The Development and Evolution of the Engineering Design Process in Engineering Education: From Sustainability towards Resilience

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Abstract

The growing global concern for natural resources and sustainability has led to the successful introduction of sustainability engineering courses in undergraduate and graduate engineering curricula. In addition, some elements of sustainability engineering have even been incorporated into discipline specific engineering design courses. Although related to sustainability, the term resilience has emerged to define the ability of systems to adapt to unintended hazards and shocks. With the growing number of global weather related challenges resulting from climate change, resilience engineering has emerged as a key term in the development agenda of world organizations and has even been considered to be the engineering challenge of the 21st Century. While the appearance of resilience engineering is recent and has not been widely introduced into engineering curriculum, it appears to be on the rise as an area of definite importance for current and future engineers. A review of current literature on the engineering design process in engineering education, sustainability engineering education and engineering resilience was conducted. The methods employed in sustainability engineering and engineering resilience are discussed in context of the design process in engineering curriculum. Graduate researchers conducted a survey of current undergraduate and graduate students from aerospace, civil, energy systems, environmental and mechanical engineering disciplines to assess their understanding of how to incorporate sustainability and resilience into the design process. Survey results confirm that students felt their understanding was lacking in both cases and especially for resilience compared to sustainability. Methods for implementing engineering resilience into current curriculum is discussed and recommended to prepare future engineers.

Introduction

The Design Process and Sustainability Engineering

Learning design in engineering education has been considered both a central as well as a distinguishing skill of the engineering profession.[1] However, Dym et al. provides an insightful history of the engineering design process in engineering education that makes it clear that teaching design in engineering education has been challenging and has changed in many ways over the years.[2] In that work, Dym et al. defines engineering design as "a systematic, intelligent process in which designers generate, evaluate, and specify concepts for devices, systems, or processes whose form and function achieve clients' objectives or users' needs while satisfying a specified set of constraints".[2] That process is difficult to teach systematically as it involves many cognitive processes and soft skills that characterize good designers. The following skills were listed as describing good designers.

1) Ability to tolerate ambiguity
2) Ability to apply systems thinking and focus on the big picture
3) Ability to handle uncertainty
4) Ability to make decisions

5) Ability to think as part of a team
6) Ability to communicate in diverse ways

Currently, the design process is taught in most engineering curriculum through a first year or cornerstone course[3] and in the capstone course. The process or structure of engineering design, although lacking in a uniform application across all disciplines or even within disciplines, often involves elements such as determining the clients' requirements, generating concepts, investigating/testing concepts, building prototypes and delivering a final product. Often the structure and skills of the engineering design process are learned through project-based learning. There are many ways to carry out project-based learning, but in general the design process and skills are learned while carrying out an actual design project. Some of the lecture time is occasionally devoted to teaching engineering design skills and structure.

While that basic approach to engineering design has been the norm for many years the considerations in the process have been expanding and evolving with the growth of the sustainability initiative that unfolded in the 1990s.[4] The ever increasing demand for food, water, energy, consumer products and materials was recognized as causing strain on natural resources such as air, water, land and raw materials. A growing concern over these resources and the environmental systems at play became part of a global awareness of the concept denoted sustainability. The definition of sustainability itself remained somewhat ambiguous and the definition varied based on the designator in several ways as discussed by Allen et al.[5] In general the definition of sustainability was concerned with 'development that meets the needs of this generation without compromising the ability of future generations to meet their needs'.[6]

Sustainability engineering became concerned with integrating social, environmental and economic factors into the evaluation of projects. This involved renewed emphasis on certain principles in the design process. In particular, the use of interdisciplinary and transdisciplinary efforts in problem solving became increasingly important and is now applied in sustainability education.[7] In addition, the use of life cycle assessment as a tool for gauging sustainability has become increasing important and has been implemented even within single disciplines in capstones projects at Syracuse University and elsewhere. In addition, certain skills became of increasing importance such as systems thinking, the ability to deal with increasing uncertainty, and ambiguity.[7] Although sustainability engineering was somewhat new, the emphasized skills are mostly the same as those called for in general engineering design as described earlier. The compatibility between sustainability engineering and the engineering design approach is apparent, but with certain skills being clearly emphasized when sustainability engineering and education are discussed in the literature.

Developments in Climate Change and Resilience

While the call for sustainability became especially prominent starting in the 1990s, Lam et al. noted that sustainability is now less prominent when compared to the concern over global climate change.[4] Although climate change is very much interrelated with some of the core initiatives in sustainability such as emissions reduction and economic risk reduction, it has started to emerge as a separate agenda in some disciplines with resilience as a distinct and key term in the change. According to the Cambridge dictionary, resilience designates an ability to quickly return to a previous, good condition. In addition, Fischer and Kothari defined resilience 'as the ability of individuals, institutions or systems to adapt and change to the rapid dislocations associated with planned or unplanned development or else to various shocks, whether positive or negative, so that they may maintain an acceptable level of functioning'.[8] Vulnerability is a key concern as the most vulnerable are often the least resilient. In other fields, the exact terminology, its definition and applicability have been questioned and challenged,[9] but for present purposes the above definition will suffice.

The term resilience has a long history in the literature dating back to the early 20th century in materials engineering, and was later adapted in the 1960s and 1970s where it has long since been applied in ecology. Resilience in ecology is concerned with the ability of ecological systems to absorb and rebound from shocks created by human actions.[10] The inability of certain ecological systems to rebound denotes a less resilient ecosystem, which cannot sustain the shock of human intervention. In fact, the concern over ecological systems resilience lead to a focus on sustainability and then to sustainability engineering. Unfortunately, human induced climate change is the result of emissions in our present day, which is causing adverse effects such as weather related hazards and sea level rise.[9] The term resilience has also been applied extensively in the social sciences such as development studies. The focus in developments studies has been on four broad categories described by Fischer and Kothari 1) the ability of individuals and groups to adapt; 2) adaptation through social movements or political actions; 3) political and institutional systems ability to adapt; 4) resilience of systems of wealth and power.[9] Bene et al. notes that resilience is becoming prominent across the whole development agenda under many initiatives.[11]

What does all of this have to do with engineering education and the design process? It should be noted that the use of the term resilience has a different context in engineering compared to the definitions given above. In particular, resilience in engineering, in contrast to ecology or other fields, is concerned with the end goal, which is the intentional creation of a resilient system by design.[12] For now, engineering resilience education is not found in the literature in great abundance, but it is certainly growing in recognition. For instance, the recent World Engineering Education Forum 2015 had a general theme of “Engineering Education for a Resilient Society”. The term has been used recently in engineering literature under systems engineering, where the methods of accomplishing engineering resilience has been incorporated primarily as a system engineering objective.[12-17] There are also a few papers discussing resilience in civil engineering for civil infrastructure resilience to earthquakes.[18,19]

Besides the literature, world organizations are calling for resilience engineering. For instance, the call for resiliency in cities, building and technologies is on the rise. The United Nations Office of Disaster Risk Reduction has issued the ‘Making Cities Resilient’ report, which calls for more careful planning of cities and the inclusion of the most vulnerable individuals within cities in order to improve the ability of the city to recover from disaster.[20] While much of the focus in developmental studies has been placed on collaboration, strategy and strong governance, there has also been mention of technological innovations that will be needed to promote resilience in the future.[20] As a result, engineers will need to play a significant role across many different disciplines in responding to the new, or perhaps just renewed, call for resilient technologies.

Two somewhat recent and familiar examples of the need for resilience are Superstorm Sandy and changes in the defense industry. In the Northeast United States Superstorm Sandy made landfall in October 2012. The impacts ranged from entire houses pushed off their foundations, to electrical and system damage from water in basements, to structural damage, to supply chain breakdown for fuel, and significant damage to the electric grid, which left nearly 2 million people without power. In addition, there were many challenges in transportation, fresh water supply, wastewater treatment, and telecommunications infrastructure. Beyond the immediate losses and destruction, which were significant, the long-term recovery or lack of resilience has sparked concern and changes. Even with relatively rapid repair of electrical substations and the help of thousands of utility workers from other states, repair of overhead lines took nearly two weeks with many in hard hit areas without power or heat for weeks.[21] Since that time redesign of systems has focused on improving future resilience. Another example is in the defense industry where a shift has occurred from design for conventional warfare using traditional approaches to asymmetric warfare with a move towards unpredictable and unprecedented threats. Neches and Madni notes that with this new scenario, unless the typical approach to design can be compressed to development cycles of only a few weeks or months (a significant undertaking), then a new approach towards Engineering Resilience Systems (ERS) is needed.[13]

When considering the ERS approach, Neches and Madni define resilience 'as robustness that is achieved through thoughtful, informed design that makes systems both effective and reliable in a wide range of contexts' and consider it to be the engineering challenge of the 21st century.[13] The authors make it clear that this is not a traditional approach to robustness and either involves overdesign or complex interactions among independent and tightly coupled subsystems, both of which are expensive to build or upgrade. Instead, they call for a slightly adapted approach described in the Engineering Resilience Approach section.

Methods and Principles in Engineering Sustainability and Resilience Education

Sustainability Engineering Approach

Although the call for sustainability education and engineering has been ongoing since 1990, the explicit description for engineering curriculum has taken time and is still being defined even in recent literature. When the National Environmental Education Act (NEEA) was established, the goal was to educate the public on issues such as limited natural resources and environmental damage through pollution. However, the goal of stimulating individual responsibility in addressing the challenge was not considered successful.[22] Instead the need today is to not only provide education but to stimulate responsibility and action. To that end, sustainability engineering programs have emerged in a variety of forms. As an example, four separate ways of teaching sustainability have emerged in the curriculum at Syracuse University. The first is through an entire academic program, Master of Science in Energy Systems Engineering, which is offered for graduate students. This program, although not explicitly entitled sustainability engineering, has four required courses that cover the three broad areas of concern in sustainability engineering; namely environmental, social and economic, as shown in Figure 1. Among the curriculum requirements are classes in "Engineering Economics" and "Managing Sustainability" which broaden student's perspectives and understanding about sustainability education and its implication for businesses and engineers. A second curriculum for sustainability education at Syracuse University is the Certificate of Advanced Study in Sustainable Enterprise (CASSE), which is offered to graduate students. The certificate is a joint effort between the Whitman School of Management, the College of Engineering and Computer Science, the State University of New York College of Environmental Science and Forestry, and the Syracuse Center of Excellence in Environmental and Energy Systems. While not a degree, this certificate is comparable to a minor for an undergraduate showing the students concentration in this area. Students take three required classes in "Managing Sustainability", "Strategic Management and the Natural Environment", and "Sustainability-Driven Enterprise." In addition, students take two technical electives in areas related to sustainability. A third curriculum for sustainability education at Syracuse University is through infiltration of sustainability engineering topics into individual disciplines. For example, many classes involving engineering design have also started to require life cycle cost analysis, which challenges students to consider the environmental, social and economic implications of their design before, during and after it is built. The diffusion of sustainability engineering principles and ideas into individual disciplines is becoming more common.[22] The fourth academic offering is the minor in Energy Systems for engineering undergraduates at Syracuse University in many disciplines including aerospace, chemical, civil, electrical, environmental, and mechanical engineering. Many other colleges are also offering academic programs in sustainability, which are similar to the ones described.

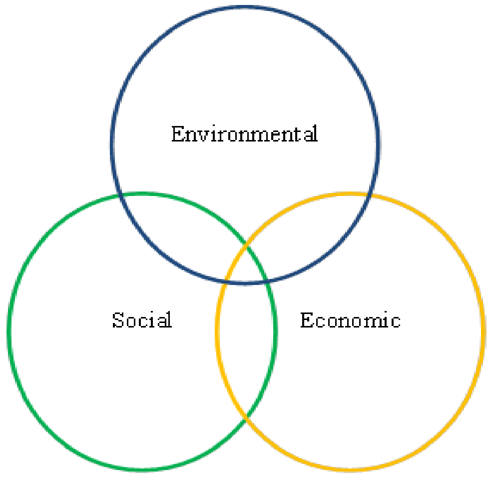

Figure 1: The triple bottom line of sustainability.

It is important to note that the sustainability engineering education approach goes beyond simply improving mass and energy efficiency and reducing emissions, which has been a somewhat traditional part of engineering design. Instead, engineering curriculum changes have been called for that incorporate a greater understanding of the fundamental issues at the heart of the sustainability challenge and a general approach for these challenges. Allen et al. have called for the incorporation of three elements into the chemical engineering curriculum in particular.[5]

1. Framing the Challenge
2. Assessment and Design
3. Systems Perspective

In this work, framing the challenge involves an understanding of the fundamental issues that are at the heart of the call for sustainability including a depletion of natural resources, increased emissions and their impact, and the environmental systems at play. While the scope of this fundamental understanding is broad and a number of factors are at play, the authors list two organizing principles for addressing these issues in engineering design, namely risk based and life cycle frameworks. The second step is assessment and design, which involves the ability to quantify the raw materials and energy used in the design product and the emissions involved over the life of the product. Calling for a systems perspective is a reminder that sustainability initiatives are often complex and involve interactions at many scales from a small subsystem to the larger architecture that will support it in the world. These three elements are not necessarily linear in application or structure, but are all involved in implementing sustainability engineering.

The framework described above is not the only change associated with sustainability engineering education. A significant factor in sustainability education became the interdisciplinary approach to education. As one author describes it “inter-disciplinarity” means bringing together different disciplines to enable mutual development often through the crossing of approaches and knowledge between disciplines.[4] Many courses focusing on sustainability such as the "Managing Sustainability" course taught at Syracuse University involve engineering, business and environmental science students working together to complete a common project. In this particular course collaboration between different disciplines is not only encouraged, but enforced by creating design teams that have at least one member from each discipline.

As described, implementing sustainability engineering into engineering curriculum has typically involved 3 methods; 1) Teaching classes that provide an understanding of sustainability issues or in other words "framing the challenge"; 2) Implementing sustainability into design quantitatively through life cycle analysis or other methods; 3) Promoting interdisciplinary approaches and collaboration during design. Each of these methods, particularly the second and third, have been promoted by adapting the engineering curriculum to focus on particular areas during the design process. While individual courses can be made to frame the challenge, the principles can also be taught during a few lectures of a design course. An example is an engineering capstone class, which requires life cycle analysis and interdisciplinary teams or collaboration. In other words, a common method for teaching sustainability engineering is to adjust courses having an engineering design component to include the three methods described.

Engineering Resilience Approaches

To this point, a clearly defined structure for resilience engineering and education is lacking in the literature. Instead, there are several different approaches that have been proposed with a range of ways to assess and deal with the resilience challenge. These particular approaches were implemented in systems engineering[12-17] to incorporate resilience engineering into system design. Currently, there are few examples of implementing these ideas into engineering curriculum.

One past engineering approach to resilience was concerned with risk analysis and reduction. However, this approach has been called into question recently as the original call for resilience deals with risks and hazards that are unknown and therefore cannot simply be assessed with risk analysis.[12] Given that the risks and hazards are both unknown and often intertwined in nonlinear ways, it is difficult to simply adapt the risk approach to make it more applicable for resilience engineering. Instead, Park et al. called for three guiding principles in resilience thinking; 1) resilience demands continuous management; 2) resilience demands embracing incompleteness; 3) resilience demands a new way of design thinking.[12] These ideas call upon and build upon the four cornerstones of engineering resilience proposed by Hollnagel et al. 1) responding to what happens; 2) monitoring the developments; 3) anticipating future threats; 4) learning from the past.[15] Both descriptions tend to be admittedly qualitative and without a definitive structure. The hope is that the application of said ideas will lead to a more clearly defined structure. While these principles provide just a few examples in engineering resilience thinking, Jackson and Ferris assessed 14 different principles found in the literature related to engineering resilience.[16]

Despite the relatively unstructured nature of the engineering resilience principles, Neches and Madni provided more structure in their Engineering Resilient Systems (ERS) approach. The ERS approach calls for some adaptation in upfront engineering or the first stages of the engineering design process.[13] The realization of this approach is haunted by the increased time spent in the initial stage of the design process, but the authors see increasing sophisticated modeling capabilities and computational power as leading to significant reductions in upfront engineering time. In particular, they call for more informative requirements to be delivered to the engineering design team at the beginning. In addition they call the engineering design team to ensure that the refinement of design requirements is grounded in the design feasibility and in a full exploration of all alternatives. Finally, they invite the design team to keep their options (design alternatives) open longer in the process than they typically are.[14] The interaction between these three factors in shown in Figure 2 below.

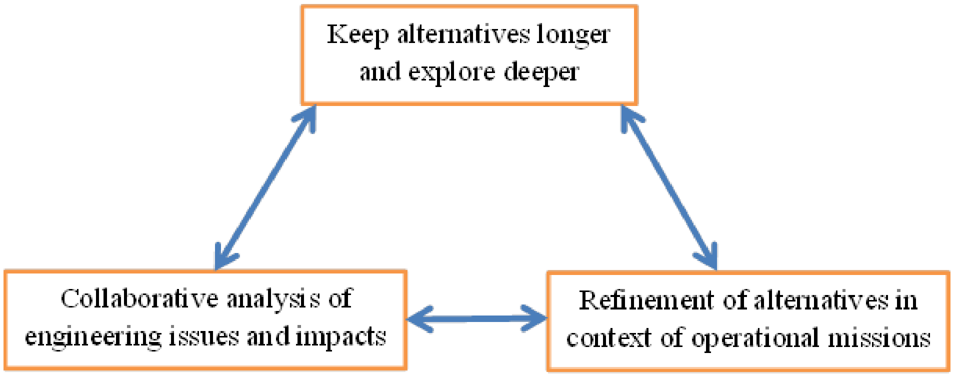

Figure 2: Key considerations in obtaining an alternative engineering approach.[13]

Besides the general framework described above, the following principles are listed as key elements of the upfront design.[13]

1) Automatically consider multiple variations
2) Propagate changes and maintain constraints
3) Introduce and evaluate multiple usage scenarios
4) Explore technology and operational tradeoffs
5) Iteratively define requirements
6) Adapt and build in adaptability
7) Learn and update

While this approach provides enhanced structure for resilience engineering in design there is still significant difficulty in providing adaptation and anticipation given the unknown threats. Uday and Marais provide an overview of the methods described here and others employed in engineering resilience.[17]

Results and Discussion: Towards Engineering Resilience Education

Given that both sustainability and resilience engineering are recent and developing trends, a survey was conducted to assess current Syracuse University undergraduate and graduate students' understanding of these topics. Figure 3 shows the results for the first survey question which stated "I have a strong understanding of sustainability and how it pertains to the engineering design process." Undergraduate students from aerospace, civil, environmental and mechanical engineering disciplines enrolled in a thermodynamics class were surveyed. Most of the undergraduate students were sophomores with only a few being juniors and seniors. There were 38 aerospace engineering, 5 civil engineering, 3 environmental engineering, and 65 mechanical engineering undergraduates surveyed. With very few results for civil and environmental engineers surveyed, their results were not included as individual pie charts in Figure 3. Their results were included in the undergraduate total pie chart. However, for completeness, 2 of the civil engineers selected "strongly disagree", 1 selected "disagree" and 2 selected "agree". For environmental engineers, 1 selected "disagree", 1 selected "neutral" and 1 selected "agree." Graduate students from mechanical and aerospace engineering or energy systems engineering programs that enrolled in an advanced fuel cell science and technology course were surveyed. There were 17 graduate students in the survey.

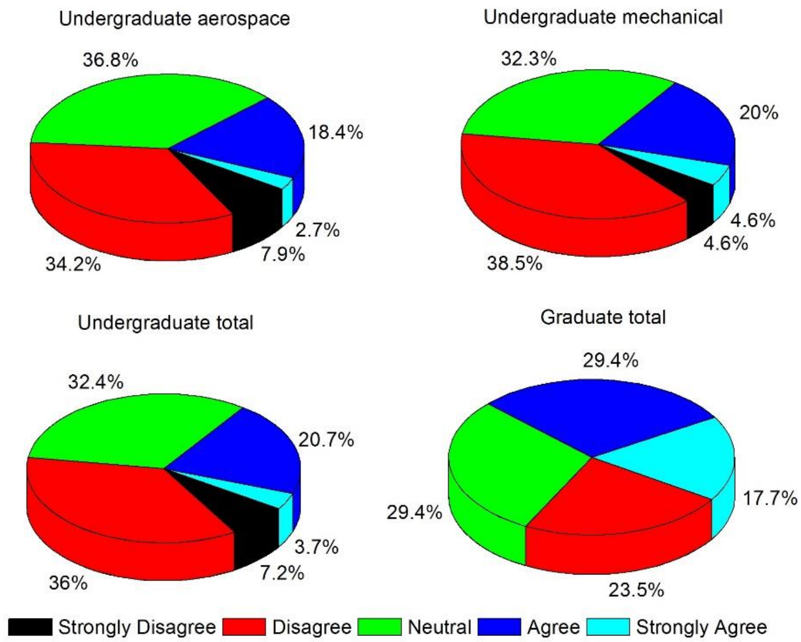

Figure 3: Aerospace undergraduate, mechanical undergraduate, total undergraduate and graduate student response to "I have a strong understanding of sustainability and how it pertains to the engineering design process."

The results of the first survey question show a very common response across aerospace and mechanical engineering disciplines when their understanding of sustainability and its implications in the design process were assessed. Specifically, the responses in each category were very similar in percentage, which resulted in the total undergraduate pie chart being comparable to both disciplines because the majority of the students surveyed were either from aerospace or mechanical engineering disciplines. However, what was surprising is that more than 75% of undergraduates surveyed selected either strongly disagree, disagree or neutral. Despite the growing awareness and incorporation of sustainability into curriculum, sophomore undergraduates did not feel strongly about their understanding of sustainability and how to apply it in engineering design. Part of this lack of understanding may partially result from the fact that the students are still at the early stages of their programs. To assess this a class of graduate students was surveyed. Graduate student results differed markedly with no graduate students selecting strongly disagree and 47.1% either agreeing or strongly agreeing. However, the majority still selected either neutral or disagree. While sustainability engineering has been discussed for many years it is clear that more work is needed to incorporate these principles into undergraduate and graduate engineering courses.

Figure 4 shows the results of the second survey question, "I have a strong understanding of resilience and how it pertains to the engineering design process." While the total undergraduate results are similar to the first survey question with 81% selecting either strongly disagree, disagree or neutral, there is a clear difference in this case between aerospace and mechanical engineers. For instance, 31.6% of aerospace engineers selected agree or strongly agree while only 13.8% of mechanical engineers made the same selections. In general aerospace engineers felt much more confident in their ability to incorporate resilience into engineering design. However, the results clearly indicate that the majority of students felt that they lacked sufficient understanding of how to incorporate resilience into engineering design. While the results were slightly better for graduate students, 76.4% still selected strongly disagree, disagree or neutral.

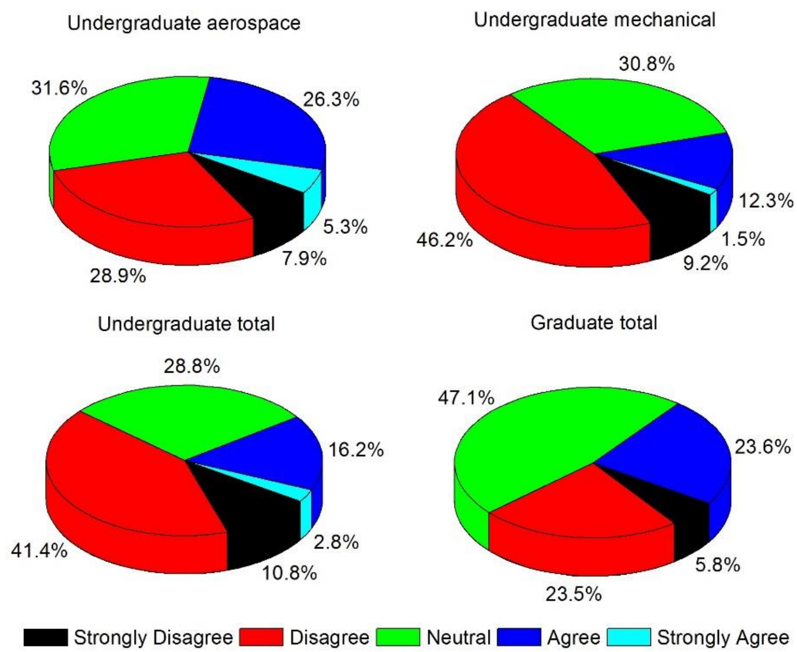

Figure 4: Aerospace undergraduate, mechanical undergraduate, total undergraduate and graduate student response to "I have a strong understanding of resilience and how it pertains to the engineering design process."

While the purpose of the survey was to gauge students understanding of sustainability and resilience in engineering design, another purpose was to assess the same students understanding of sustainability compared to resilience in engineering design. To do this, each survey result was checked to see if the student rated their understanding of resilience higher than their understanding of sustainability. For instance, if a student selected "neutral" as their level of understanding of resilience then the survey was checked to see if the same student rated sustainability the same ("neutral"), higher ("agree" or "strongly agree") or lower ("disagree" or "strongly disagree"). Table 1 shows the results of this assessment. While it is clear that students were twice as likely to rate their understanding of resilience as lower than their understanding of sustainability, the majority of students felt the same about both resilience and sustainability. This trend was evident for the undergraduates surveyed. This again may just be a reflection of the fact that the undergraduates are in the early stages of their programs. This conclusion has some merit as the graduate students rated resilience lower than their understanding of sustainability almost as much as they rated them the same. Regardless, graduate students and all undergraduate disciplines surveyed except aerospace engineering, rated their understanding of resilience as lower than their understanding of sustainability.

Table 1: Students rated their understanding of resilience at a higher, the same or lower level than the same students rating of their understanding of sustainability.

Engineering Discipline	Higher	Same	Lower
Aerospace undergraduate	8	27	3
Civil undergraduate	0	3	2
Environmental undergraduate	0	2	1
Mechanical undergraduate	7	39	19
Graduate	1	9	7
Total	16	80	32

Overall, the survey results indicate that engineering students feel like their understanding of both sustainability and resilience in engineering design is lacking. This is even more apparent for the emerging field of resilience engineering compared to sustainability engineering. At this stage, it is important to consider the future of where engineering curriculum will need to go in order to incorporate sustainability engineering and engineering resilience. The current structure of the design process and its implementation in engineering education among different design classes such as cornerstone and capstone courses has allowed the engineering design process to be taught effectively to students. In addition, some of the engineering science classes and electives have also been known to incorporate design into the curriculum. This typically occurs through final projects that require students to implement the particular theory in the course (heat transfer, vibrations, statics, fluid mechanics, etc.) into a final project that reinforces the theory in a practical environment. Some examples include bridge design during a course in statics, heat exchanger design during a course in heat transfer, or even building resonance (i.e. vibration) analysis after a course in vibrations.

This established structure for teaching engineering design has also been used for incorporating sustainability engineering into the engineering curriculum. Instead of developing new academic programs, many of the principles of sustainability engineering have been communicated and implemented in specific disciplines simply by focusing on the aspects of the design process that are crucial in sustainability engineering and by adding sustainability tools such as life cycle analysis to the design requirements. This exposure, although perhaps not as thorough as a separate, complete academic program could be, provides exposure for students to ideas that are becoming increasingly important in many industries. The survey results indicate that this practice needs to continue if students are to gain a strong understanding of how sustainability is incorporated into engineering design. With more and more businesses and industries moving, both voluntarily and by government regulation, towards incorporating sustainability into their design and practices, engineers need this exposure to sustainability even if it only comes through design courses.

While there is not currently a strong presence of engineering resilience in engineering curriculum it appears that a similar approach to teaching sustainability engineering can also be applied to teaching engineering resilience. Like sustainability engineering, engineering resilience has been applied in systems engineering by modifying or perhaps just refocusing the design process. As described in the methods section, sustainability engineering requires an understanding of the need for sustainability, interdisciplinary work and tools such as life cycle analysis that bring sustainability thinking into the design process. Similarly, the methods of employing engineering resilience have called for adaptations of the design process by modifying the early stages of the design process. Specifically, engineers need to have an understanding of the need for resilience today and they need to work carefully with clients to understand the potential for adaptation and unexpected risks. Instead of being a specific tool that can simply be applied, engineering resilience must become part of how engineers think and approach problems. Also like sustainability education, engineering resilience requires an assessment of the design years after it is built to see if the design is still appropriate given the changes that undoubtedly have occurred.

How can educators incorporate engineering resilience into curriculum? There does not appear to be one right answer. Just as sustainability engineering education has been incorporated into curriculum at Syracuse University, resilience may be able to do the same. Full programs may not be necessary, but individual classes or at least inclusion of the principles within a current class that discusses the engineering design process are a first step. One way that may provide a meaningful experience for students is to incorporate resilience into classes that have a final design project. One example is a class in statics with a final project that requires students to build a bridge that can support a specified weight. At the beginning of the project, instructors can provide the design requirements and explain the principles of engineering resilience in engineering design. After building the bridges, they can be tested under the design conditions. After testing, the teacher can then invite students to try their bridges under modified conditions. One relevant change is supporting the weight while having a high speed fan or blower blowing air on the bridges. Will some fail? It's a real possibility. Why will they fail? Scope creep is a common term used in systems engineering or project management when the scope of the project evolves. Following the failure, the instructor has an ideal setting to teach the importance of the unexpected and the need for engineers to develop resilient systems that allow adaptation. Perhaps some students saw this coming while others didn't. Either way students will have an opportunity to remember the broken bridge as well as the need to incorporate resilience thinking into their design process. This is a simple example of one way that engineering resilience can be accomplished while teaching the engineering design process. Many more details should be added about the specific instructions given to the student teams. However, the general idea of helping students apply resilience thinking to their design is the key and there are many frameworks for accomplishing this. If engineers are to meet this resilience challenge of our century, then it should start during their academic programs. Fortunately, the framework of applying sustainability in engineering curriculum appears to also be appropriate for applying engineering resilience concepts in engineering curriculum.

Conclusions

The engineering design process has become an intricate part of both the engineering profession and engineering curriculum as it has been woven into many classes from cornerstone to capstone design. A need for sustainability engineering emerged later as society gained a better understanding of the damaging effects that emissions and other actions can have on the environment and human health. While sustainability has become a common part of both curriculum and everyday vocabulary, survey results confirm that many undergraduate and graduate students still feel like their understanding of sustainability and its application in the design process are lacking. This trend is troubling given the regulations that are becoming common in many industries. Furthermore, global climate changes and other factors have resulted in a call for engineered resilience that allows complex systems to be more adaptive than ever before. This is not a small movement. It is significant enough to be considered a major challenge for engineers in the 21^{st} Century. It is a call that every engineer will be expected to answer in the future. Fortunately, the development of the engineering design process in engineering curriculum as well as sustainability engineering appear to be appropriate frameworks for introducing engineering resilience into engineering curricula. This can be done by teaching the principles of engineering resilience in engineering design courses or during final projects. Educators can use these design experiences as controlled environments for teaching students what happens when resilience is not considered during the design process.

Acknowledgement

This work was supported by the National Science Foundation under grant CBET-1403405 and by the New York State Energy Research and Development Authority (NYSERDA) under contract number 61736. NYSERDA has not reviewed the information contained herein, and the opinions expressed in this paper do not necessarily reflect those of NYSERDA or the State of New York. This material is also based upon work supported by the National Science Foundation Graduate Research Fellowship Program under Grant No. 1247399.

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