Introduction

The subcommittee took on the task of expanding the descriptions of the 5 sustainability competencies which have been developed by the Task Force so that faculty members could understand them, and see what the implications are for learning outcomes in courses. This can help them incorporate these outcomes into their courses.

It is important to note that the sustainability competencies were developed as part of the Faculty-wide effort to establish graduate attributes for students graduating from our Engineering programs. Therefore, it is assumed that the technical competencies are in place. Also it is intended that sustainability will be taught in the context of an Engineering education.

1. Triple Bottom Line

An ability to design and evaluate complex open-ended engineering systems using the triple bottom line of sustainability dimensions: social, economic and environmental. This broad inclusion of goals captures an expanded spectrum of values and criteria for measuring success and is an attempt at a method of encouraging full cost accounting in the problem evaluation process. The triple bottom line approach expands the traditional goal reporting framework to take into account ecological and social performance in addition to financial performance.

The goal of addressing the three dimensions of sustainability to engage the designer/evaluator/creator is to ensure that the design or system meets the needs of the present without compromising the ability of future generations to meet their own needs. The three dimensions of sustainability that need to be considered as an aspect of complex design analysis consist of the interconnectedness of numerous conflicting goals, including:

Social Sustainability
- The ability for a society to be productive and support a basic social system through the creation of products, services, income, communications, mobility etc.
- Standard of living influences on community values, options and choices.
- The minimization of inequality, which damages social systems.
- The disparate benefits and negative impacts of production and its infrastructure.
  Examples include accidents, health problems, congestion noise, ecosystem disruption, pollution, wars, crimes etc.

Environmental/Ecological Sustainability
- Rapid population growth, urbanization, and industrialization impacts on required resources and land must be maintainable.
- Ecological sustainability can be seriously disrupted or damaged when population densities are high due to:
- Air/land/water pollution,
- Greenhouse gas emissions and climate change,
- Disruption and damage in urban/suburban and rural areas on wildlife,
- Loss of biodiversity,
- Depletion of natural resources and ecosystem changes,
- Loss of wetlands, rain forests, clean water infrastructure-induced land use changes, partition of habitants etc.
- The recognition that the present use of environmental and mineral resources may limit quality of life for some others now and for future generations.

Economic/Financial Sustainability
- Any business, enterprise or activity needs be organized a manner that it is economically sustainable, for example, a business must be profitable, so that it can continue to operate and fulfill its other sustainability obligations.
- Industrialization and public/private infrastructure investments are essential to development and general economic well-being.
- Taxation and charges of various types are used (or miss-used) to finance governments’ and common needs.
- Mobility and advanced communication ability facilitates globalization and increased international trade of goods and services.
- Globalization and communication have compelled poorer countries towards rapid industrialization.
- Economic growth is strongly linked to impacts of energy growth.
- Humans have a right to basic services, water and food, but someone must pay.

The concept of the triple bottom line expands the responsibility from the shareholders to the stakeholders and requires the quantification of engineering impacts from the short term to long term and from local to global.

Triple Bottom Line Learning Outcomes

1. Demonstrate and understanding of the relationship between the technical, socio-economic, and environmental dimensions of sustainability.
2. Develop a sustainable engineering solution which incorporates a variety of social, economic, and environmental perspectives.
3. Identify and quantify short and long-term impacts of engineering on a scale ranging from the local to the global.
4. Design and evaluate engineering systems, including their impact and the risk associated with unsustainable practices.
5. Identify the essential characteristics of a problem from a sustainability perspective.
7. Critique and evaluate the impacts of technological advances on society and encourage solutions that foster and forge a culture of change.
2. Tools & Metrics

There are a number of methods of analysis (tools) and metrics for sustainability that are useful to apply to engineering activities. Therefore, engineering students should be conversant with these tools and metrics, and be able to apply them to evaluate engineering activities and designs. The metrics are also part of the language of sustainability, so it is important for students to know the basis of terms such as Ecological Footprint and Global Warming Potential.

Methods of analysis have been developed for sustainability. Ecological Footprint and Life Cycle Analysis are two widely used examples. The Ecological Footprint is a calculation of the area on the planet’s surface required for a specified human activity, for example, one person (all food, manufactured goods, housing, transportation and activities). This can be summed over a country or the entire planet to compare with the earth’s productive area. Sub-categories in the calculation for the area for carbon dioxide mitigation relate to engineering activities for housing and manufacturing. Life Cycle Analysis is a tool to evaluate the inputs and outputs to nature from a human activity, such as driving an automobile 100,000 km. Therefore, it is useful tool to evaluate options in the manufacturing and use of automobiles.

There are many other tools and rating systems, such as Leadership in Energy and Environmental Design (LEED) for building design, which are discipline specific.

Tools & Metrics Learning Outcomes

In pedagogical terms, at the most basic level students should be able to define the terms and metrics, and understand the fundamental basis for them. At the next level, they should be able to apply them to investigate or compare various existing designs. At the highest level, they should be able to use these tools and metrics in an engineering design to meet a desired level of sustainability.

3. Stakeholders

Engineering students should have an ability to interact and collaborate with stakeholders having a broad range of cultural and social backgrounds to consider the needs of present and future generations in developing creative solutions to an engineering problem. In this definition the "stakeholders" refers to anyone who is influenced, either directly or indirectly, by the actions or function of the design or system. The goal of understanding the needs of the stakeholder in the design/evaluation/creation of designs and systems is to ensure that stakeholders with a broad range of cultural, social and political backgrounds are considered during the process of assessment and evaluation and that the product is sensitive to the needs of present and future generations. The key aspect of the definition is the recognition that both inter-generational and intra-generational principles must be considered in the design process:

Intra-generational Principles (stakeholders in space)
The goal is to reduce gross inequities between the poorest and wealthiest both nationally and globally and ensure that the basic needs of the poorest with food, shelter, health care, clean water, access to electricity, education, and opportunity for work are met. Citizens and workers in poorer countries should be considered stakeholders to avoid exploitation of poorer country/region resources and labour. The goal is also to provide ways to protect the common good (social, environmental, economic) locally and globally through national and international
governance/cooperation, so as to maintain stable institutions that protect human rights, adjudicate conflicts, and allow responsible trade and market economy activities.

Inter-generational Principles (stakeholders in-time)
Every generation has obligation to protect interests of future generations and should not pursue actions that pose a realistic threat of irreversible harm or catastrophic consequences unless there is some compelling or countervailing need to benefit either current or future generations.

The types of stakeholders include:
- People directly affected by the endeavour or who influence the work.
- The private sector or groups of individual who can affect or who is affected by design or system including customers, owners, employees, associates, partners, contractors, and suppliers, people that are related or located nearby.
- Parties interested in a project/design or service success in delivering intended results and in maintaining the viability product and/or service.
- Any organization, governmental entity, or individual that has a stake in or may be impacted by a given approach to environmental regulation, pollution prevention, energy conservation, etc.
- A participant in a community representing a particular segment of society such as environmental organizations, labour unions, industry trade groups, educational members, elected officials, neighbourhood advisory council members, analysts and media, and religious leaders etc.
- Future generations.

The stakeholders are the individuals and constituencies that contribute to or are affected by the design/evaluation/creation and are therefore it’s potential beneficiaries and/or risk bearers.

Stakeholder Learning Outcomes
1. Demonstrate an ability to effectively communicate with stakeholders with a broad range of cultural and social backgrounds, and political perspectives.
2. Assess and research the needs of stakeholders and future generations.
3. Demonstrate sensitivity to the needs of stakeholders and future generations.
4. Devise creative solutions to overcome opposing needs.
5. Show an ability to collaborate with designers and experts of all disciplines.

4. Sustainability Ethics and Responsibilities

Engineers have three duties: 1) to their clients, 2) to their profession and 3) to society. Sustainable ethics means that engineers put on an emphasis on the third duty and interpret it broadly. That is, sustainable ethics means that engineers will consider the present and future impact of their decisions on people and the environment. Engineers need to recognize and value diversity, intra and inter-generational equity and natural ecosystems. Considering the broader impact of engineering decisions is challenging because of uncertainty and the complexity of environmental, social, economic and technological systems. The best decision is rarely obvious, with engineers being forced to balance the competing concerns and make judgments based on imperfect knowledge.
Sustainability Ethics and Responsibilities Learning Outcomes

The learning outcomes for sustainability ethics and responsibility include:

1. The ability to describe the concept of ethics and the system of moral principles that apply in the practice of sustainable engineering.
2. Evaluate critically the ethical decisions of others.
3. Identify the ethical issues that are relevant for a particular case study.
4. Select and justify an engineering design decision for a case study that incorporates complexity (environmental, social, economic and technological). The justification would reference ethical principles, the Engineering code of ethics and recognize the need to deal with complexity and uncertainty.
5. The ability to recognize ethical issues associated with intra-generational and inter-generational equity, diversity, and the environment in their own design projects.
6. The ability to distinguish between facts and values and select between them appropriately in design decisions.
7. The ability to inspire respect for diversity, the environment, and past, present and future generations in all engineering decisions.
8. The ability to recognize and value the importance of meeting sustainability challenges.

5. Complexity

We live in a very complex world, and it is important for engineers to recognize that their activities have an impact on society or the environment that is often hard to evaluate. Many different systems are very complex. Environmental systems are very complex and hard to model; the collapse of fisheries is a good example of poor understanding and policy by humans. Economic systems are also very complex; the recent recession is a good example of the interconnectedness of economic systems and the poor control that is available. Technological systems are very complex; no one person knows the details of all systems on a modern airplane, and crashes are sometimes the result of several simultaneous failures that were unforeseen. The complexity has been increasing over time, and humans have responded with more complex solutions, but a gap is developing between the requirements and the solutions, the so-called Ingenuity Gap.

Therefore, it is important for understand that their activities and designs will be operating in very complex systems. There are many implications that should be considered, both locally and globally, and environmentally and socially. The complexity means that there is often an unknown amount of uncertainty regarding quantification of the impact of engineering activities.

Complexity Learning Outcomes

From a pedagogical perspective, at the most basic level engineering students must understand the complexities described above that limit our ability to model and control. At a higher level the students should be able to examine engineering activities, and analyze the potential impact on the Triple Bottom Line in complex situations. At the highest level, students should be able to discuss the potential impact that their design may have both locally and globally.