that both tomatoes and lettuce would have the same payload since no transportation studies could be found with those specific crops. If the semi-trailers have an assumed max load of 19 tons as the Pirog study states, that represents a payload of roughly 79%, which was then also applied to the medium heavy-duty vehicles used in local transportation, resulting in a payload of 5.5 tons based off of an assumed 7 ton max load. Refrigerated vehicles are not available in GREET so although payloads of refrigerated semi-trailers were used, the emissions are based on non-climate controlled vehicles.

Due to the climate in Virginia, getting local crops requires them to be in season. Based on information from Charles, an estimated 60% of tomatoes, 30% of strawberries, and 10-15% of lettuce used by the dining services on campus come from local sources throughout the year. These numbers vary depending on local harvest conditions and availability and can come from a variety or combination of farms in the area ranging from 16 to 140 miles away. Tomatoes and sometimes strawberries are obtained from Florida which was an estimated 950 miles from campus. California was estimated to be 2,750 miles away and provides lettuce and the rest of non-local strawberries. Some lettuce also comes from Arizona, which was estimated to be 2,380 miles to campus. Approximately 13% of chicken meat and eggs come from local sources but again varies with seasonality and menu changes. A majority of egg purchases are met by a supplier in Lititz, PA, roughly 220 miles from campus. Due to the variety of suppliers and distributors used, other information regarding how and where the chickens are raised was unavailable in my limited survey.

The water and electricity inputs were the same for the three crops and based on the SimaPro database for tomato production. For 100 kg of product, 1.05 m³ of water and 109.8 MJ of electricity were used. Nitrogen,
phosphorus, potash, and sulfur inputs were taken from USDA information and can be seen in Table 1. Based on these inputs and the information regarding transportation, emission data was obtained from GREET. Chicken inputs included 55 kWh of electricity, 67 g nitrogen, and 200 kg of corn for raising, and 60 kWh electricity and 5 kg of plastic packaging to produce an estimated 90 kg of processed chicken from every 100 kg of chicken raised. Emissions results are given in Global Warming Potential (GWP), which the EPA uses as a label to compare emissions from different gases. It reflects how much energy the gaseous emissions will absorb over time compared to carbon dioxide, which has a GWP of 1. Higher GWP values from other gases mean they absorb more energy over time and therefore cause a greater rise in the Earth’s temperature over a set time period (EPA 2016). Most often a time period of 100 years is used, as is the case in emissions results from GREET.

**Results and Analysis from GREET-based transportation model of food sources**

This study aimed to identify carbon emissions related to food transportation of the JMU dining service, focusing the comparison of local and non-local tomatoes, lettuce, strawberries, and chicken. Transportation is often left out of food life cycle assessments (LCA), only partially included, or the emissions are assumed to be overall negligible, but the results from this GREET-based model suggests transportation emissions are not negligible in this particular food system.

Of the three produce items, lettuce from California had the highest emissions (103.99 kg/100 kg lettuce), followed closely by strawberries from California (102.41 kg/100 kg strawberries). Emissions per 100 kg of processed chicken equaled 197.55 kg using the only known location for chicken products made available (Lititz, PA). As seen below, CO$_2$ emissions were very close to the GHG100 emissions for all of the produce items (4-6% higher GHG100 emissions) whereas chicken production showed a significant difference between the two, with GHG100 emissions being 28% higher as shown in Figure 4.

It is worth noting that none of these items come from so far away that they need to be flown into the country. As shown earlier, air transport can release approximately six times the amount of CO$_2$ as road transport (Pirog et al. 2001). Using only road transportation reduces the impact associated with the selected foods compared to other food items that get transported through the air. Despite an additional 390 g of chemicals per 100 kg of lettuce grown in Arizona, the relatively small savings in distance to JMU of 370 miles was enough to result in a lower emissions output compared to lettuce from California. Similarly, chemical inputs in Florida for strawberry production were by far the highest of the three locations (Figure 5) but were not reflected in the overall emissions (Figure 6). Little information on where the dining service gets chicken was available but based on estimations for inputs it is highly likely that meat production creates a greater amount of CO$_2$ emissions and a much greater amount of other greenhouse gases (Table 2). Chickens are often considered a carbon friendly meat product as well so other meats like beef would likely have an even greater impact.
Table 1. Inputs for crop production

<table>
<thead>
<tr>
<th></th>
<th>Tomato - Local</th>
<th>Tomato - FL</th>
<th>Lettuce - Local</th>
<th>Lettuce - CA</th>
<th>Lettuce - AZ</th>
<th>Strawberry - Local</th>
<th>Strawberry - FL</th>
<th>Strawberry - CA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water (kg)</td>
<td>2,527</td>
<td>2,527</td>
<td>2,527</td>
<td>2,527</td>
<td>2,527</td>
<td>2,527</td>
<td>2,527</td>
<td>2,527</td>
</tr>
<tr>
<td>Electricity (MJ)</td>
<td>110</td>
<td>110</td>
<td>110</td>
<td>110</td>
<td>110</td>
<td>110</td>
<td>110</td>
<td>110</td>
</tr>
<tr>
<td>Nitrogen (g)</td>
<td>298</td>
<td>422</td>
<td>454</td>
<td>418</td>
<td>617</td>
<td>125</td>
<td>240</td>
<td>142</td>
</tr>
<tr>
<td>Phosphoric Acid</td>
<td>199</td>
<td>-</td>
<td>302</td>
<td>227</td>
<td>594</td>
<td>45</td>
<td>336</td>
<td>43</td>
</tr>
<tr>
<td>Pot. Oxide (g)</td>
<td>488</td>
<td>737</td>
<td>-</td>
<td>111</td>
<td>-</td>
<td>-</td>
<td>992</td>
<td>62</td>
</tr>
<tr>
<td>Sulphuric Acid</td>
<td>77</td>
<td>442</td>
<td>-</td>
<td>65</td>
<td>-</td>
<td>22</td>
<td>-</td>
<td>21</td>
</tr>
</tbody>
</table>

Figure 4: $\text{CO}_2(e)$ transportation-related emissions for tomatoes, lettuce, strawberries and chicken
Table 2. Emissions in kg per 100 kg of product

<table>
<thead>
<tr>
<th></th>
<th>Local</th>
<th>Florida</th>
<th>California</th>
<th>Arizona</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>CO₂</td>
<td>GWP</td>
<td>CO₂</td>
<td>GWP</td>
</tr>
<tr>
<td>Tomatoes</td>
<td>23.38</td>
<td>24.74</td>
<td>46.57</td>
<td>48.82</td>
</tr>
<tr>
<td>Lettuce</td>
<td>23.33</td>
<td>24.79</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Strawberries</td>
<td>17.57</td>
<td>18.62</td>
<td>46.49</td>
<td>48.62</td>
</tr>
<tr>
<td>Chicken</td>
<td>154.06</td>
<td>197.55</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

Amount applied (g)

- Local & Florida
- California

- Nitrogen
- Phosphoric
- Oxide
- Potassium
- Sulphuric
- Emissions
In September of 2015, JMU dining service purchased 1,378 lbs. of tomatoes, 2,098 lbs. of lettuce, 990 lbs. of strawberries, and 61,091 lbs. of chicken, resulting in the total GWP emissions shown in Table 3. Figure 7 shows the total emissions as a result of these numbers and the proportion of those food items gotten from local sources mentioned previously. When non-local foods came from two separate areas the amount was simply halved since specific information on how much came from which state was unavailable. Nearly all of the differences in emissions come from transportation. As an example, if transportation was removed from the lettuce model, the emissions from production between local and California are the same, while Arizona has CO$_2$ emissions .96 kg higher and GHG100 emissions 1.17 kg higher per 100 kg of product. The increased use of chemicals for lettuce production in Arizona results in minimal increases in greenhouse gas emissions, which explains why the 370 fewer miles traveled to reach JMU results in lower emissions for Arizona lettuce compared to California. The complete breakdown can be seen in Table 4. Overall, the emissions associated with production are very similar despite differences in chemical applications. As a result, emissions differences are due almost entirely to transportation.

<table>
<thead>
<tr>
<th>Table 3. September GHG emissions in kg per product</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tomato</td>
</tr>
<tr>
<td>Lettuce</td>
</tr>
<tr>
<td>Strawberries</td>
</tr>
<tr>
<td>Chicken</td>
</tr>
</tbody>
</table>

Emissions associated with local food acquisition are minimal compared to the emissions from getting food from other states, except in the case of tomatoes when over half of the produce comes from local sources. If 10% more of the three produce items were gotten from local sources, emissions would be reduced by 73 kg for tomatoes, 343 kg for lettuce, and 124 kg for strawberries. Since the dining service gets the least
amount of lettuce from local sources and both non-local sources are on the other side of the country, there are of course the greatest savings to be had from getting more lettuce locally. While unrealistic, if all three of these produce items came entirely from local sources GWP would be reduced by 4,076 kg (compared to 540 kg from a 10% increase in local food) for just one month. September through April are the busiest months for the dining service since school is in full session during these times. If the 10% increase in local food is applied to these eight months, total GWP for these three produce items would go from 51,048 kg to 46,728, a decrease of over 4,000 kg. This decrease is based entirely on transportation, but could be offset if local production was done in greenhouses instead of open fields. Conversely, if the non-local production takes place in greenhouses a shift toward local production in fields would result in an even greater decrease in carbon emissions.

| Table 4. Breakdown of GHG100 emissions (kg) by product and region |
|------------------|------------------|------------------|------------------|------------------|
|                  | Tomatoes         | Lettuce          | Strawberries     |                  |
|                  | Local FL         | Local CA AZ      | Local FL CA      |                  |
| Production       | 19.21 19.7       | 19.68 19.68 20.85| 18.11 19.5 18.11 |                  |
| Transportation   | 5.53 29.12       | 5.11 84.31 72.96 | 0.51 29.12 84.3  |

It is evident that emissions related to chicken outweighs that of produce due to both the significantly higher amount used and the moderately higher emissions associated per 100 kg of product. With only one known location for where JMU gets chicken products there is no way to compare local and non-local numbers in this study. However, if that one location were 10% closer, meaning the chicken only traveled 198 miles instead of 220, GHG100 emissions for September would be lowered by nearly 7,000 kg. Over the course of a school year this would result in a decrease in GHG100 emissions of approximately 55,500 kg.

Results show lower carbon emissions associated with food production than the other LCAs cited in earlier chapters that included any form of transportation. For tomatoes, one Italian LCA showed 98.88 kg CO₂ equivalents per 100 kg of product (Cellura et al. 2010), but included a cradle-to-grave study and is notably more detailed. A separate study that didn’t include any post-production steps resulted in only 27.56 kg of CO₂ equivalents per 100 kg (Torrellas et al. 2012). Local results from this study are very similar, but tomatoes from Florida fall somewhere between the two. Lettuce in the study comparing civic and industrial production showed emissions of 8 and 25 kg per 100 kg of civic lettuce and 32 kg per 100 kg of industrial lettuce (Hall et al. 2014). This study also included transportation and local lettuce production numbers from this study match very closely. It is unclear how far the lettuce traveled in the study but based on the numbers it was likely grown much closer to the final destination. In a different study on lettuce, associated emissions totaled 566 kg per 100 kg of product and was again more inclusive, notably including storage, packaging, and distribution centers (Gunady et al. 2012). This same study looked at strawberries and showed 184 kg of CO₂ equivalents per 100 kg of product (Gunady et al. 2012). A comparison of greenhouse and open field production of strawberries in Iran showed emissions of 77 and 65 kg of CO₂ equivalents per 100 kg of product respectively, but did not take into account transportation or any other post-harvest processes (Khoshnevisan et al. 2013). The civic versus industrial study shows emissions from chicken production to be around 770 and 400 kg CO₂ equivalents per 100 kg of product for civic production and 260 kg CO₂ per
100 kg of industrial production (Hall et al. 2014). Another study of broiler chickens in Finland showed approximately 360 kg of CO₂ equivalent emissions per 100 kg of product (Katajajuuri 2007). The GREET-based transportation model for chicken results confirm earlier assumptions that a lot of information regarding production was missing, as emissions are much lower than other studies. This model provided a comparison to produce items but lacks the detailed information needed for a more complete LCA.

Contrary to popular opinion in LCAs done on food production, transportation may play a larger role than is often assumed. The results from tomatoes, lettuce and potatoes in this study are comparable to others that have more thoroughly assessed the inputs needed for food production and accounted for the use of things like greenhouses and tractors for farming. Results from this study show that transportation is a large contributor to overall emissions in JMU dining service’s food acquisition.

Chicken production is shown to produce more emissions than any of the other foods. However, small scale local chicken production is not nearly as efficient as large-scale production and this study yielded results similar to those of Hall et al. which concluded local and small scale chicken production did not significantly reduce impacts based upon this analysis method. The distance of 220 miles traveled for the majority of JMU’s egg and liquid egg needs is not very far compared to other transport for goods and is likely a much more efficient process than anything closer to campus. Even if there was an area on campus designated for raising chickens off of the dining hall waste, the footprint associated with housing structures and then transporting them away from campus for butchering and processing and back to campus for consumption would likely result in greater emissions than the current system. A more in depth study would need to be done in order to understand the emissions related to JMU and its chicken consumption and where that process can be improved.

Summary

This study compared GHG emissions from local and non-local food production. The results show similarities with other reports in the literature. The main takeaways from the study are as follows:

- Carbon emissions associated with food from local produce sources are lower than non-local sources according to this GREET-based transportation model. Purchasing these foods from local sources could significantly reduce fruit and vegetable impacts. The impact reductions associated with locally sourced chicken were less substantial.
- The amount of publicly available data regarding crop cultivation makes life cycle assessments difficult to complete.
- The scale of University food purchasing operations created significant impact reductions for locally sourced food due to the quantity of food purchased.
References


Gunady, M. G., Biswas, W., Solah, V. A., & James, A. P. (2012). Evaluating the global warming potential of the fresh produce supply chain for strawberries, romaine/cos lettuces (Lactuca sativa), and button
mushrooms (Agaricus bisporus) in Western Australia using life cycle assessment (LCA). Journal of Cleaner Production, 28, 81-87.


U.S. Department of Agriculture (2015). Agricultural marketing services’s national organic
program.


Simultaneous air/water backwash in water filtration systems has been shown to be more effective in cleaning filtration media than water-only backwash or sequential water and air backwash. However, simultaneous air/water backwash operations can result in unacceptable media loss. This work is an investigation of troughs as flow obstructions in gray water filtration tanks during backwash operations. These flow obstructions can generate quiescent zones near the liquid surface and allow for the settling of media particles thus decreasing media loss. Flow studies in a laboratory scale square tank (4ft x 4 ft x 3 ft) quantifying the effect of a custom designed trough/baffle on liquid velocities will be presented. Media loss and velocity measurements in a pilot scale cylindrical tank (D= 42 in) system will also be discussed. Air and liquid flow rates of up to 2 SCFM/ft² and 5 GPM/ft² respectively were investigated. Commercial anthracite and Greensand PlusTM were used as filtration media. The rationale for the trough design used will be discussed in the context of the complexity of these systems.
Project-based learning with a real client: Sustainable Facilities

Jess Everett, William Riddell, Samantha Valentine, Kevin Dahm, Sarah Zorn, Shalyn Brangman, Robert Krchnavek

Introduction
This paper describes a long running project-based learning (PBL) initiative at Rowan University focused on sustainable facilities. Projects are completed for the New Jersey Department of Military and Veteran Affairs (NJ DMAVA) and the New Jersey Army National Guard (NJ ARNG). Projects include building audits, building information modelling (BIM), solar hot water assessment, and facilities management. All of the projects focus on maximizing the sustainability of NJ DMAVA / ARNG facilities. Much of the work is completed by undergraduates enrolled in Engineering Clinic courses. Some work is performed by paid student interns, graduate students, and staff.

The objectives of this paper are to:

- Describe the Rowan University Engineering Clinic
- Describe each Sustainable Facilities Project
- Describe pedagogic and programmatic lessons learned from 5 years of experience, to help institutions develop similar sustainable facilities PBL initiatives.

Rowan University Engineering Clinic
The Rowan University College of Engineering enrolls approximately 350 first-year students annually. Students pursue majors in Biomedical Engineering, Civil & Environmental Engineering, Chemical Engineering, Electrical & Computer Engineering, Engineering Entrepreneurship, and Mechanical Engineering. All Engineering students complete eight Engineering Clinics, one each semester of the four-year curricula in each major. Each clinic course incorporates project-based learning (PBL). Laboratory research, field research, or design projects -- along with the resulting written reports and presentations -- provide opportunities for students to learn experientially. This description of the Rowan University Engineering Clinic program is largely based on Everett et al. (2018).

The objectives of the Engineering Clinic sequence are to (Everett et al. 2004):

- Create multidisciplinary experiences through collaborative laboratories and coursework;
- Incorporate state-of-the-art technologies throughout the curricula;
- Create continuous opportunities for technical writing and communication; and
- Emphasize hands-on, open-ended problem solving, including undergraduate research.

Freshman Engineering Clinic sections are multidisciplinary, with 20 to 25 students from all six engineering disciplines. Fall Freshman Engineering Clinic introduces students to 'Engineering in a Broad Context' as well as the fundamentals of engineering measurements. The Fall clinic is also used to teach academic survival skills, e.g., note taking, cooperative learning, learning styles, report writing, and problem solving. 'Design for All' is introduced in Spring Clinic, using Universal Design (designing for people of all ages and abilities to the greatest extent possible) and Design for the Other 90% (designing for people living in impoverished circumstances).

Sophomore Engineering Clinic (SEC) focuses on communication and engineering design throughout the Fall and Spring semesters. Students solve realistic design problems in multidisciplinary engineering teams. SEC has significant communication components, both writing and speaking (Riddell et al. 2008, Dahm et al. 2009, Riddell et al. 2010) and is team-taught with communications faculty. Students write about and give oral presentations on the engineering projects they complete during laboratory sessions.
Working together, communications and engineering faculty assess student work. SEC fulfills two Rowan Core requirements for graduation from Rowan University, College Composition II and Public Speaking.

The PBL, teamwork-oriented, communications focus of the first two years of Engineering Clinic prepares students for Junior and Senior Engineering Clinic (JSEC). JSEC students work in small teams on open-ended projects under the supervision of one or more professor. Professors in the College of Engineering are expected to work with at least 2 teams of 3 or 4 students each semester. This counts as one course of a professor's teaching load. Over 150 projects run in the college of engineering during a typical semester. Students indicate their preferences by ranking a reasonable number of available projects. Professors also indicate how many students, and from which majors, are needed for each project. An algorithm matches student to one of their preferred projects.

Each JSEC team works on a unique project, which can be multiple semesters long. Many are interdisciplinary. A typical sequence includes: information search and review; development of a clear and concise goal or problem statement; planning; research, experimentation, design, prototyping, and/or testing activities; and presentation of results. Industry or governmental agencies fund most JSEC clinics. In some clinics, undergraduates work with graduate students, post-doctoral students, or even full-time staff.

Ten to twenty students currently work each year on NJ DMAVA/NJARNG sustainable facilities projects in JSEC (semester) or paid internships (summer). Because students are only assigned to a preferred project, students with ethical or moral concerns are not made to work for a military client. In 2012, NJ DMAVA entered into an agreement whereby Rowan University students complete building energy and water audits at facilities across New Jersey. Students inventory energy and water consuming devices, estimate consumption, recommend improvements, and determine payback periods and other financial parameters. A second project began in 2014, supported by NJ ARNG, in which JSEC students and interns created the NJ ARNG Energy and Water Master Plan and a Green Management Handbook and continue to publish an associated quarterly newsletter. The project was expanded in 2016 to include the creation of Building Information Models (BIM) using 3D laser scanning technology and again in 2017 to include gathering data to integrate all NJARNG facilities into a BUILDER Sustainment Management System (SMS) for NJ DMAVA/ARNG. BUILDER SMS is a web-based software application developed to assist with building asset lifecycle management and investment decision analysis (https://www.sms.erdc.dren.mil/Products/BUILDER). In 2015, a third project was initiated to investigate opportunities to use solar hot water at NJ DMAVA facilities. A fourth project, started in 2017, assists NJ DMAVA with facilities maintenance using the software program FacilityDude (https://www.dudesolutions.com/). NJ DMAVA / ARNG has committed 10 or more years of support to three of the projects.

The program was recently recognized as one of the top five Army community partnerships in the nation (Kimmons 2016). The program also won the 2016 Federal Energy Management Program (FEMP) Award for the Program category (EERE 2017). NJ DMAVA staff actively promote the program to other government agencies, a testament to its success. The next four sections are used to describe the four clinics in greater detail.

**Building Energy and Water Audits**

Building energy and water audits are conducted to assess the energy consumption of buildings and evaluate measures to minimize energy and water consumption, e.g., energy efficient light sources, occupancy sensors, efficient HVAC systems, solar power, and low flow appliances. Before visiting buildings to conduct an audit, students analyze utility bills from the previous 3 to 4 years. This time frame provides better estimates of the energy consumption pattern for heating, ventilation and air conditioning (HVAC). Energy and water consumption per unit area is tracked and compared to other facilities.

During the on-site portion of a building audit, energy consuming items are identified, light levels measured, and occupants interviewed. The occupant survey is used to obtain information on how the
facility is used (e.g., how many hours a day lights are turned on and thermostat set points), comfort levels, and facility information such as building materials, wall insulation, and HVAC systems. When necessary, energy consumption and/or hour of operation are measured directly using meters and data loggers.

Information on energy consuming items is entered into a Light and Plug Load Model (LPM). The LPM is an Excel sheet containing device quantities, energy consumption per hour and operating times. It is used to estimate the energy consumption of lights and appliances under actual and hypothetical conditions. For example, the effect of replacing particular lightbulbs can be simulated.

Floorplans and facility information are used to create a 3D eQUEST model (DOE 2016). eQUEST predicts energy consumption for lights, hot water, and HVAC. The model can be used to determine savings from upgrading HVAC systems or windows, changing thermostat set-points, etc. The LPM and eQUEST models are validated by comparison with utility bills. Water consumption is assessed by comparing current water usage to other facilities. The stated water consumption of existing water fixtures such as sinks in kitchens and bathrooms, showers, toilets and urinals in both men’s and women’s restrooms is also examined.

Based on audit observations and simulations using the LPM and eQUEST models, student audit teams recommend energy conservation measures (ECM) and water conservation measures (WCM). The teams also evaluate renewable energy measures (REM). Energy consumption can often be reduced by replacing or modifying the operation of appliances, lights and HVAC. ECM measures include improved light bulbs, delamping, programmable thermostats, occupancy sensors, Energy Star (EPA 2018a) appliances, new water heaters, boilers and/or air conditioners. WCM measures include replacing existing water fixtures with WaterSense (EPA 2018b) low-flow fixtures. Depending on the location, site configuration, and roof situation, it may be possible to generate renewable energy via solar or wind power (REM). Student teams often recommend solar arrays for NJDMAVA / ARNG facilities.

Professors request three students for an audit of a single building, one from CEE, ME, and ECE. CEE students typically take the lead on structural issues and water consumption, MEs on HVAC issues, and ECEs on electricity consumption. Student teams give two presentations and submit a final report to the client. ECM, WCM, and REM recommendations are provided in both presentations and reports. Student recommendations include capital and installation costs, lifetime, annual energy or water savings, payback period, lifetime savings, internal rate of return, and net present value, and savings to investment ratio.

Feedback was obtained from twenty-seven students who complete Building Audit clinics in Fall 2015, Spring 2016, and Fall 2016. The results are reported in more detail in Everett et al. (2018). Overall, students favorably compared Building Audit clinics to other JSEC clinics and believed they learned how to complete a building audit. The most commonly identified favorite activity was the site visit. Future work is planned to obtain feedback on other NJ DMAVA/ARNG clinics.

**Energy/BIM/Builder**

The Energy-BIM-BUILDER Program (EBB) is split into three distinct but synergistic parts. The program began in 2014 as the NJARNG Energy & Water Intern Program with a focus on supporting the NJARNG’s energy and water conservation efforts and developing federally required planning documents. The main deliverables in the Energy & Water program were a comprehensive energy and water master plan, an energy security plan, and energy conservation outreach and education through presentations and a quarterly newsletter. Energy audits, economic analyses, and preliminary project development and designs are also completed as needed or as requested by the NJARNG.

The program expanded in 2016 to include the development of Building Information Models (BIMs) of NJARNG facilities. While BIM is not a current requirement, the need for more modern record-keeping and database management is imperative for effective asset management and informed decision making by NJARNG leadership. BIM was initially added to improve the building energy modeling performed by the Energy Audit Center but was found to be useful for several aspects of facilities management such as...
space utilization and material inventory. To create the BIMs, students use a FARO Focus 3D X130 (https://www.faro.com) to take interior and exterior scans of the building to be modeled. The data from these scans, in the form of point clouds, is imported into a reality capture software such as Autodesk ReCap (https://www.autodesk.com). Figure 1 is used to show an exterior scan of a building and the resulting BIM.

![Exterior Point Cloud and corresponding BIM](image1)

ReCap is used to combine scans and then export into more functional parts, such as each floor, room or elevation. These point clouds are brought into a BIM software such as Autodesk Revit, which was chosen due to student familiarity with Autodesk software. Students bring in a ‘floor plan’ point cloud into Revit to “trace” the walls and place windows and doors in correct positions. To confirm the sizes and placement of the envelope elements, the building elevations are brought in and aligned to the floorplan. The BIM is further developed to match the point cloud as exactly as possible, using the point cloud and various imagery to incorporate all of the building’s relevant assets and elements, such as building material, lighting, plumbing and HVAC. Completed models are used for various assessment, such as space utilization analysis and energy modeling, and design purposes, such as lighting retrofits and building renovations or additions.

The program expanded again in 2017 to include the implementation of a BUILDER Sustainment Management System (SMS) for the NJARNG. The implementation of this software, which includes inventory and initial assessment of various building components, is required by a Department of Defense facility condition assessment policy, issued on September 10, 2013. The policy established a DoD-wide, standardized facility condition assessment process that incorporates the BUILDER SMS developed by the
Many military installations are meeting this requirement by hiring architecture and engineering firms. The NJARNG is instead utilizing Rowan because of the program’s history of completing complex tasks. Incorporating the BUILDER SMS software into the Energy-BIM Program was a natural tie-in due to the inventory elements of all three. In order to fulfill the requirements set by the facility condition assessment policy, students in the program inventory building systems, such as HVAC, down to the subcomponent level. The condition of subcomponents (i.e., distresses and the severity of those distresses) are assessed through observation. The BUILDER software analyzes the inputs and computes several indices, including a Facility Condition Index (FCI). Paid summer interns will complete a majority of the inventory and data entry. JSEC students will use BUILDER to predict future trends and costs, generate work orders and projects, and develop courses of action for NJARNG facilities. There are several documents that are required with the implementation, including Location Reports for each facility, which both paid interns and JSEC students will contribute to.

The three distinct components that make up the EBB Program are all directed with the focus of increasing the sustainability of NJARNG infrastructure. The EBB Program is influencing the NJARNG and its method of planning and programming through the use of several software programs to assess and improve asset management, energy consumption, life cycle costs, and investment decision making.

**Solar Hot Water Opportunities**

Another project is investigating opportunities for NJ DMAVA to utilize solar hot water. There are both long term and short-term benefits for this project. The short-term benefit is to identify one or more specific buildings for which solar hot water makes financial sense. The long-term benefit is to identify types of buildings or building usage patterns that are likely to benefit from solar hot water so that additional buildings could be screened for potential application of solar hot water.

There are several technical challenges associated with this task. The most significant challenge is determining accurate measurements of hot water demands to use for system design. While the ASHRAE manual (ASHRAE 2011) has recommended hot water demands for use in design, the values are determined based upon building use. However, NJ DMAVA buildings do not fall neatly into the various building use categories identified in the ASHRAE manual. Furthermore, the intermittent use of some NJ DMAVA buildings (e.g., dorm facilities that are not always occupied) raises questions about whether the standard design approaches are appropriate.

Early stages of the project focused on identifying appropriate methods of measuring hot water demand for use in modeling. As most buildings have water meters, but do not separately measure hot water use, ultrasonic flow meters were employed to monitor hot water use in situ. Three buildings were selected and meters rotated to allow for several two-to-three-week monitoring sessions for each building. Both the amount and timing of hot water use was measured. Once obtained, the measured water use was compared to values predicted using the ASHRAE handbook for various building uses. For the buildings investigated, it was found that the “professional office” category with the appropriate average daily occupancy was a good predictor for daily hot water use. It was also recognized that in some buildings, the only use of natural gas in the summer is a natural gas fired hot water heater. In these cases, using summer natural gas use as a proxy for hot water demand holds potential as a means to estimate hot water use.

Hot water demand was combined with standard methodology, as described by the ASHRAE manual, to predict the required size of solar array and storage tank systems, and typical costs were considered to calculate payback periods. A more detailed MATLAB model was developed that allows the effects of the timing of hot water use throughout the day, and the effect of uncertainty of water demand on actual payback period, to be investigated.
The solar hot water project involves calculations and design problems that fall into the realm of several different engineering disciplines. For examples, calculations related to utility use (water, electricity and gas) as well as CO\(_2\) emissions are often considered by Civil and Environmental Engineering students, the design of mechanical systems for buildings are typically performed by Mechanical Engineering students, whereas the modeling the thermodynamics of heat and mass transfer between system components such as the panels and storage tanks is a typical Chemical Engineering problem.

**Facilities Management**

The Facility Management Internship Program was created in 2017 to enhance facility maintenance at New Jersey Department of Military and Veterans Affairs (NJ DMAVA) facilities. The project is still in the early phases. The first key completed task was assessing options for a cloud-based energy and facility management software program that includes services for utility bill tracking and analysis, measurement and verification, event management, and work orders. The current methods in place for these services involve older and sluggish software, as well as traditional email, phone call, and face-to-face communication. The issues with current methods is lack of tracking, speed of action, and paper-based record-keeping, which lead to difficulty in decision making and asset management.

With technological solutions currently outpacing antiquated methods, there are many options for a facility management software program. The software chosen was FacilityDude, which best met the needs of NJ DMAVA and the NJARNG Facilities Management Bureau. FacilityDude is one of several software suites made by Dude Solutions (https://www.dudesolutions.com/), and has several management “solutions” available. The NJARNG is utilizing the Maintenance Management, Energy Management, and Event Management solutions. The Maintenance Management Solution will be used for work orders and preventative maintenance (PM), inventory and asset management, and budget forecasting. The Energy Management Solution will be used to improve utility bill accounting, reporting and documentation. The Event Management Solution will be used by NJ DMAVA to schedule facility spaces and plan events. In addition to their typical function, National Guard facilities are often rented out for a variety of different events by the communities in which they are located.

Using a web-based automated system will lead to better tracking of NJARNG assets overall in terms of costs and time, which will lead to better decision making and management. NJ DMAVA and the NJARNG Facilities Management Bureau have already begun using FacilityDude and integrating it into their operations. In the earliest stages of the Facilities Management Intern Program, Rowan students are helping in the implementation of the software through site visits and information gathering to observe current equipment and conditions to populate the system, as well as providing training to NJ DMAVA staff and NJARNG personnel. Future work by the interns will include data analysis and verification to identify issues and problems areas. Life cycle cost assessments will be performed by the students to determine best options for replacement or repair of equipment. The interns will also be involved with the assessment and project development and management of large scale facility upgrade projects through grants, Energy Saving Companies (ESCOs), Utility Energy Service Contracts (UESCs), or similar programs.

**Pedagogical and Programmatic Lessons Learned**

The sustainable facilities clinic projects described here vary widely in scope, including literature review, data collection, life cycle cost analysis, modeling and preliminary design. Some activities, such as utility billing analysis, energy benchmarking, and inventorying building components, have a clear set of tasks, deliverables and expectations for the students to follow. Students are provided with detailed task schedules, report templates, and process descriptions that help them produce professional engineering reports over the course of a semester. These have been developed over time and are continually evaluated and streamlined based on student input. The students are actively engaged in the learning process through assessment and feedback on workflows. Even in cases where there is a clear set of tasks, situations arise where critical thinking and/or creative solutions are necessary. For example, while utility billing analysis
is clearly defined, when the utility bills do not agree with the LPM and eQUEST models, what is the best course of action? In the ECM component of an energy audit, the student team may recommend switching out existing lighting for LED lighting. However, early LED lighting was less efficient than fluorescent lighting and payback periods were long. As LED technology improved, the lumens/watt surpassed fluorescent lighting and payback periods shortened so that LED lamps are generally a viable ECM. But because technology changes so rapidly, students must continuously evaluate the current state of technology to make accurate ECM recommendations.

Other projects are broad in scope, allowing students to develop skills in critical thinking, project management and scheduling. These broader projects generally have a significant research component. For example, REM usually consists of adding solar panels or wind turbines. With proper facility orientation and available grid access, payback times are often less than half of the lifetime of the system. But New Jersey has a large solar installation – second in capacity (CA is first) in the United States. Recently, certain grid feeders are restricted from additional solar installations due to the potential for grid instabilities. This could impact REM at NJARNG facilities. Research in the area of microgrids could provide solutions to this problem for NJARNG facilities as grid feeders become unavailable for solar.

The US Department of Defense often looks to fund projects that are innovative and replicable. If an innovative new energy concept or energy conservation opportunity is determined to have potential benefits for NJ DMAVA / ARNG, a project is developed for JSEC students to evaluate the opportunity and make recommendations to the client based on economic viability or other applicable metrics. The students are first assigned the “idea” and then they determine the steps necessary to evaluate and develop a written report for the client, usually submitted as a shorter format information paper or white paper. This methodology leads to a unique program where the students take control of their own learning. Oversight of task management is provided by Rowan faculty, staff, or graduate students.

Some projects fall in between the first two project types. Key deliverables are laid out by the NJ DMAVA / ARNG, but intermediate tasks or guidelines are not. The development of federally mandated documentation is an example of this type of project. The comprehensive energy and water master plan was developed by JSEC student working with Rowan faculty and staff, with some insight from the NJ DMAVA Energy Manager. The key components of the master plan were known, but the students developed formatting and the technical components. Another example of this type of project is the sustainable newsletter, Clean Cut Quarterly, created by JSEC Students to enhance the NJARNG’s energy conservation education and outreach program. The students are given deadlines and a general format but have the opportunity to investigate topics that may be of interest to them and compose articles or information pieces in a more journalistic manner. The development of NJARNG documentation is an exercise in technical communication in the real world, which engineering students do not typically experience.

The Building Information Modeling (BIM) work conducted in JSEC illustrates the natural development of PBL in long-term repeated projects. JSEC students create 3D models of NJ DMAVA / ARNG facilities. BIM is an emerging area in Civil Engineering. At the start of the project, student developed methods by trial and error. They produce fewer models, but developed critical thinking skills by evaluating their successes and failures. They refined methods and produced work guides. Current students use those guides and quickly become efficient and professional at creating the models. They develop stronger BIM-related skills. They have time to use models, e.g., to model building energy consumption. All of our PBL projects fall on this continuum. Less well-defined projects provide students opportunities to develop critical thinking skills, constantly asking questions such as ‘how can I do this better?’ and ‘how can this method be improved’. As methods are refined, student develop stronger task-specific skills and are able conduct higher-level analysis.
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Partnering Academia with Industry to Engage Students in Providing Sustainable Solutions for Water Recovery in Food Manufacturing

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Abstract

Rowan University Engineering Clinic projects have engaged students in applying green engineering strategies to food manufacturing through a partnership with Nestlé USA. A grant from the U.S. Environmental Protection Agency’s Pollution Prevention Program has supported this effort. This partnership uses a unique service-learning project based approach with a vertical integration of students from the junior year through graduate study. Faculty-student problem solving teams are engaged in a “clinic” experience to reach out to and assist industry in applying sustainable engineering practices in a particular manufacturing operation. Past collaborative endeavors have focused on the pharmaceutical, petrochemical, specialty chemical industries. Our most recent project with Nestlé, at their Freehold, NJ factory, examines water reduction in the manufacture of soluble coffee products. The curriculum is designed with a required engineering clinic course which students take along with other traditional courses. Through the clinics, we address many of the “professional skills” such as the ability to working teams, manage a project, and effectively communicate results. Projects like this allow students to apply sustainability principles to real-world situations and can help them advance these ideas when they enter the professional world. Students evaluate state-of-the-art technologies with actual factory waste to determine both technical feasibility and sustainability implications. This type of learning experience takes students beyond the traditional classroom by educating them in a particular sustainable technology, in this case membrane separations, and how this can be applied to a manufacturing challenge, such as water recovery.

1 Introduction

Through Rowan University’s engineering clinic program we have developed partnerships with industry to advance sustainable solutions to problems for various industry sectors. We currently have support from the U.S. Environmental Protection Agency (EPA) for faculty-students teams to apply green strategies to manufacturing processes in the food industry. Our current partnership with Nestlé involves water recovery from soluble coffee manufacturing. We have applied environmental metrics and investigated green processing strategies at their factory in Freehold, New Jersey. This project has the broader goal of supporting sustainability in the food processing sector.

The mission of most publicly supported universities are teaching, research and service; and through our unique engineering clinic program we are providing those elements related to sustainable processing strategies in food manufacture. Our engineering college is quite unique in its multidisciplinary clinic program in which faculty and students partner with industry to tackle real-world engineering challenges. Although many other academic institutions have industrial collaboration programs, it is the green engineering aspect of our clinic projects that provide the additional context.
Curriculum enhancement through integrating sustainability into a class experience or individual laboratory/design experience provides a solid foundation (Hesketh et al., 2007; Hesketh et al., 2006; Slater and Hesketh, 2004). While this is a valuable experience, the teaching of sustainability in the curriculum is greatly enhanced by active participation of students in real-world projects (Slater and Savelski, 2011). Sustainable engineering is a multidisciplinary topic that, if practiced to the fullest, would greatly improve how industry operates and provide a sustainable future (Allen and Shonnard, 2012; Allen et al., 2016). Incorporating sustainability into the curriculum through active student engagement enhances their ability to practice engineering (Hawkins et al., 2014).

2 Engineering Clinic

The Rowan’s clinic program provides an opportunity for students to apply their knowledge and learn more about engineering through their projects. Integrating sustainability into these projects through environmental consciousness brings even more value to the projects. Many other models and initiatives have been developed to integrate green engineering in industry. Most of these have been implemented by Universities and federal programs to show the benefits green engineering through the reduction of costs and energy savings. These incentives make green engineering more desirable for industry to follow its practices. For example, Canada’s Enviroclub initiative enhances the environmental performance of small and medium sized enterprises (Huppé et al., 2006). Participants attend workshops to learn how to improve their prosperity and competitiveness through pollution prevention. Rowan’s clinic model strives to incorporate industry within the University’s engineering program to initiate green engineering and sustainability principles (Slater and Savelski, 2011). Our previous projects have focused on the pharmaceutical and fine chemical sector and were funded by grants from the U.S. Environmental Protection Agency, through their Pollution Prevention Grants Program. The record of success with industrial partners with clinic projects at Rowan has resulted in significant outcomes (Slater et al., 2013; Sujo et al., 2009; Slater et al., 2012a; Slater et al., 2012b; Raymond et al, 2010; Tozzi et al., 2017; Savelski et al., 2017; Pastore et al., 2016; Slater et al., 2016; Wisniewski et al., 2017).

Students are encouraged daily to look at the big picture of their project in terms of the issue as a whole. Students are encouraged to recognize that the reduction and recovery of material from waste streams will then result in a reduction of costs, energy, and greenhouse gases. To implement green engineering strategies in their projects, students are encouraged to follow the structure in Fig. 1.

Figure 13. Clinic Strategy Sequence
At the beginning of each clinic project, students are presented with a problem that they are to define. To develop appropriate strategies to solve their problem, the first step students take is to investigate the problem presented to them. This results in a comprehensive literature search of previous strategies and solutions. Although this is a common part to almost any engineering project, the literature search benefits the students by allowing them to become more aware of the environmental issues. The previous accomplishments of case studies can be used to generate enthusiasm for green engineering and spawn ingenuity of how they will proceed to solve their problem. The applicability of the literature to their projects help students appreciate the initiatives of others and give them a basis for their own sustainable engineering strategies.

As the project becomes defined more clearly through their investigations, students will recommend a solution. This comes from their engineering knowledge and their understanding of their research. Students realize that their recommendations may affect an actual company in the terms of their processes. The environmental and cost concerns that companies face are brought into the picture and students must propose according to these. The industry involved will give back feedback to the students regarding their recommendations and facilitate the needs of the company. If the recommendations are made relevant to the company and are attractive, the students can make a difference through their proposals. After recommending a change, students will then ensure that their proposals are acceptable. This takes place in the lab or with detailed calculations and simulations. It is up to the industrial project contact at this point to “sell” the green proposal to their management.

Our approach is quite transferable to other institutions and can help satisfy accreditation criteria of the Accreditation Board for Engineering and Technology (ABET), (ABET, 2018). Engineering schools in the United States and well as those throughout the world that seek professional accreditation, typically have a cap-stone or senior design experience. Our clinic serves this purpose and engages students in the junior and seniors years in the open-ended project environment. Therefore, any institution can adapt an approach to integrate an element or multiple elements of sustainability within the context of their projects. Outcomes can also be mapped to the Principles of Sustainable Engineering (Abraham, 2006). In addition, the student outcomes of the project can be assessed to show how their engagement satisfies ABET student learning outcomes. Our program goes a step further by soliciting a partnership with business and industry to engage students in a focused project that that applies some aspect of sustainability to a “real-world” project. This would not be possible without industry or government support.

3 Project with Nestlé

Our current project with the Nestlé USA Beverage factory in Freehold, New Jersey focuses on the soluble (instant) coffee manufacturing process in which water consumption is significant and limited water recovery occurs. The freshwater intake and the amount of energy required to treat the wastewater creates an environmental concern. Wastewater is pretreated at the Nestlé plant to conform to county limits before it is discharged. The objective of the clinic team was to work with Nestlé plant personnel to understand the full extent of the issue and apply green engineering design strategies to effectively recover water from wastewater for reuse. Proposing design strategies for the recovery of water requires an understanding of the instant coffee manufacturing process and water quality in different process applications (Wisniewski et al., 2017).

Typically, our engineering clinic teams are composed of 3-5 undergraduates (Junior and Senior level) and an additional graduate student. Faculty advisors conduct biweekly meetings with the team which is
supplemented by feedback from Nestlé via telecom and plant visits. An initial review session/kick-off meeting was held at the Nestlé Freehold, NJ plant to allow for face-to-face interaction with Nestlé staff, technical personnel, and management. The engineering clinic team maintained contact throughout the project period with Nestlé to clarify process and wastewater parameters to determine which recovery methods are favorable for Nestlé to implement. We also believe that it is important to understand the processes from an unbiased and objective viewpoint, so we sought to do an independent background analysis of the current issues related to water use in the food and beverage industry. This effort could prove beneficial to broader corporate sustainability goals at Nestlé and the food and beverage industry.

Mid-year reviews was conducted with Nestlé to obtain feedback on our project. At the review session, we discussed some of the background information we had analyzed on the Nestlé process as well as methods investigated for the recovery of water from wastewater streams. Nestlé engineering staff offered valuable feedback and expressed high interest in the progress and success of the project.

The main project objectives centered on approaches to water recovery and potential reuse for specified industrial wastewater streams (Wisniewski et al., 2017). The streams are identified at various locations in the plant, and the overall coffee process wastewater (the “concentrated” stream). The main course of action for the investigation has included a thorough study on water recovery techniques, including both simulated (modeled) and experimental test methods. From the study, operating and capital costs as well as life cycle assessments will be performed on the proposed recovery processes. Students follow U.S. EPA metrics in evaluating the effectiveness of their approach, in terms of both hazardous and non-hazardous waste reduced, water saved, carbon dioxide-equivalents reduced, and cost saved. The team used sustainability software SimaPro® 8.0 (PRé Sustainability, Amersfoort, The Netherlands) in determining the life cycle emissions / impact. The final deliverable to be presented to Nestlé will be a proposal for the recommended approaches, including design strategies and financial and environmental impact.

Although this project is still on going, there are some initial “take aways” from a sustainable engineering perspective. The most important, centers around the major consumable raw material used in the processing, water. In past EPA P2 projects with the pharmaceutical and specialty chemical industry, the organic solvent use per finished product was quite high (sometimes in excess of 50:1). When a solvent recovery solution was proposed, and both economic and life cycle metrics were applied, the savings were usually quite large due to the cost and life cycle impact of producing and disposing of the organic solvent (which in most cases was considered a toxic or hazardous material). Now, with water, it becomes more of an issue relative to the plant location and practices of that region. For instance, in locations where water supply and waste disposal (in this case non-hazardous waste) are not major issues, then cost and environmental impact may not figure in that greatly. But, in other regions of the United States and globally, where water supply is scarce and local waste disposal regulations are more stringent, such as the recent drought concerns in California, economic and environmental metrics are more favorable for water recovery. Therefore, students need to understand that water use and disposal are important factors to consider, even though many of the early sustainability metrics and guides were focused on organic solvent use and toxics in the workplace.

Sustainable solutions involve the installation of separation process equipment, which for water recovery from complex waste mixtures, present in a soluble coffee manufacture, increases the capital cost versus more simplistic separations where odor or color removal may be the only objectives. Therefore, it is important for the students to consider the quality of the recovered water to be reused, since this does drive the economics. Students need to understand that their sustainable solutions will need to be reviewed not only on process and life cycle environmental factors, but also operating and capital costs. The integration
of life cycle thinking from an economic and emissions perspective helps prepare students, so they can be
effective advocates of “green” solutions in their professional career.

Although this project focuses primarily on water use and waste at the coffee manufacturing plant, students
are tasked to look more closely at the life cycle of coffee (from bean to brewed cup to disposal), and
sustainability implications that exist. It is important for students to have an appreciation of where their
sustainable solution fits in from an overall perspective. Geographic issues related to water use are also
investigated.

Students also learn the “culture” and terms-of-art of the beverage industry. This is important since most
engineering schools do not have dedicated food processing courses, and at the most may only be introduced
to food manufacturing technology through applications-oriented problem in core chemical engineering
courses or some isolated laboratory exercises. Through an integrated project-based experience in food and
beverage manufacturing, we believe a student has a much greater ability to apply chemical engineering
principles to this area, and opportunity to succeed as a professional in that field. Students also learn about
the food-water-energy nexus (United Nations University, 2013). This interconnectivity of demand,
resources, and use cycles is critical to their broader understanding of societal issues, and how these must be
harmonized for a sustainable future.

It should also be noted that one of our graduating senior students, John Morton, was hired on a full-
time basis by the Nestlé Freehold factory as a Production Supervisor. This shows how much the Freehold
management views the sustainable engineering education and training that the students on a Rowan clinic
project receive.

The project was assessed based on ABET student learning outcomes, using a rubric driven spreadsheet
method developed by Dahm et al., 2003 for team-based projects. Using this method, we can track
improvement in their skills as they progress from Fall to Spring terms. We have mapped the project
outcomes to the various ABET student learning outcomes, commonly referred to as $a – k$. We are only
reporting on those most related to the sustainability objectives of the project.

| Table 1. ABET a-k Criteria in the Water Recovery in Coffee Manufacturing Project |
|---------------------------------|-----------------|-----------------|
| **Criterion / Description**     | **Fall semester** | **Spring semester** |
|                                 | Project score   | Project score   |
|                                 | 5 pt Likert scale* | 5 pt Likert scale* |
| $c$: an ability to design a system, component, or process to meet desired needs within realistic constraints such as economic, environmental, social, political, ethical, health and safety, manufacturability, and sustainability | 3.5   | 4.6   |
| $e$: an ability to identify, formulate, and solve (sustainable) engineering problems | 4.2   | 4.7   |
| $f$: an understanding of professional and ethical responsibility | 4.1   | 4.4   |
| $h$: the broad education necessary to understand the impact of engineering solutions in a global, economic, environmental, and societal context | 3.8   | 4.6   |
Our survey results show that in each case, student attainment of the learning objectives related to sustainability have increased as they progress from their Fall to Spring terms. One missing element, which we will incorporate in a future survey, is a pre-test at the beginning of the semester. The results shown are based on final student portfolios at the end of the particular term. It is clear that the “design” student outcome increases the most, and is most indicative of the overall focus of a senior-level major project experience in engineering that involves multiple constraints.

4 Summary

Through the support of the U.S. Environmental Protection Agency, we have developed project-based experiences within our chemical engineering program, where students can work on real-world food engineering problems. Through our engineering clinics, students can learn about an industry or process application that they may not have much opportunity to do within the context of their typical curriculum. The project described in this paper relates to water recovery in a soluble coffee manufacturing plant. Students have been able to do experiments and provide design approaches to water recovery from various waste streams at the factory. Overall, our results, to date have been very promising, from both the technical results and student engagement in the project. Continued efforts in this field can help promote sustainability education in a project based environment.

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Ensuring Organizational Sustainability in Today's Challenging Work Environments

James Porter

Abstract

Sustainable pursuits require organizations to be operationally excellent. This presentation will discuss how leading organizations are reinventing their operations excellence efforts to meet the competitive challenges of today's complex and volatile work environments.
Using a practice-based approach to develop the holistic engineer

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Abstract

Accelerating globalisation and technological advances mean that the needs of industry and society are rapidly changing, and so too must the graduate engineering workforce in order to meet those needs. With internet connectivity becoming ubiquitous, learning can no longer be only about acquiring a set of facts. Instead, future engineering graduates will have to develop the skills to work collaboratively, think creatively and critically, synthesise knowledge, be agile in embracing change, and more. A seismic shift is needed in university engineering curricula, in which students not only develop the technical knowledge of their field but also have structured opportunities and experiences to facilitate the development of requisite personal and professional skills. The creation of authentic and relevant experiences to develop these skills in students in a meaningful way cannot be done in the isolation of the ‘ivory tower’, but must be done in conjunction with their future employers and other industry stakeholders, as well as education specialists, professional bodies, and industry experts.

At Swinburne University of Technology, in Melbourne, Australia, we are developing a new practice-based engineering degree to meet these challenges. From Day 1, students will join the Engineering Practice Academy as Associates. The curriculum is being co-designed and co-delivered with industry. Instead of the traditional focus only on technical content, graduates will also develop the professional skill-sets and mind-sets identified by our industry partners as being essential for the 21st century engineering workforce.

Rather than traditional lectures and exams, this new project-centric curriculum will see Associates collaborate in teams on real-world projects while at the same time developing professional (e.g. teamwork, communication) and technical (e.g. mathematics, manual tools) skills through a framework of credentials. They will apply these skills in their projects, and, just like pro bono work in a professional consultancy, they will also work on a long-term service-learning project to have real impact in their local community.

In addition to demonstrating professional and technical competencies, and completing their project work, students will be assessed on their progress through their own negotiated Individual Development Plan. Each term, students will set ‘SMART’ goals, aligned to their career goals, against each of the following: becoming a citizen, becoming a learner, becoming an engineer, and a passion project. They will gather evidence against each of these goals, and then evaluate and reflect on their progress in a performance appraisal meeting with staff and industry representatives. Students’ holistic development will be an explicit focus of this assessment process.
1 Introduction

At Swinburne University of Technology in Melbourne, Australia, a revolution in engineering education is taking place. A new degree program, the Bachelors of Engineering Practice (Honours), is being developed and implemented that completely does away with traditional lectures and exams, with instead a focus on developing the holistic set of skills, required in the 21st century workplace, through real-world project experiences (Swinburne University of Technology 2017). Through consultation with industry and other stakeholders, the essential technical and professional skills required of graduates have been identified and incorporated into the curriculum. Students will develop and apply these skills in industry and service projects. Students’ work on these real-world projects means that not only will they be job-ready graduates, equipped to contribute to global social challenges when they enter the workforce, but they will already start to do so throughout their degree.

2 Curriculum

Throughout 2017, an iterative and consultative curriculum co-design process was undertaken with industry partners and other stakeholders, to identify and characterise the skill-sets and mind-sets required of engineering graduates entering the 2nd quarter of the 21st century (Cook, Mann et al. 2017). The results of this process, and how they address the challenge of developing holistic engineers, are described below. However, it should be noted that this iterative curriculum development process is ongoing. With our industry partners we will be reflecting on lessons learned through the curriculum implementation with our first pathfinder cohort in 2018, and incorporating this feedback into subsequent iterations of the course in coming years.

The curriculum is divided into five domains, as shown in the curriculum map below in Figure 1. These domains are Thinking, Process, Self, Work, and Discipline. The Discipline domain corresponds to the traditional technical content of existing engineering programs, reimagined in this course to be contextualised wherever possible in project work, and with fundamental (and therefore mandatory) disciplinary knowledge distinguished from specialist (i.e. elective) content areas. The individual domains are explored in detail below, but overall the reader should note the explicit and deliberate space given to the various non-disciplinary areas, the details of which indicate how the horizontal bar of the so-called ‘T-shaped engineer’ is being operationalised in this new course (Oskam 2009). They incorporate what was identified in our curriculum co-design process as the essential professional or ‘soft’ skills of the holistic engineer.

Each of these domains has been unpacked into several capabilities. The choice of the term ‘capability’ is deliberate, to signify what graduates will be able to do, rather than a collection of disparate facts that they know but have not necessarily been required to apply.
Capabilities are further broken down into streams, and then finally into the base level of credentials – the outermost circle in Figure 1. To reveal the detail of this substructure, a section of the overall curriculum map has been enlarged below in Figure 2.

Each credential represents a small self-contained separate unit of learning, requiring 4-6 hours of student time, and may in turn be a pre-requisite of subsequent credentials in the same stream, or of related credentials elsewhere in the curriculum. Non-disciplinary credentials are divided into core (i.e. mandatory, Levels 1-3) and extension (Level 4, optional). Students are required to complete a minimum set of core credentials as a hurdle requirement to graduating.
Each credential has several learning outcomes, learning tasks, and finally application tasks, where students put their learning into practice. To achieve a credential, students have to collect and curate evidence from these application tasks, to demonstrate that they have achieved competence in that particular area. Although there is a detailed rubric for each credential, describing ‘developing’, ‘proficient’, and ‘advanced’ levels of competence for all aspects of the learning outcomes, overall each credential is either ‘achieved’ or ‘not yet achieved’. That is, credentials are not graded. Instead, students are assessed on their progress through their own negotiated Individual Development Plans. Individual Development Plans and their framework of assessment will be the subject of future publications and are beyond the scope of this paper.

2.1 Discipline Domain

This domain represents the technical knowledge specific to the engineering profession. The curriculum has been designed in this way, distinguishing discipline-specific knowledge and skills, from broader skill sets arguably common to all professions, such that this curriculum model can easily be adapted to other professions. For example, in designing a new practice-based degree in architecture, or IT, for the most part only this Discipline domain would have to be reconstructed.
For engineering, this domain contains traditional areas such as *Structures, Fluids, Electronics,* and *Mathematics.* Each of these content areas is further partitioned into mandatory Core credentials, and elective Specialist credentials of which students can choose a subset aligned to their own interests and aspirations.

2.2 **Work Domain**

The *Work* domain contains five capabilities – *professionalism, communication, teamwork, project management,* and *business acumen.* These first three include streams addressing typical professional skills like ‘Working with others’, ‘Presentations’, or ‘Conflict & negotiation’. As with the other domains, many streams include elective levels. For example, in ‘Conflict & negotiation’, the compulsory credentials are ‘conflict management’ and ‘negotiation’, but there is also an elective credential: ‘Mediation’.

The emphasis given to *Project management* and *Business acumen* was motivated by the consultation process with industry employers, who identified these areas as currently lacking in the typical engineering graduate.

2.3 **Self Domain**

The *Self* domain contains three capabilities: *being a professional engineer, personal development,* and *local global citizen.* This domain is about students becoming good citizens (through for example learning about globalisation, sustainability, and social justice), good learners (career-aware reflective practitioners conscious of their own learning strategies), and good professionals (through learning about contemporary and emerging engineering practice, and engineering and professional ethics).

2.4 **Thinking Domain**

The *Thinking* domain is the smallest of the five domains and so in the curriculum framework has only streams rather than capabilities: *design, social, critical, systems, creative,* and *analytical, and analogical thinking.* These have all been framed as equipping students with different tools to help make better judgements and decisions.

2.5 **Process Domain**

Finally, the *Process* domain contains four capabilities: *research, design, make,* and *operate.* The *Research* capability interprets the term broadly - from writing literature reviews, to understanding research ethics, and all the way to lab skills, calibration, and analysis. The *Design* capability spans the entire design process – from problem framing and stakeholder research, to developing and validating detailed designs. *Make* includes practical skills such as soldering, machining, or surveying, while for example there are streams in *Operate* addressing safety and maintenance.

Two key feature of credentials are worth reiterating. First, they are not graded. Or, if you will, they are graded on an ‘achieved’/‘not yet achieved’ basis. Second, to achieve a credential, students must collect evidence of application – of their ability to *apply* the relevant skills, in practice, primarily in the context of their industry and service projects.
3 Practice-Based Pedagogy

At its heart, the Engineering Practice degree is built around a practice-based pedagogy. This approach puts professional practice at the core of all learning experiences, and focuses on the integration of knowledge, skills and attributes in the context of undertaking actual practice. In practice-based learning, students are situated within an actual practice context, and work alongside practicing professionals undertaking real work (Higgs, Barnett et al. 2013). They develop as professionals through both learning and working, with the work informing what needs to be learnt, and the learning being applied just in time to work. While similar to work-integrated learning which captures the learning undertaken while in a workplace, practice-based learning aims to develop the whole curriculum needing to be learnt by a student rather than just aspects.

In the context of the Engineering Practice degree, students join the Engineering Practice Academy as associates. Set up as a functioning engineering practice at Swinburne University of Technology, students spend their time working on industry projects for clients, supporting engineers undertaking service projects for community groups or not-for-profit organisations, and undertake a structured program of professional development. On projects for clients, students are led by a project principal, who is a practicing professional responsible for the ultimate delivery of the outcome to the client. The project principal becomes a mentor to the students, guiding their work as engineers.

The Engineering Practice Academy itself is structured and run as an engineering practice. Students working as associates work and learn within a purpose-built physical academy space, which supports activity-based working and includes communal areas with a large kitchen. Partners and staff of the academy also work in and frequent the spaces, supporting the students to develop themselves as working professionals within a workplace, and not just as technical engineers.

4 Projects

Over the course of each year, Associates will work on four industry projects. These will each run in 6-week Sprints, with the first two Sprints aligned to the first semester of the university calendar, and likewise the latter two Sprints aligned to the second semester dates.

Initially the student project groups will be effectively offering ‘research and development’ services to the industry clients. However, as students’ skills, agency, and independence increase towards their final year of the program, and as they play a greater role in negotiating and coordinating projects, it is forecast that they will be autonomously delivering real project deliverables to clients by the end of their degree.

The first cohort entered the Academy in February 2018. The first client in Sprint 1 is Engineers without Borders Australia (EWB), and through them the Cambodian Rural Development Team (CDRT) as part of the EWB Challenge. The EWB Challenge is a design competition for first-year students around Australia and overseas to develop creative design solutions to address real-world challenges faced by EWB’s community-based partner organisations in developing countries (Jolly, Crosthwaite et al. 2011). Each year, competition finalists have an opportunity to present their designs to these community partner clients. In past years, clients have included the UNHCR in Zambia, and Live & Learn in Vanuatu, and this year the partner is CRDT. CRDT works in natural resource management and community development in northeast Cambodia (Engineers without Borders Australia 2017). Further industry clients for subsequent Sprints this year include Hobson’s Bay City Council in Melbourne,
which is developing a creative technologies hub to engage their local community with emerging technologies, Nexans Olex, an electrical cable manufacturer wanting to improve its maintenance approaches, and MedCorp Technologies who is developing new wearable technologies. All of these industry clients have real projects and needs that students in the course are developing solutions for.

Additionally to the industry projects, students also undertake service projects, which are the pro-bono work undertaken by the Engineering Practice Academy. The clients for these projects are either community groups or not-for-profit organisations. These projects are led by an engineer who oversees the engineering work undertaken, and is responsible for the long-term relationship development and project delivery.

5 Future Prospects

The first cohort of 26 Associates joined the Engineering Practice Academy in February 2018. An internal Monitoring, Evaluation, Reporting and Improvement plan has been put in place for the Associates’ experience, and the Academy’s interactions with project partners and other stakeholders. A number of academic research projects are also underway, looking at for example the development of Associates’ socio-technical thinking and more broadly the development of their identity as an engineer and practicing professional, and how successful our admission procedures are in being both inclusive and predictive of success within the program. Collectively, these processes will inform the ongoing development, refinement, and expansion of the Engineering Practice Academy. Other ongoing processes include developing a pipeline of industry projects for future years, developing and refining credentials, and preparing for full accreditation of the degree program with Engineers Australia (which can only take place once the first cohort has graduated).

In the future it is envisaged that in addition to recruiting a larger annual engineering cohort, this practice-based educational approach will be expanded to other disciplines, to develop practice-based degrees in science and IT.

6 Conclusion

The Engineering Practice Academy is realizing a long-held ambition of the engineering education community – putting real-world professional practice truly at the core of undergraduate training. With industry- and service- projects from Day 1, tailored Individual Development Plans, and by accrediting the granular development and contextual application of professional engineering capabilities, we are reimagining how engineering education can develop and empower holistic engineers to address the significant social and global challenges of today, and tomorrow.

References


Creating experiences, not lectures: experiential methods in the context of sustainable development teaching

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Abstract

Active, experiential learning approaches that go beyond traditional lecture based methods have been applied to many disciplines with the understanding that student motivation, engagement, and learning are increased. As one type of active learning method, problem-based learning focuses on increasing students’ ability to solve complex problems. This is particularly relevant to the field of sustainable development and engineering education where multiple stakeholders must be considered and there are no clear solutions. However, in order to embed problem-based learning within engineering education, there are various possible approaches. Within this scope, the authors have independently developed two different types of problem-based learning tools currently in use by material science and engineering educators at technical universities. The first tool *Active-learning ToolKit - Sustainable Development* was created to support teaching in the form of a workshop (or a whole course) to help in structuring the analysis of proposals for various sustainable technologies by providing a methodology, templates for group work, and several case studies. The second tool *In the Loop* is a serious game that was developed to create awareness about material criticality and circular economy through application of game-based learning techniques. Both tools are supported through the use of both digital and paper-aids.

This paper aims to advance knowledge on how to approach experiential learning in the context of sustainable development by presenting a case study of these teaching tools. Drawing on the authors’ experiences in applying the tools in engineering classrooms and workshops with academics, we critically reflect on both approaches. This includes discussing their benefits, challenges, and limitations in terms of integrating sustainability strategies as well as the approach of using both digital and paper-aids at the same time. We conclude with recommendations for educators interested to develop their own or use existing experiential learning tools in their classrooms as a way to integrate sustainable development in engineering education.

1 Introduction

Experiential learning is a general pedagogic trend due to the fact that one learning style does not ‘fit all’ (Kolb, 1984). By using a technique and tools that allow students to experience subject matter first-hand, experiential learning can increase engagement and provide a “safe” learning environment for students. Within education for sustainable development, such interactive approaches have gained popularity due to the complex nature of the topic (Sadowski et al., 2013). As sustainable development issues span many disciplines, education that provides experiences rather than facts is often advocated as it encourages
development of critical thinking skills and illustrates the connections between different stakeholders. Finding ways to integrate experiential sustainable development approaches within engineering education may be a challenge for educators. Although some universities and educational programs have sustainability-specific courses, in many cases it is not possible to add separate courses focused on sustainable development to the curriculum (Jones et al., 2008). Considering this, one approach is to embed the topic within existing courses. Here, materials science and engineering disciplines is one logical fit given that the resource perspective links to important areas of the sustainable development discussion including critical materials, resource efficiency, and circular economy.

Within this scope, the authors have independently developed two different types of experiential tools currently in use by material science educators at engineering universities: Active-learning ToolKit - Sustainable Development (further ToolKit) (Ashby and Vakhitova, 2017) and In the Loop game (Whalen et al., 2017). Both tools build off traditional problem-based learning approaches that require students to find solutions to an open-ended problem. Additionally, these tools combine digital resources with physical materials (e.g. handouts, templates, physical game), aligning with the ongoing trend of using digital materials to enhance educational experience (Basilotta Gómez-Pablos et al., 2017). In this comparative case study, we assess these two approaches, reflecting on the type of learning facilitated and on participant engagement. Specific attention is paid to the combination of digital and physical teaching materials and its observed impact on participant experience.

2 Background

Problem-based learning (PBL) shapes the pedagogical theoretical foundation for both tools. This section briefly introduces PBL, making reference to both tools, before describing them in more detail.

2.1 Problem-based learning

PBL is a pedagogical approach that guides the learner without imposing a clear outcome. This makes it appropriate to learning situations where there are no fixed solutions, and considering this, it is not surprising PBL has been adopted within scope of education for sustainable development, where educators advocate moving away from a focus on the ‘right answers’ (Shephard, 2008). The ToolKit, for instance, encourages critical thinking and does not offer ready-made solutions. Instead, it provides a structured approach to factual reflection of the problem at hand. While this may be difficult for students from technical backgrounds who are used to solving for a specific answer to a provided problem, it is, however, important for their future work in interacting with different stakeholders and facing dilemmas where critical thinking is essential. In the case of In the Loop, while games do have an objective, there is no clear outcome to achieving this objective. This results in students needing to solve their way to a solution using critical thinking and the material given.

Methods to PBL vary depending on the context and learning objectives (Boud 1985; Barrows, 1986). However, one process can be generalized through four main steps: meet the problem, explore knowns and unknowns, generate possible solutions while considering consequences, and choose the most viable solutions (Mathews-Aydinli, 2007). These four stages are closely linked to Kolb’s (1984) four stages of learning: active experimentation, concrete experience, reflective observation and abstract conceptualization. Furthermore, as addressing the entire learning cycle has been linked to increased engagement (i.e. Sadowski et al., 2013), PBL is considered more engaging than traditional classroom
approaches which only address the latter two stages of learning. Finally, closely related to engagement is the concept of flow. Flow is a highly focused mental state, where participants are concentrated and immersed in the activity at hand (Csikszentmihalyi, 1997). The next section presents the two PBL tools in this comparative case study.

2.2 Tools Descriptions

2.2.1 Active-Learning ToolKit - Sustainable Development

The Active-learning Sustainable Development ToolKit was developed to support teaching about sustainable development based on an identified need from a survey\(^1\) with responses from more than 200 academics. The ToolKit is intended to be used for teaching at bachelor or master level students and is well suited to work with interdisciplinary groups.

At its core the ToolKit has a five-step methodology for assessing proposed sustainable development. It has been validated in many workshops both in Europe and the USA and is described in detail in the textbook "Materials and Sustainable Development" (Ashby et al., 2015). After being confronted with a problem scenario, students follow the five-step methodology for assessment of sustainability which includes analyzing stakeholders, reviewing facts with the use of Granta’s educational software (CES EduPack\(^2\)), making reflections, and assessing alternatives solutions, including long-term scenarios. This corresponds well with the Kolb’s stages of learning, described earlier.

The ToolKit has eight main parts (a mix of pdf and ppt files): introduction and content, method, handouts, assembled case studies, micro-projects for preparatory work, information about the software’s Sustainability Database, instructor experiences, templates and check lists. The fully analyzed case studies provide detailed and clear guidelines on how to apply the five-step methodology to a variety of sustainability topics including biopolymers, electric vehicles, wind farms, and low carbon concrete.

The ToolKit, together with the software, is now used in workshops and incorporated into teaching at a number of leading Universities including the University of Cambridge and TU Delft. The format of a standard workshop is illustrated in Figure 1. The format can be compressed into a 3-hour workshop (which includes an introduction to the software) or (preferably) expanded into a week or term-long project-based course, allowing room for guided or in-depth research. The approach supports group work and, with the help of templates, a structured discussion\(^3\).

The teaching experience is greatly enhanced if participants are given preparatory reading, including a short paper on the five-step methodology. In case they are new to the software, a couple of introductory videos to familiarize with the software are also distributed in advance. The installation link for the software is also sent with the material above. On arrival, participants receive a delegate’s pack containing: an agenda for

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\(^1\) This survey of 240 academics worldwide was completed between January and March 2015. The survey was distributed on-line through https://www.smartsurvey.co.uk website to the academic database of CES EduPack users – educators with an interest in sustainable development and eco design.

\(^2\) The CES EduPack Sustainable Development Edition contains interlinked databases with data on materials, processes, including extensive environmental properties, regulations and legislation, socio-economic data and tools, such as Eco Audit Tool and Materials and Process Selection tools.

\(^3\) For more practical information on how to set-up a similar workshop, please, look at the information provided in the ToolKit Part 6 "Instructors Experience": https://teachingresources.grantadesign.com/Type/teaching-packages/PACWOREN17
the day, a short summary of the case study that will be used during the workshop, templates, and check lists – 1 pack per group (~5-6 people) and the feedback form.

![Figure 1. Workshop process for Active-learning ToolKit - Sustainable Development (Ashby and Vakhitova, 2017)](image)

2.2.2 *In the Loop*

In the Loop is a physical, serious game initially developed to support Dutch companies in creating awareness about critical materials. It resulted from a need identified through research conducted by TU Delft and the FME-CWM Association (FME), as countries including the EU and US have created a shortlist of ‘critical’ materials, or materials with high economic importance and significant supply risk (Moerland-Masic, 2012). In the Loop’s application has since expanded and it is now part of educational programs at numerous institutions including Politecnico Institute of Milano, UCL, and TU Delft.

In the game, players take on the role of product manufacturing companies and must collect the critical materials (i.e. niobium, cobalt, antimony) necessary to produce products. As many critical materials are associated with a transition to renewable energy and high-tech products, such products are the focus of the game. Changing market conditions of critical materials (i.e. supply and demand) are represented by Event cards drawn every few minutes during gameplay. This illustrates the consequences of material criticality and also forces players to experiment with different types of sustainability strategies.

Represented by Strategy cards, the game contains a variety of strategies including circular economy themed cards such product remanufacturing and material recycling. More information about the theoretical framework of the game can be found in Whalen et al. (2017) and Whalen & Peck (2014).

A standard workshop format for using In the Loop is shown in Figure 2. The workshop length is usually 2.5 hours in total, with gameplay lasting 45-90 minutes depending on the number of participants. A digital Facilitator’s Guide accompanies the physical components and contains additional materials to support each phase of the workshop. This includes instructional videos, a content background presentation for instructors to briefly introduce the topic of critical materials and circular economy, and suggested open questions for the group reflection. Finally, on the backs of the material tokens, there are QR codes which link to a digital materials library which provides information about the materials from the Granta Design materials database.
3 Methods and Approach

This comparative case study draws on experiences from two specific workshops, one with the ToolKit and one with the In the Loop game. The case study is explorative in nature, thus drawing on a variety of research methods (Eisenhardt, 1989; Stebbins, 2001). These include reflection on our experience in designing the workshops, reflection on our interactions and noted observations with participants in the workshops, and analysis of feedback and assessment documents provided by participants. In reflecting on In the Loop, we have also used an online program (https://www.the-qrcode-generator.com) to monitor the number QR codes scans. To further describe the research context, Table 1 shows a comparison between the two case examples in terms of the number and types of participants as well as the methods for assessment that were utilized.

<table>
<thead>
<tr>
<th>Workshop type</th>
<th>Active-Learning ToolKit - Sustainable Development</th>
<th>In the Loop Game</th>
</tr>
</thead>
<tbody>
<tr>
<td>Location &amp; participants</td>
<td>Cambridge University Materials Science and Engineering Dept., April 2017, international group of academics</td>
<td>Chalmers University, Production Engineering Department, May 2016, master’s students</td>
</tr>
<tr>
<td>Number of participants</td>
<td>16 (+ 2 facilitators)</td>
<td>40 (+ 3 facilitators)</td>
</tr>
<tr>
<td>Assessment</td>
<td>Feedback forms</td>
<td>Free-form reflection essays submitted after workshop</td>
</tr>
<tr>
<td>Length of session</td>
<td>3.5 hours (including introduction to the software for 0.5 hours)</td>
<td>2 hours</td>
</tr>
<tr>
<td>Technology available</td>
<td>CES EduPack software, Sustainable Development Edition</td>
<td>QR codes with link to more information (optional)</td>
</tr>
</tbody>
</table>
4 Comparison and Reflection

In reporting the main experiences from the two workshops we have divided our reflection into two stages: content reflection, where we reflect on the tools’ abilities to integrate sustainability strategies, and usability reflection, where we reflect on the process of how the tools were used by the participants and facilitators.

4.1 Content reflection

Both tools were observed to address multiple topics related to the complex subject of sustainable development in a short timeframe. For example, participants using the ToolKit were able to identify stakeholders’ concerns, analyze various data points, and create an informed reflection on the given problem within the timeframe of an average seminar (between 2-4 hours). The comments from participants emphasized the tool’s strategic approach to a complex problem of sustainable development, capacity to provide a guided step-by-step methodology, and ability to connect stakeholder concerns to factual data as well as the impact on environment, society and economics. The final reflection step allowed for a comparison of short-, medium-, and long-term solutions and highlighted alternative ways to solve the problem at hand. Exchange of ideas and a quick access to relevant data allowed for enriching the experience with new knowledge and skills. However, the time limit of a workshop does not allow students to undergo thorough research, especially if the software with the databases is not available. Therefore, it should be introduced within a course or series of seminars. It is also recommended to share preparatory information and to follow up with individual reports or a group presentation, if the time allows.

In the case of In the Loop, participants reflected on a variety of criticality issues including the causes, effects and solutions for addressing challenges associated with critical materials. Participants emphasized business ethics related to sustainable development issues and reflected on how they could address material criticality concerns in their future engineering careers. They also linked the events in the game and resulting gameplay to sustainability issues in their written reflections. However, one potential limitation with addressing many topics in a short amount of time is the resulting depth of learning possible. For example, while the In the Loop workshop touched on all four stages of Kolb’s learning, the majority of time was dedicated to the gameplay (i.e. active experimentation and concrete experience). Therefore, increasing the time allowed for reflective observation and abstract conceptualization could be one way to deepen the learning in this type of workshop. Some future possibilities include a longer introduction, more frequent discussions during gameplay, or a more in-depth reflection afterwards.

4.2 Usability reflection

In terms of usability, it was observed the workshops triggered participant engagement by encouraging group work. In both cases, the group work was guided by a process document (templates in the case of the ToolKit and game instructions in the case of In the Loop) which proved helpful in providing the groups with a framework for interaction. In fact, participants of the workshop with ToolKit explicitly reflected on this stating ‘provides structure and clear guidelines’ and ‘avoids being overwhelmed’, helping to see things holistically’. Moreover, participants appreciated both tools for their ‘engaging and interactive nature’.
Of particular note in the cases is the observed difference between each tool in terms of flow and the use of digital aids. In the case of In the Loop, the QR codes were scanned only twice during the workshop. (In other workshops they have been scanned more.) Although many factors could influence this (such as the students were not interested in looking for more information on the materials), desire to not break the flow of the physical game appears one possibility as it was observed participants did not welcome outside interference, preferring to stay focused on the game even when the facilitators tried to get the classes’ attention. However, in the case of the ToolKit, all groups in the workshop made use of the accompanying software as it was needed to gather information for analysis of the stakeholder concerns at the fact-finding stage. Having access to the software, its tools and data enabled a quick review of the information relevant to the problem at hand and also helped to visualize and compare data points. For instance, in the case of an electric car (as an example of “sustainable technology”), participants were asked to find more information on Lithium and Neodymium and to compare their annual production with the amount required of each material for production of the number of electric cars suggested by a regulator.

Therefore, one clear takeaway from this is that in order to ensure the use of supplemental digital aids, educators must provide clear instruction and ensure they are incorporated in the workshop. This could be also done, for example, through questions afterwards as to not break the flow or by making the digital aids necessary in order to proceed in the learning situation.

5 Recommendations

In this paper, we have reflected on two tools that approach experiential learning in the context of sustainable development. In particular we have compared and reflected on the main takeaways from two case studies in terms of supporting participant learning (content) and the use of the tools, including associated digital aids (usability). While these results are exploratory in nature, they can help in the development of hypotheses that can be further tested. We conclude with three recommendations for educators interested to develop their own or use existing experiential learning tools as a way to integrate sustainable development in their classrooms.

1. Provide a clear framework to guide interaction and processes, especially if students will work in groups and the time is limited.
2. Scope the learning objectives in relation to the given timeframe. For example, depending on the knowledge of the CES EduPack software, the ToolKit can be more focused on the case study itself and on hands-on work with the software and its data. Alternatively, as a part of coursework, participants could be encouraged to look at the stakeholder analysis in more detail through interviews or surveys, explore more facts, and prepare extended reports. If time is limited and the software is not available, a simple internet search can also help with providing additional information.
3. Consider the relationship between the workshop flow and digital aids. Keeping the flow is a challenge with the incorporation of digital aids in combination with physical materials. However, as seen through the tools and potential recommendations, it can be addressed and managed by dedicating specific time slots and by providing clear guidelines before and during workshops. In some cases such as In the Loop, reflections and in-depth discussions may be more suitable afterwards as to not disrupt flow. In the case of the ToolKit, discussion between the group members and with moderators is encouraged and integrated within the workshop.
References


CREATING THE HOLISTIC ENGINEER VIA SUSTAINABLE MATERIALS RESEARCH THAT UTILIZES ALTERNATIVE, YET COMMONLY RECOGNIZABLE RESOURCES

Joseph Stanzione

Abstract

Green chemistry and engineering, sustainability, and cyclical economy are topics of great import to all engineering disciplines and in developing holistic engineers. In the Sustainable Materials Research Laboratory (SMRL) at Rowan University, we are integrating these topics into engineering education via hands-on, team-based, undergraduate and graduate research endeavors. These projects are aimed at advancing fundamental and applied science and engineering technology that utilizes nature’s chemistries, particularly those renewed on an annual basis by the biosphere, to enhance material performance and improve our global sustainability. The continuing development of new bio-based feedstocks, including biofuel coproducts, opens opportunities to increase the resource base from which chemical and material engineers can draw to meet specific polymer property requirements. This paper presents SMRL examples that highlight our efforts in utilizing alternative, yet commonly known resources to (1) advance sustainable materials development and (2) create a new generation of engineers that are grounded in engineering fundamentals but practice with a holistic mindset. Specifically, team-based projects that have utilized birch bark extract, agricultural and forestry residues, cashew nut shell liquid, and recycled carbon fibers in the generation of novel polymers and polymer composites will be presented. The results of our studies illustrate that new materials can be designed in a comprehensive manner through the strategic use of chemical functionalities that are inherent to nature’s diverse palette of abundant renewable resources. The intent of this paper is to share and discuss our efforts in EESD and in materials for sustainable development.