# AC 2007-1262: USING INSIGHTS FROM NON-ENGINEERS TO IMPROVE INTRODUCTION TO ENGINEERING VIA FUNCTIONAL ANALYSIS

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# Using Insights from Non-engineers to Improve Introduction to Engineering via Functional Analysis


## Abstract

This work describes an effort to identify and utilize insights from non-engineering students in technological literacy courses to identify themes that may enliven introduction to engineering courses. Beginning engineering students may have interests more closely aligned with their non-engineer peers than current engineering professionals. Technological literacy courses on a number of campuses have established that explaining technology from a "how things work," perspective captivates the interest of a broad range of students. This "how things work" approach is characterized by a focus on technology familiar to the students in their everyday life, use of visual and graphical explanations such as concept maps, and inclusion of information that helps to establish a sense of empowerment upon understanding the technology. Incorporating this "how things work" approach into introduction to engineering will help achieve engineers that exhibit "practical ingenuity," and an ability to communicate technical issues to non-engineers, two critical attributes of the Engineer of 2020 as identified by the National Academy of Engineering. This work suggests that the visual and concept map approach is analogous to the engineering design technique of functional analysis or functional decomposition. Functional analysis provides a mechanism to discuss how things work with engineering students that is rooted in established engineering design methodology. Additionally, important devices or components in familiar technology can be treated as sub-functions in the functional analysis context. As these sub-functions consistently reappear throughout products or processes developed by the various engineering disciplines, authentic engineering knowledge can be introduced to introductory engineering students. Initial implementation of this approach in an Introduction to Engineering course at Hope College is outlined.


## Introduction

Engineering departments have long sustained a one-way relationship with their campus communities. Engineering students, as part of their broad education, take classes offered by various departments across campus. However, it had been uncommon for anyone but a fully committed engineering major to appear in engineering classes. Few engineering departments offered service courses for non-engineers.

Notable exceptions existed to this rule, and recent developments have fostered a more reciprocal relationship between some engineering programs and liberal arts departments. In 1996 the National Science Foundation's *Shaping The Future: New Expectations for Undergraduate Education in Science, Mathematics, Engineering, and Technology* called for greater attention for the 80 percent of college students who are not planning on careers in science, engineering, mathematics, or technology[1]. In 2002, the National

Academy of Engineering (NAE) published *Technically Speaking*[2], advocating that all Americans need to know more about technology. The goals of *Technically Speaking* challenge engineering educators to engage a broader spectrum of students. In 2005, The American Society for Engineering Education established the Technological Literacy Constituent Committee to advance these goals.

At the same time, in *Engineer 2020,* the NAE called upon the engineering education community to develop engineers that exhibit "practical ingenuity," and an ability to communicate technical issues to the non-engineering public.[3]

Since the call to action initiated in *New Expectations*, a representative of the engineering courses for non-engineers include Project-Based Introduction to Engineering at the University of New Haven[4], Technology 21 at the University of Denver,[5] Materials: The Foundations of Society and Technology at Washington State University,[6] and How Things Work at North Carolina State University.[7] More complete summaries of recently developed courses for non-engineers can be found in Byars,[8] and Krupczak and Ollis.[9]

## Science and Technology of Everyday Life at Hope College.

The work reported here is based on the results of teaching the "Science and Technology of Everyday Life," at Hope College. This course is intended for students from non-technical majors and includes students from business, history, fine arts, and pre-service education students. First offered in the Spring 1995 semester,[10,11] the objective of the course is to develop a familiarity with both the engineering aspects of how various technological devices work, and an understanding of the basic scientific principles underlying their operation. The course focuses on the wide variety of technology used in everyday life. More than 1000 students have taken the course. The percentage of women enrolled has been consistently near 60%. The largest single constituency for the class is pre-service teachers. The percentage of pre-service teachers in the class has averaged 26%.

## Course Themes found Attractive to Non-Engineering Students.

In offering courses with a primary audience of non-engineering students, instructors have identified several themes that resonate with this group.[12-15] These are summarized in Table 1. In learning engineering topics, non-engineers place a high value on knowledge relevant to familiar technological devices, seek practical applications and skills, and aspire to a sense of empowerment in their relationship with technology. While non-engineers are willing to pursue and even welcome developing in-depth understanding of technological principles, mathematical arguments alone are not sufficiently compelling in this regard.

Engineering educators might consider these preferences and priorities of non-engineering students as valuable data. Insights from non-engineers can help to identify the most compelling aspects of the field. The interests of first year engineering students may have more in common with their non-engineer peers than experienced working engineers.

**Table 1:** Important Elements of Technological Literacy Courses for Non-Engineers.

| |
|---|
| Relevance to familiar technological devices. |
| Practical applications and skills. |
| Appreciation for hands-on experiences with technology. |
| Avoiding dependence upon mathematics for explanations. |
| Developing a sense of empowerment in relationship with technology. |

**Impact of non-STEM majors preferences on presentation of material.**

One consequence of addressing the inclinations of non-STEM students in a "how things work" course is the use of visual explanations and schematic block diagrams or concept maps for conveying information.

In a schematic diagram or concept map, technological components, devices, or systems can be described in a visual format by considering the major operational elements. Brief descriptions are developed explaining what function each block provides. Interconnections then convey a systems level view of the device or component.

An example of the use of block diagrams or concept maps in the Science and Technology of Everyday Life course at Hope College is the description of the Fuel/Air and Exhaust/Emission Control systems for an automobile engine. This is shown in Figure 2.

The use of block diagrams or concept maps with non-engineering students helps to develop the organization of knowledge that characterizes experts compared to novices.[16] They help to provide the understanding needed for problem solving and facilitate troubleshooting exercises. These abilities bestow the type of empowerment with regard to technology sought by the non-engineers.

**Connection to Engineering Education**

Utilizing block diagrams to explain how things work to non-engineers is a simplified type of functional analysis used in engineering design. In functional analysis or functional decomposition a product is represented as a functional system.[17-19] The "black box" function transforms input into the outputs. Figure 2 illustrates the basic functional analysis representation.

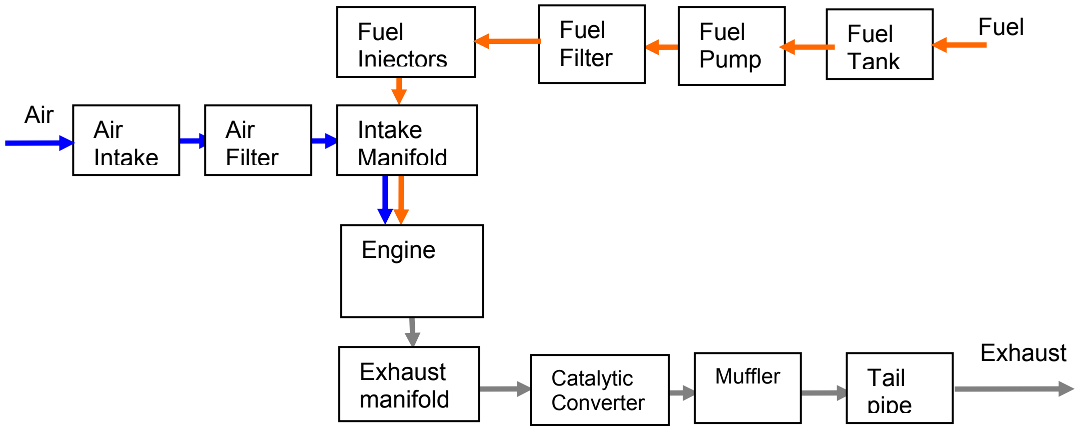


**Figure 1:** Schematic Diagram Concept Map of Engine Fuel/Air and Exhaust Systems.

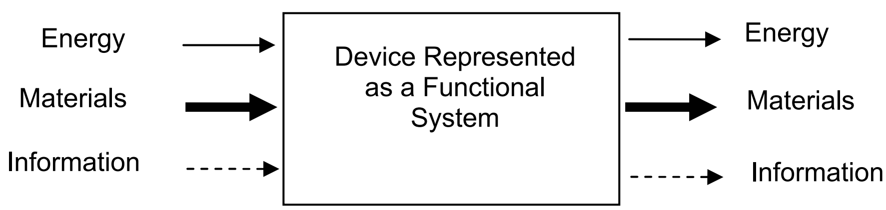


**Figure 2**: Basic Functional Analysis Representation.

The overall representation of a device must be divided into recognizable subtasks often termed subfunctions. Subfunctions are expressed using verb-noun pairs. Verbs must be active verbs. Examples might be actuate-electricity or transmit-torque. Often some physical entity is associated with each subfunction. An illustration of a hypothetical device subfunction structure is shown in Figure 3.

Otto and Wood[17] report the results of a functional decomposition of 60 consumer products. They propose a vocabulary of standardized verb-noun pairs to describe common subfunctions. For example, the electric motor, one of the most common devices in appliances, is given the subfunction: “electricity to torque.”

Functional analysis provides a framework for a “how things work approach” rooted in a major technique of engineering design methodology. This produces several benefits for engineering education. Introduction to engineering courses often emphasize the design process as a defining characteristic of engineering. While this is accurate, most engineering designs must be produced from physical objects. A frequent complaint of engineering instructors is a lack of awareness on the part of the students of the actual physical components from which designs might be realized and the procedures and techniques for their utilization. Functional analysis emphasizes the role of subfunctions which may be manipulated, modified and adapted to a particular design problem. Important devices such as the electric motor can be introduced to novice engineers in an engineering context as common subfunctions. Additionally, innovation in product design is frequently achieved through improving existing or creating new subfunctions. Innovation can be merged naturally with engineering education using the structure and vocabulary provided by functional analysis.

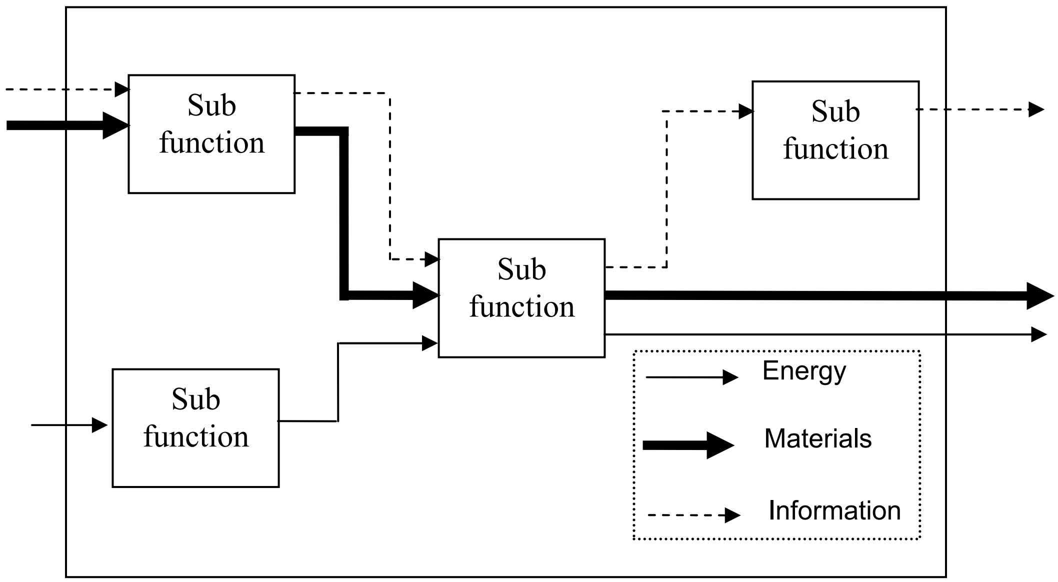


**Figure 3:** Illustration of a hypothetical device subfunction structure.

## Integration into an Introduction to Engineering Course

An Introduction to Engineering course is taught at Hope College as part of an ABET accredited BS Engineering degree. Most of those enrolled are first year students who are strongly considering pursing an engineering major. The introduction to engineering course is a prerequisite course for solid mechanics and electronics which all engineering students take in the second year. Since most Hope College engineering majors do not take general physics in the first year, the introduction to engineering course must teach critical prerequisite information students need before enrolling in solid mechanics and electronics. The course has two lectures and one 3 hour laboratory per week for 14 weeks. Details of this course have been described by Krupczak et al. [20]. Table 2. contains a listing of the major course topics in introduction to engineering at Hope College.

Mechanics

In the mechanics section of the course students learn the concepts of vectors, forces, free-body diagram, static equilibrium, stress, strain, Hooke's Law and stress-strain diagrams. Laboratory activities include tensile testing of various metal and non-metal materials to determine Young's Modulus along with yield and ultimate strength.

Mechanical Design Sub-function: I-beam
The I-beam is introduced as an important sub-function or design element used in mechanical design. The beam provides the function of supporting a load. While the students do not yet have the background to derive the behavior of I-beam under various loading conditions, the characteristic shape of an I-beam can be readily grasped in a visual way.

**Table 2:** Schedule of Topics in Introduction to Engineering at Hope College.

| Topic | Weeks |
|---|---|
| Fields of Engineering | 1 |
| Units and Dimensions, Engineering Estimates | 1 |
| Mechanics | 3 |
| Electrical Circuits and Electronics | 3 |
| Thermodynamics | 2 |
| Fluid Mechanics | 1 |
| Engineering Design | 3 |
| **Total** | **14** |

The I-beam shape can be understood using concepts that the introduction to engineering students have just learned. Consider a simply supported beam of rectangular cross-section under load. Maximum stress and strain will occur on the upper and lower surfaces of the beam. To strengthen the beam and reduce the deflection more material should be located where stresses are greatest, that is near the top and bottom surfaces. More material reduces the stress in these locations and, by Hooke's law, reduces the strain. A number of authors use this heuristic approach, a typical example is Holtzapple and Reece.[21]

Students have now acquired an intuitive and visual understanding of the I-beam as an important mechanical design element. There is little possibility that this explanation can be misunderstood. A foundation of accurate prior knowledge has been established for later study at a more advanced level. They can also now do basic I-beam design problems using algebraic equations.

Understanding and using the I-beam mechanical design sub-function provides the sense of empowerment and connection to the "real world" that engineering majors are seeking from their education. The I-beam is a familiar, easily recognized mechanical design element that appears widely in the human-built environment. Design problems in which students must grapple with actual product information about standard sized I-beams provides, both a sense that they are learning skills that are useful and a familiarity with the important engineering design concept of utilizing standardized design elements.

Electrical Circuits and Electronics

In the electrical circuits section of the course students learn basic concepts of charge, current, voltage, resistance, and power. Ohm's law and Kirchhoff's current and voltage laws are applied to analyze DC circuits and verified through laboratory exercises. This introduction provides a necessary foundation to continue to a more advanced electrical circuits class in the second year of the program. However, for most first year students, analysis of DC resistive circuits is not particularly motivational or inspiring.

Electrical Design Subfunction: Operational Amplifier

The operational amplifier is introduced as an important electronic design element. The technological importance of the sub-function provided by this device: amplify signal, is readily apparent to the first year engineering student.

The behavior of the operational amplifier is explained by first discussing the operation of a bipolar transistor as a current amplifier and a more primitive sub-function of the op amp. The simplified internal schematic of a 741 op amp is explained using functional decomposition. Students are not expected to learn how the details of the internal circuit schematic however, prior knowledge is established for later course work. What is expected of the students is to learn the key features of operational amplifiers: maintaining a virtual short circuit between the inverting and non-inverting inputs, and nearly infinite input impedance. With these intuitive concepts firmly grasped, then the gain for basic inverting and non-inverting configurations can be calculated using Ohm's Law and Kirchhoff's laws.

The students in introduction to engineering now do basic amplifier design problems using only algebraic equations. In laboratory, students amplify the output from the headphone connection on an iPod to levels audible through a small loudspeaker. This provides a critical sense of empowerment.

While DC circuit analysis is essential, becoming familiar with using an integrated circuit device such as a 741 op amp begins to develop practical capabilities and skills utilized by design engineers. The use of special purpose integrated circuits of all types follows similar patterns. The students learn to shift through manufacturer's datasheets to find information relevant to their particular design situation. Prototype circuit assembly, troubleshooting, and testing is similar for all such circuits. Additionally the distinct integrated circuit appearance of the op amp promotes a sense of connection to the "real world" of modern electrical devices.

## Summary and Conclusions

Non-engineers are receptive and even enthusiastic about learning about technology when the subject is approached from a "how things work" perspective. Characteristics of this approach include attention to familiar everyday technology, an emphasis on practical information and skills, and use of visual explanations and concept maps rather than mathematics to convey key principles. Beginning engineering students share the same aspirations as their non-engineering counterparts in seeking a sense of empowerment from their study of technology. The "how things work" approach can be transcribed in an authentic manner by focusing on the technique of functional analysis, a foundational pillar of classic engineering design methodology. Functional analysis provides both the concept map structure for explaining "how things work," and helps to highlight key sub-functions that are characteristics of particular domains of engineering design. This approach has been implemented in an Introduction to Engineering course at Hope College. Sub-functions studied include the I-beam in mechanics, and the operational amplifier in electronics. This functional analysis approach has several advantages including introducing engineering concepts to first year students in a genuine manner, establishing appropriate prior knowledge for future courses, familiarizing students with the use of existing sub-functions in design and creating a sense of practical empowerment in novice or even tentative engineers.

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