A Perspective on Engineering and its Relationship to Systems Analysis and Science

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Engineering is a multifaceted endeavor to which students typically have little exposure in high school. In light of this, and anticipating that Engs 22 will be one of the first engineering courses students will take at Dartmouth, I offer below some thoughts on what engineering is and how engineering differs from science. In addition to providing a general overview, my second objective is to introduce this course by presenting the view that systems analysis is a central and characteristic feature of engineering.

What is Engineering? Civil and mechanical engineering, with physics as the fundamental foundation, were the first activities to be recognized as engineering. Engineering today includes electrical, chemical, materials, biological, environmental, and computer engineering. Thus engineering can and does draw from the full breadth of scientific activity. Indeed, many of the areas of engineering expected to have the largest impact over the coming decades – e.g. biological, environmental, and computer engineering – have as their scientific foundation disciplines that were not defined in their modern form 30 years ago.

Although different people have used different words in contemporary definitions of engineering and its practitioners, most definitions are reasonably consistent. Thus we have for example Holtzapple and Reece’ definition of an engineer as someone who:

“…combines knowledge of science, mathematics, and economics to solve technical problems that confront society.”

and Prausnitz’’ definition:

“Engineering is the application of science for human benefit.”

Commenting on the definition of engineering, Prausnitz has said: “If engineering is the application of science for human benefit than the engineer must be a student not only of the application of science, but of human benefit as well.” The individual engineer, and engineering-based organizations and institutions, have an opportunity to be of service to society when their energies and talents are applied in a manner consistent with a coherent and morally defensible framework for evaluating benefit. Economics is a sufficient evaluative framework for benefits that are readily monetized, such as a lower-cost manufacturing process or product. In cases where benefits are difficult to monetize – such as health, sustainability and environmental quality, equity, security, and well-being – other evaluative frameworks need to be considered. Most of the difficult technology-related dilemmas facing society involve a combination of monetized and non-monetized benefits and costs.

Speaking personally, I believe that the engineering profession represents a viable path to a life of service and positive world impact. Walking this path involves devoting energy to carrying out and acting upon evaluation of technology in relation to human benefit.
Analysis is central to the application of science as practiced by engineers. We use analysis to ask questions such as “How should a system be configured in order to achieve some specified objective?”, or alternatively “How will a system respond given some specified set of inputs?” Most engineering analysis begins with a disaggregated representation of a system of interest and results in an aggregated representation. In some cases, the disaggregated representation is obtained by application of a physical principle (e.g. conservation of energy or matter) to an infinitesimally small (differential) element within the system. Examples from among many include analysis of the stress on an airplane wing, image analysis for breast cancer detection, the effect of fossil fuel utilization on global climate, and the effect of solar storms on satellite communications. In other cases, the disaggregated representation is a set of descriptions of the behavior of system components. Examples, again from among many, include any electronic device, a machine or robot, a cell, the human body, communication networks, and the environment. Mathematics is used to convert the dissaggregated representation, whether based on a differential element or a set of component descriptions, into an aggregated representation of the macroscopic and/or multi-component system. This process of modeling a system, and extracting useful descriptions of its behavior from the model is called systems analysis, and is the topic of this course. Because different types of systems can often be analyzed using the same mathematical tools (and often are represented by mathematically identical equations!), it can make sense to study systems as a discipline independent of any particular physical systems. However, in this class we will base our study of the techniques of systems analysis on physical systems, and learn the techniques in the context of their applications.

The Relationship Between Engineering and Science. There is no clear boundary between engineering and science. Hence differentiating engineering from science is a matter of identifying central tendencies rather than of drawing absolute distinctions. Notwithstanding this reality, the central tendencies of science and engineering differ with respect to defining objectives, the expectations of society, and dominant intellectual directionality (discussed below). Understanding these differences is important in order to comprehend how engineering and science, and also engineers and scientists, function in our increasingly technological world. In addition, understanding these differences is important for the technically-oriented college student who is choosing a major and taking the first steps toward defining a career.

The etymology of “engineering” and “engineer” derives from “engine” and “ingenious” both of which come from the Latin root in generare, which means “to create”. By contrast, “science” and “scientist” derives from the Latin scire which means “to know”. Thus engineering and science are defined by different objectives. Consistent with this, society has different expectations of engineers and scientists. The creations resulting from engineering endeavor are judged primarily by whether they are useful and beneficial. The knowledge resulting from scientific endeavor is judged primarily by whether it is correct and consistent with prior knowledge. As discussed in the previous section, the central tendency of engineering is to proceed from the disaggregated to the aggregated (see above). Thus the dominant intellectual directionality of engineering is inherently integrative. By contrast, the central tendency of science is to proceed from the aggregated to the disaggregated. Consider that the primary focus of physics has changed over time from macroscopic phenomena such as mechanics and optics to atomic, sub-atomic, and sub-sub-atomic. The primary focus of biology has changed from multi-
cellular organisms to cellular, sub-cellular, and molecular phenomena. Similarly, most of the frontiers of chemistry today involve phenomena at the molecular and atomic scales. Consistent with the different dominant intellectual directionalities of engineering and science postulated here, engineering education typically involves a greater emphasis on tools of systems analysis as compared to education in the sciences.

I summary, it seems to me that key features of engineering that distinguish it from science are:

1. Practical problem-solving as a defining objective.
2. Systems analysis as a primary intellectual directionality.

The first of these requires application of evaluative frameworks for technology and may include a significant service element. The second, the focus of this course, involves using mathematics to progress from a disaggregated description and understanding of a system to an aggregated description and understanding. Figure 1 is a diagrammatic representation of the line of thought developed here.

**Figure 1. A Perspective on Engineering Endeavor and its Relationship to Systems Analysis and Science**

![Diagram of Engineering Endeavor](image)

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**References.**