Beyond The Fundamentals: Why the Undergraduate Mechanical Engineering Curriculum Needs Reform

by

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S.B. in Mechanical Engineering
Massachusetts Institute of Technology

Submitted to the Department of Mechanical Engineering
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Abstract

The addition of a systems engineering concentration through the MIT Mechanical Engineering Alternative (course 2A) curriculum will be shown to have the potential to increase the number of engineering degrees in comparison to non-engineering degrees, to better prepare MIT engineering graduates, and to increase the percentage of graduates that pursue careers in engineering rather than finance and consulting. Original data was collected from Careerbridge and used along with existing information available through the registrar and careers office to provide a quantitative breakdown of the trends in Mechanical Engineering department enrollment, degrees awarded, and skills demanded of graduating alumni. These results are used to suggest that the number of MIT Mechanical Engineering graduates can increase by recognizing the existence of a type of engineer defined as the Systems Engineer. Systems Engineers are currently switching out of engineering into business, finance and consulting, and this can be corrected through a concentration in 2A similar to an existing program called the Gordon Engineering Leadership Program.

Thesis Supervisor: Warren Seering
Title: Weber-Shaugness Professor of Mechanical Engineering

Acknowledgements

Thank you to my parents for always telling me that I could do anything I set my mind too. Now, setting my mind to something has been a difficulty in my life, but one that I have recently come to tackle thanks to my education at MIT. I have truly found paradise, and just when I was beginning to enjoy it, it is time to leave.

I would also like to thank the teachers that I have had along the way. I would like to thank Warren Seering, for his support through the creation of this thesis, John Lienhard, my advisor who I wish I would have talked with more, Joel Schindall and Ed Crawley, founders of the MIT Gordon Engineering Leadership Program, Sanjay Sarma because he is “the man”, Mr. Bradley for his belief in me, and most importantly Mrs. Mazzeon for starting me on my educational journey over 15 years ago.

Without the help and guidance of the administrators at MIT I would have failed long ago and so I say thank you to Dean Henderson, Lori Hyke, Chevalley Duhart, the Gordon Program Staff, and the un-named others.

I would also like to thank Laura Wilkinson, for her help in gathering data from Careerbridge, the alumni of Phi Delta Theta for their quick responses to my survey, and the alumni office for their online alumni directory.

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would see this as a business venture, I see this as my brother and I using the same problem solving skills we had used in math and building roller-coasters in a different system; a system that paid well. We weren't just selling lemonade that we bought at the store, and we weren't put up to it by our parents. In fact, a couple times they questioned what we were up to, because they were a little worried about us climbing through ditches, playing with chemicals, and sitting next to the cart path between holes. We were collecting balls, cleaning them, and then returning them to their owners at a fee. One technical detail in this system was the ball cleaning process. To return to the purpose of this thesis, we were engineers at heart, but we had a propensity to think on a different wavelength that involved bringing the many elements of the business together. This thesis aims to show that while children grow up and want to become engineers, being an engineer can include being a specialized engineer focusing on fundamental engineering concepts such as chemicals, one who may refine the golf ball cleaning process, but there are also engineers who think in systems, and want to bring the chemical engineer and the supply base engineer (distribution) together.

As I reflect on my engineering education I feel lucky to have made it through the technical 'weeds' because I don't think it was by design, but by chance. It seemed natural that I would be an engineer since I loved math, building things, and creating roller-coasters out of tiny plastic pieces, but it also seemed natural that I would become a businessman or a salesman. As this thesis will show, many engineers, in fact half, are geared as I am, and are not trained for the professions they wish to pursue as Systems Engineers.

1.2 Background Literature

Engineering is an important profession, one that is becoming more and more important in the modern economy. While more engineers are needed, the supply and quality of engineers is not keeping up with the demand. Neha Batra (Batra 2010) summarizes the importance of engineers in our modern day economy well in the introduction to her thesis, "A Look to the Future: MIT Alumni and their Course 2 and 2-A Educational Experience". She also addresses the need for engineering education reform, which is also a goal of this thesis.

> In the NAE report, Engineering of 2020, the authors argue for the revamp of U.S. engineering education to support U.S. international competitiveness. In the year 2006, 129,000 engineering students graduated in the USA with bachelors degrees(NAE and Gereffi). In the same year, 220,000 students graduated with BS-equivalent degrees in engineering from India and 575,000 from China (Gereffi). The NAE report, Engineer of 2020, also argues that U.S. engineers will require unique abilities to set them apart from graduates in other nations. This includes understanding the principles of leadership, applying skills to careers as they advance, possessing a framework for high ethical standards, and maintaining a strong sense of professionalism.

In a recent National Academy of Engineering (NAE) report, NAE (and former MIT) President Charles VEST (2008) noted that, "globalization is changing the way in which engineering work is organized and in which companies acquire innovation." These changes may require "a nimble new kind of engineer." The professional environment of engineering practice today is one in which engineers need strong professional abilities, such as writing and teamwork, as well as the ability to address complex problems with no clear disciplinary boundaries. Worldwide, colleges and universities that offer engineering degrees have adopted different strategies to address the changes in engineering practice. Some have chosen to enforce a firm technical foundation to give students a strong basis with which they can explore future fields of interest. Other schools have chosen to enable a curriculum of flexibility to allow students to delve into a specific topic especially for students who have selected their career path.

Now that the motivation for this thesis and background literature on the importance of engineers in the modern economy has been discussed, the purpose of this thesis will be explained and put into context.

1.3 Purpose

The purpose of this thesis is as follows: 1) To demonstrate the existence of two personalities within engineering, the Specialized Engineer, and the Systems Engineer, 2) To show that Alumni 10 years after graduation settle into a steady state careers, half of which are Specialized Engineers and half Systems Engineers 3) To create data representing the demand that new hires out of college have Systems Engineering skills equal to that of their Specialized Skills, contrary to current academic beliefs, 4) To show that those who may have been Systems Engineers do not find an academic track appealing to them within the current engineering curriculum, and leave engineering temporarily for several years in careers such as finance and consulting, and 5) To propose the Gordon Engineering Leadership Program as a new path for the Systems Engineers since no clear path currently exists, thus increasing the number of students in Engineering.

2.0 Two Engineering Mindsets: The Fundamental Engineer and the Systems Engineer

This chapter aims to identify the two mindsets of Engineers; the Fundamental Engineers, and the Systems Engineers. Identifying these two mindsets is necessary first because it aims to correct the misunderstanding that the former mindset, that of the Fundamental Engineer, is the only engineering mindset that exists.

2.1 The Misunderstanding that Only One Type of Engineer Exists

There is the common misconception that engineers are of one mindset only, the Fundamental Engineer. Fundamental Engineers are defined as the stereotypical engineers who are good at math, have strong analytical skills, problem solving skills, and a strong grasp of the core fields such as Mechanics and Materials. All engineers are often stereotyped as Fundamental Engineers, even though half of the Mechanical Engineering Alumni surveyed in Kristen Wolfe's thesis are Systems Engineers, often labeled as Project Management, or other positions within teams. The Fundamental Engineering mindset is also evident in the MIT Mechanical Engineering curriculum.

Upon reviewing the Mechanical Engineering Curriculum (Course Catalog 2010) you will find a required class list of:

- Mechanics and Materials I and II
- Dynamics and Control I and II
- Thermal-Fluids Engineering I and II
- Design and Manufacturing I and II
- Product Engineering Processes
- Numerical Computation for Mechanical Engineers
- Mechanical Engineering Tools
- Measurement and Instrumentation
- Project Laboratory
- Differential Equations
- Undergraduate Thesis
- 2 Electives (Almost Entirely Technical, except for 2.96)

Almost every class in this list caters to teaching the Technical Mindset through deep theory and fundamental study of mechanical engineering phenomena. Exceptions to this include the 2.009 "Product Engineering Processes" class, the "Project Laboratory" class, and the elective 2.96, "Management in Engineering".

While the Fundamental Engineering mindset is important, it is not the only mindset that exists. It will be shown throughout this thesis that the Systems Engineering mindset not only exists, but one that is demanded in the engineering industry of both veteran engineers and new-hires.

Now that the claim that two mindset exists, it is next necessary to characterize the definitions or skills of each mindset, and this will be done in the following section.

2.2 Kristen Wolfe's Thesis and Definitions of Engineering Skills and Characteristics

Characterizing the definitions of the different engineering skills and characteristics of engineers has been done through the work of Kristen Wolfe in her Thesis, "Understanding the Careers of the Alumni of the MIT Mechanical Engineering Department" (Wolfe 2004). Her work will be referenced throughout this thesis.

To summarize Kristen's work as useful to this thesis, her research provides an understanding of what knowledge and skills Alumni 8 to 12 years after graduation find valuable. Her work surveyed over 300 Alumni through the use of an online survey that is included in the appendix. From her conclusion she says, "MIT does a good job of providing the students with a broad range of technical knowledge and reasoning. This is also evidenced on the source table with around 80% citing MIT as the primary source of their knowledge in these areas." From this it is shown that MIT targets the Fundamental Engineers and does a good job arming the students with a wide variety of technical knowledge. From her graphs, the technical knowledge is similar in diction to the required courses in the Mechanical Engineering Curriculum, and the complementary "Systems Engineering" knowledge is referenced from the CDIO (Create Design Implement Operate) syllabus.

2.3 Fundamental Engineers and the Standard Curriculum

At the beginning of this chapter the Fundamental Engineering mindset was explained as the generally understood engineer stereotype. Also, the engineering curriculum was shown to academically support this mindset through fundamental classes based mostly in theory. It is understood that many engineers are Fundamental Engineers and thrive in this curriculum, but the Systems Engineers do not. It will be shown later in Chapter 5 that the standard curriculum, built for Fundamental Engineers, is alienating the System Engineers, and that the current curriculum needs another possible path for these types of engineers.

2.4 Systems Engineers and Definitions

While Fundamental Engineers are clearly understood, the values and needs of the Systems Engineers are not. From Kristen's works, there are terms that characterize these values.

A new program at MIT called the Gordon Engineering Leadership Program established in 2007 is a continuation of Professor Crawley's work that teaches Systems Engineers the values that they need to succeed. An in depth description and analysis of the Gordon Engineering Leadership Program is continued in Chapter 6. For now, a brief overview of the terms from both Kristen's thesis and the Gordon program are as follows.

From Kristen's work, the values are defined as follows:

- Teamwork
- Communications
- Independent thinking
- Professional skills and attributes
- Personal skills and attitudes
- System Thinking
- Experimentation and Knowledge
- Engineering Reasoning
- Designing
- Developing
- Marketing

From the Gordon Program, the "Affective Capabilities" of an engineering leader are reduced to:

- Attitude
- Initiative
- Decision making
- Urgency to Deliver
- Resourcefulness
- Ethical Action
- Loyalty
- Trust
- Diversity
- Vision
- Intention
- Self-Awareness
- Relating
- Inquiry
- Advocacy
- Interpersonal Skills
- Sense-making
- Visioning
- Innovation
- Invention
- Implementation
- Operation

These terms are somewhat intangible and can be labeled as buzzwords; diluting their validity. While these terms can be labeled as buzzwords, the Gordon Program clearly defines them, and these definitions are included in the appendix. Credibility for the value of these traits or "Affective Capabilities" is shown in chapter 4 through my own research, and through the support of the Gordon Program by influential and established engineering leaders such as Bernie Gordon himself.

It was first necessary to list these terms thus framing what it is that Systems Engineers value and need to be taught. Next, these terms will be shown to be of value to MIT Alumni after 10 years in the workplace (Kristen's thesis), and then that these values are demanded of our most recent Alumni when they are new hires.

3.0 Alumni Careers 10 Years After Graduation

3.1 Katherine Kelly's Thesis Shows Equal Distribution of Engineers Between Fundamental Engineering Work and Systems Engineering Work

Ten years after graduation from MIT, the alumni settle into their steady state career paths (Kelly 2003). This point was proven in Catherine Kelly's Thesis, "Some Trends in the Career Paths Followed by Alumni of the MIT Mechanical Engineering Department". The graph below summarizes the main point from Catherine's research showing that after 10 years out of MIT, the alumni careers settle into a consistent 35% engineers, which I have referred to as Fundamental Engineers, 35% Management, which I refer to as Systems Engineers when the Management is in an engineering context, and 30% other professions. The data from her research was on the graduating classes from 1967 through 2002.

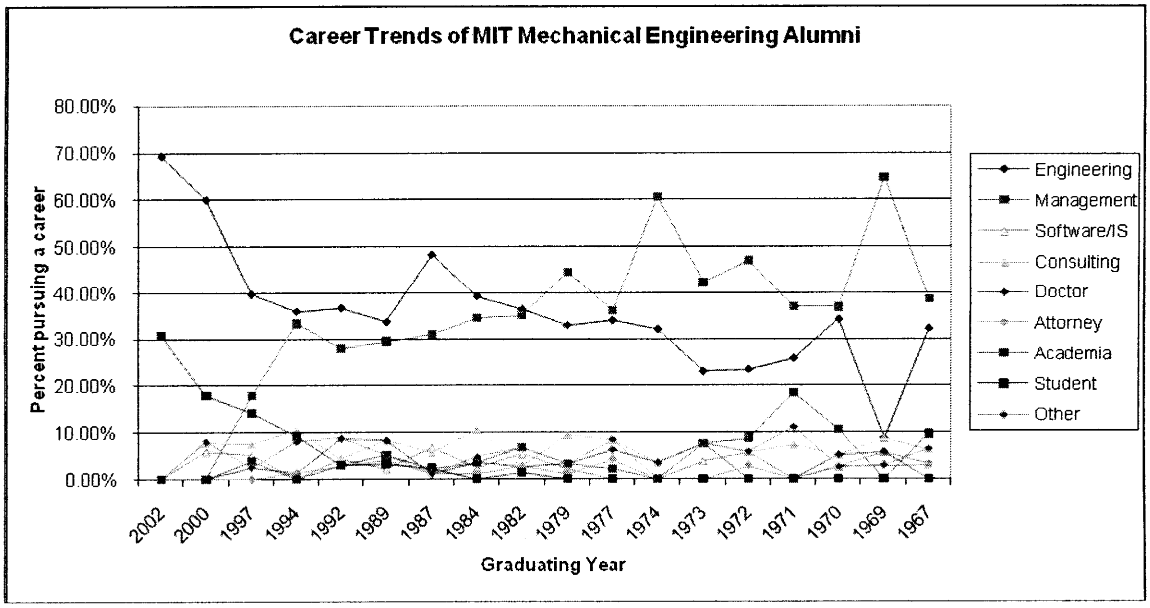


Figure 1 As MIT Mechanical Engineering alumni settle into their careers after graduation, as a whole the career distribution reaches an equilibrium of roughly 70% in engineering, half of which are engineers, and the other half are management (Figure from Kelly 2003).

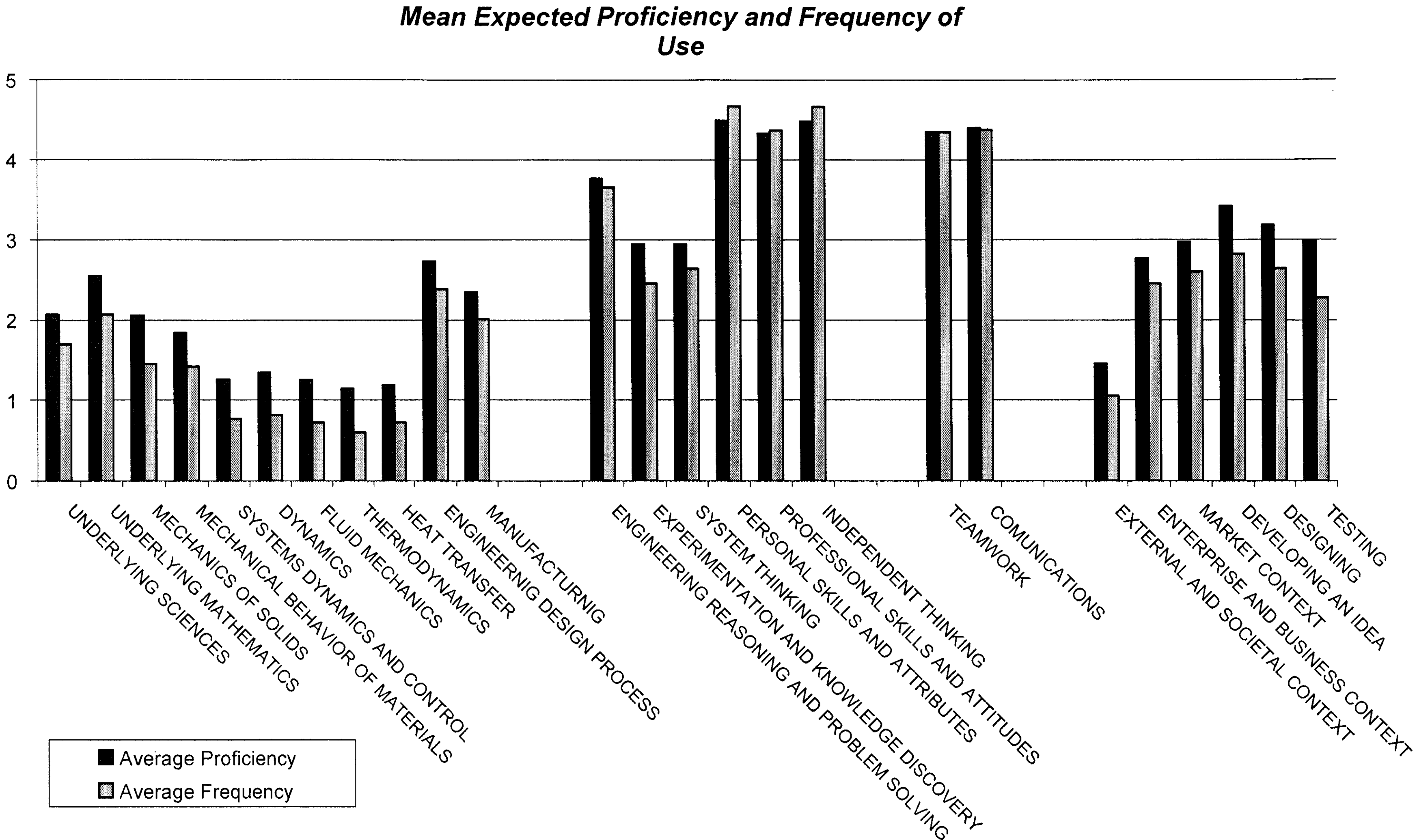
Some noise in the data from alumni in the classes 1974 and 1969 realize as peaks, but can be considered as outliers when this data is taken in perspective as an average over time. Since the management and engineering are negatively correlated, a rise in one parallels a drop in the other and thus the differences in the percentages are magnified.

If alumni are pursuing Fundamental Engineering and Systems Engineering equally as shown in Catherine Kelly's work, then the skills and knowledge considered valuable by both groups should be considered valuable enough to be taught.

Kristen Wolfe's work continued Katherine's by surveying older alumni and identifying both what they perceived as valuable and where they learned their skills and knowledge. This evaluation is elaborated on in the following section.

3.2 Kristen Wolfe's Work on What Skills Alumni Find Valuable in Their Careers

Alumni that were ten years into their careers found teamwork, communication, and a host of other soft skills listed in Section 2.4 to be used more often than their fundamental engineering skills. Kristen's graph is reproduced below. Her work surveyed over 300 alumni. One concern is that the soft skills appear more used when they may be reflecting general concepts versus the fundamental engineering concepts that are more focused. The data shows that the soft skills are indeed valuable to some degree or another and the problem of the terms being loaded is left for future works. Since they are valuable, the next steps will show that they are not being taught explicitly, and as a result, the skills are not being learned in the undergraduate education and are delayed until the student learns the skills in the field, when they in fact need them throughout college and are expected to know them upon graduation.



Expected Proficiency: 0 To have essentially no knowledge of, 1 To have experienced or been exposed to, 2 To be able to participate in and contribute to, 3 To be able to understand and explain, 4 To be skilled in the practice or implementation, 5 To be able to lead or innovate in.

Frequency of Use: 0 Never, 1 Hardly ever - a few times a year, 2 Occasionally - at least once a month, 3 Regularly - at least weekly, 4 Frequently - on most days, 5 Pervasively - for most everything I do

Figure 2: A graph from Kristen Wolfe's thesis showing the results from a survey of over 300 mechanical engineering alumni. The terms were scored for both the expected proficiency the alumni had and for the frequency of use.

For the standard Fundamental Engineering curriculum terms, grouped on the left of figure 2, the frequency of use varies between one and two, with an average just below two. In comparison, the terms from the CDIO syllabus that are more typical of a Systems Engineer, are valued between 3 and 5 with an average above three. These results show that alumni are generally using the Systems Skills more frequently. Again, Kristen's thesis analyzes these results from the MIT Alumni who have been graduated for about 10 years and reached a steady state career path in their lives. Demonstrating that these skills are valuable to them is a suggestion that they could be valuable to students, but it does not clearly explain if the alumni needed these skills sooner, and more importantly where they learned these skills that they use so frequently.

This next graph answers the second question of where they alumni learned the Systems Engineering skills that use and thus consider valuable. From Kristen's work, the alumni were also asked where they had learned each of the skills in the survey. Below is a graph showing the sources of the 30 year old alumni's valued skill sets.

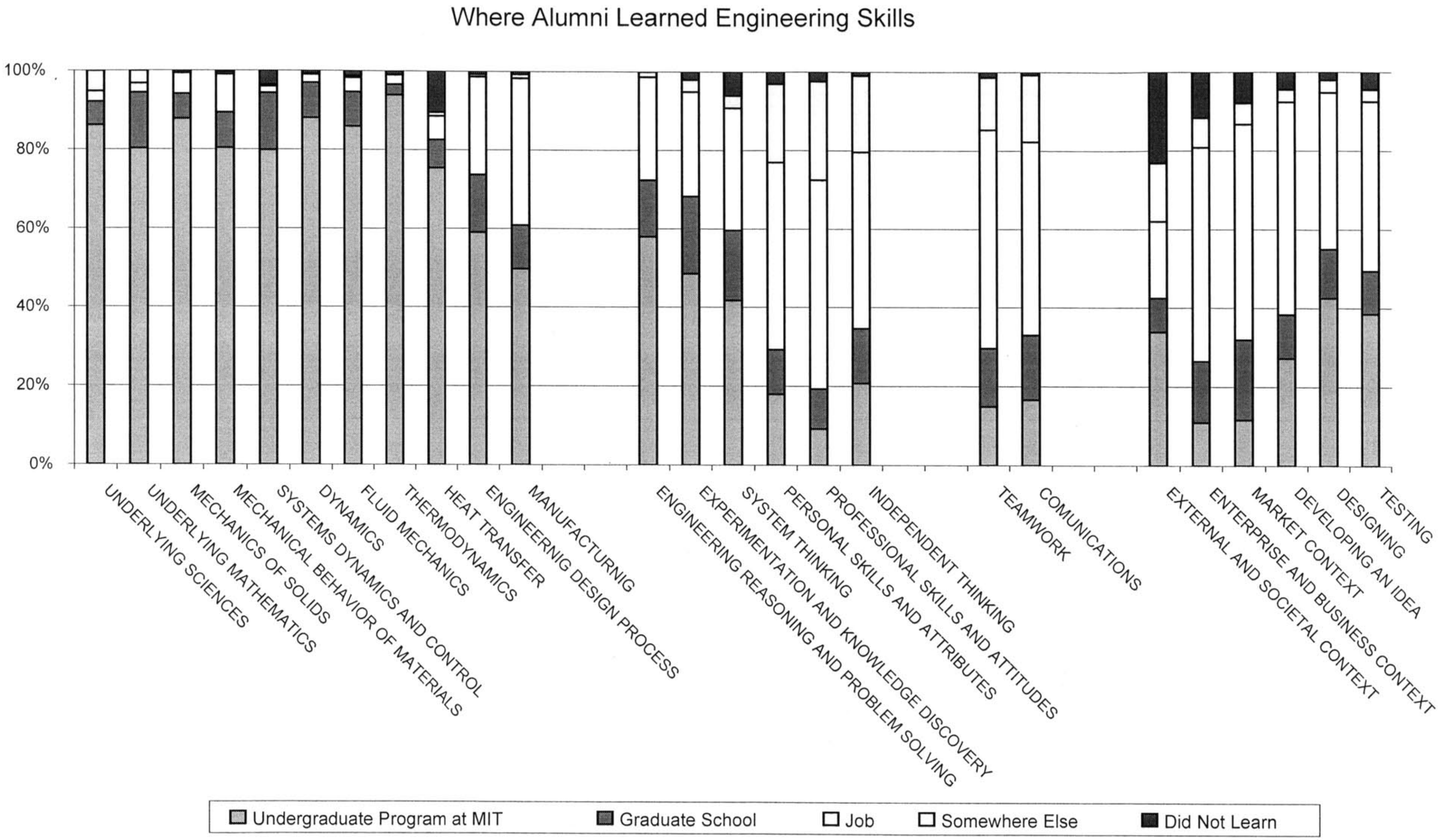


Figure 3: This figure shows the sources where alumni learned the defined skills and is a result of Kristen Wolfe's thesis.

From this graph two main points are apparent: The alumni learned their technical skills while at MIT, and more than half of their Systems Engineering skills on the job. Some of the systems skills were learned at MIT, ranging from 10% in professional skills, to 50% in engineering reasoning and problem solving. Engineering reasoning and problem solving is one of the Systems Engineering skills that is taught through the curriculum at MIT, mostly through lab classes, project classes, and independent UROPS. Many professors believe that the systems skills are implicitly taught in the background as the technical skills are taught. If this is true, than the source for these skills would appear more in the academic realm.

In summary of the main points in this chapter; MIT Alumni use the Systems Engineering skills more often and the Fundamental Engineering skills less often. The technical skills are learned almost entirely in the academic curriculum explicitly as defined content, whereas the systems skills are learned mostly in the workplace. While the lack of explicit Systems Engineering training in the undergraduate curriculum has been shown to exist, there has not been any demonstrated need for this training, and it could in fact be argued that learning these skills in the workplace is a natural and fitting place to learn them. This claim is not true. In fact, the next section, will demonstrate that Systems Engineering skills are needed throughout the undergraduate experience and most definitely upon graduation.

4.0 New Hire Engineers Fresh Out of MIT

4.1 Skills and Characteristics Demanded

Newly hired engineers from MIT, when considered as an entire population, are not only expected to be Fundamental Engineers, but Systems Engineers as well. These needs may be separate, but contrary to current beliefs, there exists a demand for recent graduates to have Systems Engineering Skills. These skills have been explained briefly in Chapter 2, drawing from the words used in Kristen's survey as well as those defined by the Gordon Engineering Leadership Program, both of which are defined clearly in the appendix.

A model for the skills and characteristics demanded of recent graduates was created using the MIT Careerbridge job postings as a data set. Careerbridge is a database of over 8000 job postings hosted by the MIT Careers Office. Since recruiters post descriptions of jobs for new hires to Careerbridge, it can be reasoned that these postings describe what the companies value, and the skills and characteristics expected of the students applying for the job.

By searching these job descriptions for the keywords describing Fundamental Engineers and Systems Engineers, the occurrence of each word can be found and then plotted. Keywords that appear in more job descriptions are assumed to be more valuable than those occurring less frequently. The keywords that were searched for were the terms discussed in Kristen Wolfe's thesis that the alumni found valuable, as well as the terms from the Gordon Engineering Leadership Program.

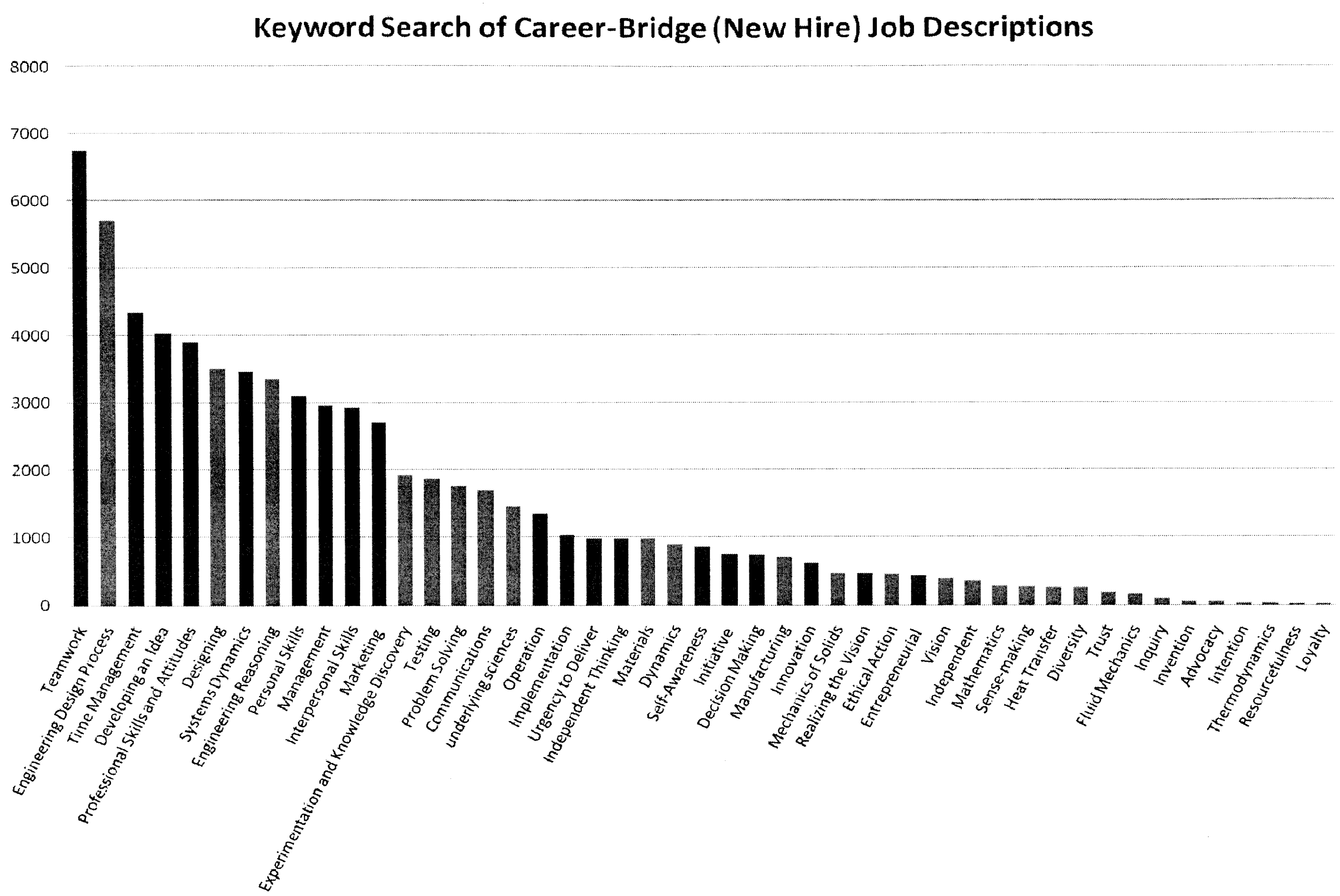


Figure 4: From this figure the occurrence of keywords valued by Fundamental Engineers (in blue) and Systems Engineers (in red) are plotted. Keywords with many returns are assumed to be more valuable than keywords occurring less frequently.

Hopefully by now, it is starting come as no surprise that the most commonly found keywords were typical of the Systems Engineering skills. Systems Engineering skills are thus shown to not only be valuable to alumni several years into their careers, but also to recent graduates, and even more importantly, it is shown that these skills are being recruited for and are thus demanded of new hires.

"Professional skills and attitudes" appears to be in demand since the job descriptions key word search returns almost 5000 hits. This contrasts the previous belief that these skills were only valuable to graduates after 10 years in the field. In fact, "professional skills and attitudes" was one of the least taught skills in the undergraduate curriculum as found in Kristen Wolfe's work on the sources of alumni skills. Only 10% of "professional skills and attitudes" were learned during the undergraduate education. This means that professional skills and attitudes are in demand for engineering students and recent grads, but they are not learning them in college, and thus not acquiring the skills that they need, when they need them.

4.2 Careers That Recent Graduates Pursue

It is important to understand the careers pursued by recent grads since those pursuing careers in engineering are to be characterized as the supply of MIT engineers. Graduates of the MIT Mechanical Engineering department should going into engineering related careers, but many are not, and thus the supply of engineers is not all that it could be.

For the last 10 years the MIT Careers Office has surveyed the graduating senior class regarding their plans upon graduation (Graduating Survey). Over the last four years, the survey began to include more specific definitions of work pursuits including the percentage of the graduating class pursuing finance, consulting, and engineering. In the following analysis, the work pursuits of MIT graduates over the last 10 years are first broken down into the categories of grad school, work, and other.

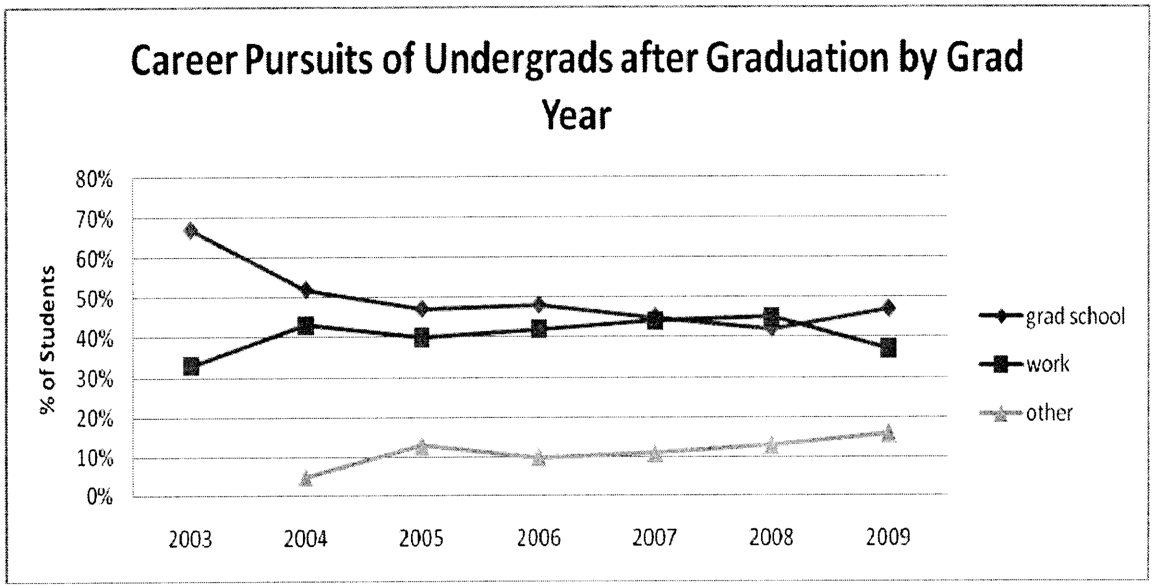


Figure 5: Out of the responding graduating seniors (all majors), 45% of go on to graduate school, almost 40% begin work, and 15% pursue other options. The trend shows that less graduates are continuing on to graduate school.

Roughly 40% of graduates have been going into the work place over the last 6 years. Within the 40% of graduates that pursue work, the types of work are broken down into finance, consulting, engineering, and other.

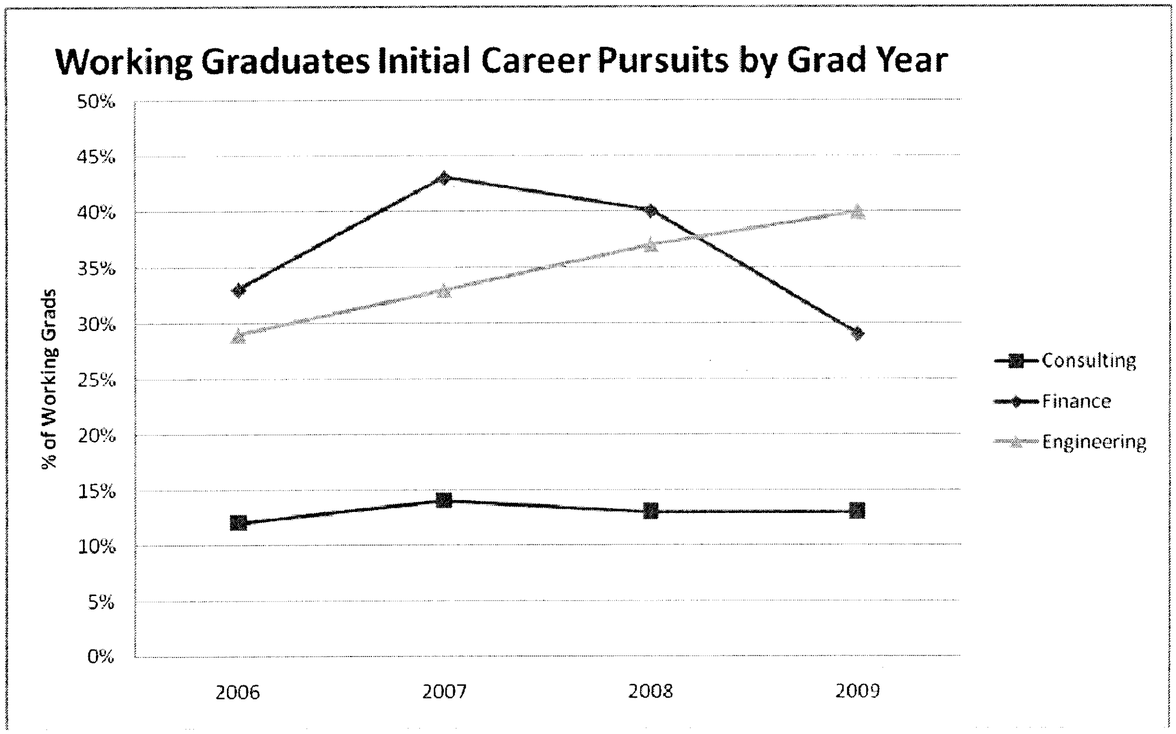


Figure 6: Over the past four years the number of graduates (all majors) pursuing engineering has increased from 30% to 40%, finance has swelled and now dropped to 30%, and consulting has held steady near 13%.

From this graph it can be seen that of the graduates that are accepting jobs in industry, that roughly 30% of students are pursuing finance, 40% engineering, and around 13% are pursuing consulting. The other career paths are not plotted since they are small and numerous. Finance appears to have experienced a boom that peaked in 2007 and has since declined, most likely due to the stock market crash. Engineering on the other hand has experienced a steady incline. At the same time, the following question can be asked: "Why are so many students from an institute of technology, with an education in engineering or science, pursuing careers in finance and consulting.

4.3 The Attraction of Finance and Consulting for Engineers

Recent graduates pursue finance and consulting jobs for many reasons, but this argument is focused on engineers that choose finance and consulting who originally intended on pursuing a career in engineering. Although these engineers initially wanted a career in the engineering industry, they switch to finance and consulting, often with little intention of staying in finance or consulting for very long.

In fact, the engineers that are leaving engineering for finance and consulting are doing so because they want to "get rich quick" and they have become disillusioned with engineering.

A current graduating student with a job at a consulting firm said during an interview, "Students want to feel important, like they are changing the world and engineering companies don't give us that satisfaction. Consulting, management, and finance, paint a vivid picture full of opportunity. The students are just acting in a rational manner and investing in a future in finance or consulting because that is where the money and the satisfaction are." Students like this and several others that were interviewed expressed this idea that non-engineering jobs are more appealing.

Future works should look into providing data on whether engineering students that share this view that non-engineering jobs are more appealing are indeed Systems Engineers. One proposed way to do this is by looking at enrollment data showing classes that engineers take outside of their required lists and correlating this with their career pursuits. This data is obtainable through the office of registrar and the provost, but was beyond the scope of this thesis.

It is my opinion that the engineering students who do pursue finance and consulting do so only because they do not find "their calling" in the engineering industry. Going further, I believe this calling was not found because the current engineering curriculum caters to the fundamental engineer and the systems engineers are not able to find their niche. Systems Engineers thus have a misunderstanding of all the possible job functions in engineering and do not realize that their skills are in fact in demand in the engineering industry.

It was hypothesized that many Systems Engineers become disillusioned with engineering and pursue non-engineering jobs as recent graduates, only to eventually make their way back to engineering several years later. The next section compares data on current job functions of alumni from the Alumni Information Directory with the records of recent graduates' pursuits from the MIT Careers Office.

4.4 Initial Graduate Career Pursuits Compared with Steady Alumni Careers

Kristen Wolfe's thesis showed that MIT Mechanical Engineering Alumni settle into a career 10 years after graduating from MIT. When these alumni do settle into their careers, roughly 75% are working in the engineering industry with half working as fundamental Engineers and half working as management. Of the graduates going into industry, initially 40% of graduates are pursuing finance and consulting jobs and approximately 35% are pursuing engineering positions, as shown by the MIT Careers Office statistics. After 10 years in the field the number of graduates in engineering becomes 75% as shown by Kristen Wolfe's thesis and the number of graduates in finance and education becomes a small portion around 10%. This means that the number of MIT graduates in engineering increases as they become older alumni, and that it could be graduates that are switching out of the finance and consulting industries. This data is just a beginning, and further works could aim to enhance these findings. Also, these findings agree with the sentiment of students as quoted earlier in that many students plan on working in finance and consulting for a short while rather than as a career. These short term plans are often salary motivated, and as discussed earlier, due too many engineers becoming disillusioned with the engineering profession. It can be speculated that these engineers return to engineering and after returning settle into engineering as a long-term career.

5.0 Current Paths of Engineering Students at MIT

To contain the scope of this chapter, only a select number of paths through MIT will be considered. First, it is assumed that most students will have only one major and another area of academic interest that could be a HASS concentration, a minor, or a second major. Secondly, the majors that will be considered are Mechanical Engineering (Course 2), Mechanical Engineering Alternative (2A), and Business Management (15). Much of this section is based on my personal experience as a Mechanical Engineering major and from interviews of several Mechanical Engineering students including freshmen, sophomores, juniors, and seniors, as well as some students who switched out of engineering into Business Management.

5.1 Definition of Paths

Differences between course 2 and 2A are subtle, so it is helpful to reference the Mechanical Engineering Department website (Course Catalog).

> All of the educational programs in the department prepare students for professional practice in an era of rapidly advancing technology. They combine a strong base in the engineering sciences (mechanics, materials, fluid and thermal sciences, systems and control) with project-based laboratory and design experiences. All strive to develop independence, creative talent, and leadership, as well as the capability for continuing professional growth.
>
> The traditional program that leads to the bachelor's degree in mechanical engineering (course 2), is a more structured program that prepares students for a broad range of career choices in the field of mechanical engineering. The second program (course 2A) leads to a bachelor's degree in engineering and is intended for students whose career objectives require greater flexibility. It allows them to combine the essential elements of the traditional mechanical engineering program with study in another, complementary field.

A description of the MIT Management Science (SB in Management 2010) degree from the Sloan School of Management is:

> Management science is a professional discipline that applies the scientific and mathematical approaches of operations research to managerial decision-making. It combines quantitative methods such as probabilistic analysis, statistical

inference, optimization, mathematical modeling, and computer programming with qualitative skills in communication, psychology, and organizational behavior.

These courses are relevant to this discussion because it will be shown that many Systems Engineers who came to MIT to be Mechanical Engineers were instead switching to Management Science up until the creation of course 2A, which has returned the balance to a level similar to 1999.

5.2 Enrollment Statistics

Another way to track the flow of engineering students and the careers they will enter is through the number of degrees awarded in the Mechanical Engineering department versus the Management Science department. Over time, it is assumed that a relatively homogenous group of students is attending MIT and thus the number of degrees in two established majors such as Mechanical Engineering and Management science should change very little. However, between 1999 and 2004 the number of Mechanical Engineering degrees awarded dropped from 126 to 59, a reduction of 50%! At the same time, the number of degrees awarded to Management Science increased by almost 65% from 66 to 108. Figure 5 illustrates the change in the number of degrees awarded to each major.

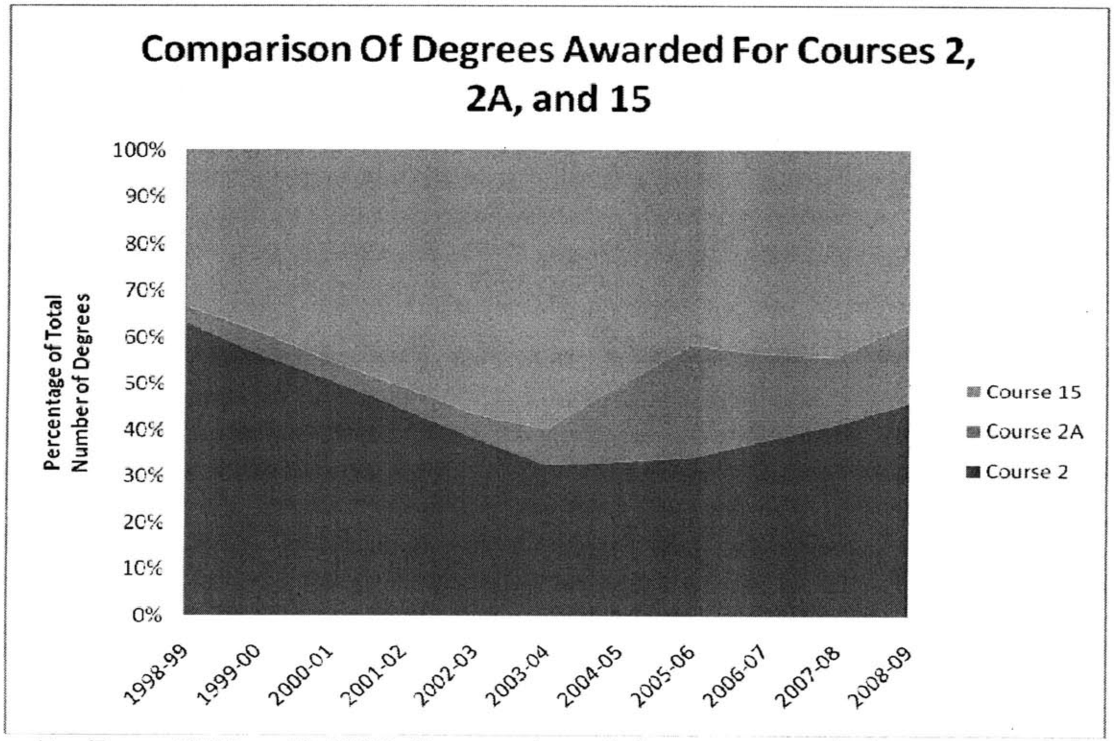


Figure 7: From 1999 until 2003, the number of degrees awarded to course 2 dropped 30% compared to course 15. This graph shows how many degrees were awarded to each major relative to each other. In 2004, course 2A grew significantly, pushing the engineering/management balance back to 1999 levels.

This trend shown in figure 5 of course 2 shrinking and course 15 growing would be even more compelling if the data showed that students were switching from course 2 to course 15, but this data was not obtainable and is something that could be done in future works. However, simply the relative change in size of each undergraduate body is compelling. If it is assumed that similar groups of students attend MIT year after year, what can warrant such a large swing in the composition of the student body such that the number of Mechanical Engineers is equal to the number of Management Science students? From the graph above, even a more compelling argument emerges; an argument that may suggest the content of the traditional course 2 curriculum was not attractive to the students who were also interested in Management Science. Starting in 2004, the number of degrees given to students in 2A grew such that by 2009 the number had more than doubled and returned the total number of mechanical engineering degrees awarded to the levels seen in 1999. At the same time that the number of mechanical engineers swelled back to cumulative levels of approximately 120, the number of Management Science degrees awarded returned to 1999 levels near 60. These fluctuations are not assumed to be coincidental, but a rather the result of the introduction of a more flexible mechanical engineering program that appealed to the same type of students that were previously pursuing management science degrees.

It is hypothesized that the type of students that were pursuing Management science in ever increasing numbers until 2004 are Systems Engineers. These Systems Engineers found management science more appealing than mechanical engineering, at least until the adoption of course 2A which allowed more flexibility, and thus arguably the option for these students to choose their concentration in management rather than leaving engineering all together.

It is theorized in this thesis that many Systems Engineers still exist that could and should be mechanical engineers but are still choosing other paths such as management science. These students need to be captured by the Mechanical Engineering department, but this can only be done through a new type of academic path that is detailed in chapter 6.

5.3 How Students Select Their Path

Generally speaking, students select their majors with little or no understanding of what their majors entail, and thus some students who realize they do not fit in their original department switch majors. This section includes data from the office of the registrar that tracks the number of students declared courses 2, 2A, and 15 for each graduating class from their sophomore year through their senior year. Figure 6 shows several trends evident from this data.

Enrollment in Courses 2, 2A, and 15 Following Each Graduating Class From Sophomore Year to Senior Year

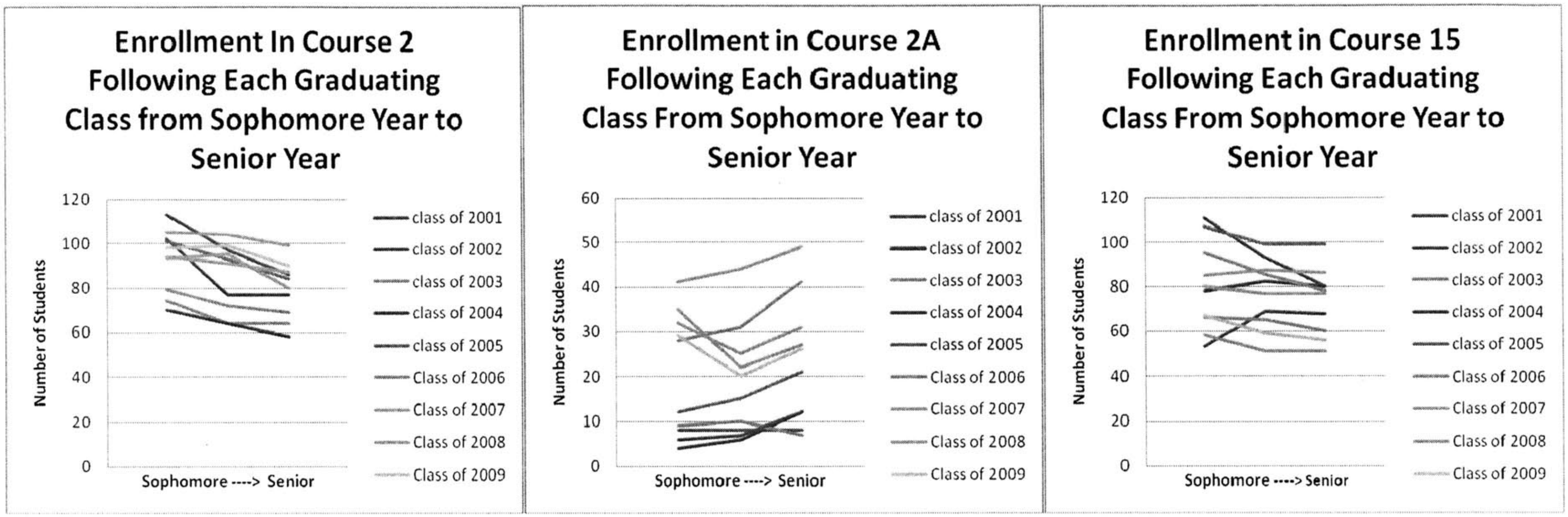


Figure 8: These graphs compare trends of enrollment between 2, 2A, and 15. It is clear that the number of students enrolled in courses 2 and 15 tends to decrease from sophomore year to senior year, while the enrolled number of students in 2A increases.

Courses 2 and 15 have a decreasing number of enrolled students between a graduating classes' declaration year (sophomore) and graduation year (senior), while course 2A has an increasing number of registered students year after year, both within graduating class years and from older class years to present class years.

Several course 2 students were interviewed and the findings are discussed in the following paragraph. Almost all of the students interviewed are self described as Systems Engineers interested less in fundamental engineering, and more in the application of engineering in a business setting. Many of these students have switched out of engineering as a degree or as a career (for now) and one younger student interviewed said, "I used to want to be an engineer, but I realized that I want to go into business."

One sophomore who has taken three of the required classes in mechanical engineering voiced his displeasure with the curriculum and his intent to switch out. He said, "2.001 and 2.003 are all problems sets and completely theoretical. I enjoy practical stuff more." This same student also commented on his thoughts on how the knowledge gained in college would be used after graduation. "The concepts could be useful in the long term, but the details are unnecessary, especially at the level you go into. If you need to use these concepts, you'll learn them in your job. I don't remember details from stress and strain, but if I need them, I can learn them later by reading a book online, or in the workplace. The details are unimportant." When reflecting on a more project based class, 2.00B – Toy Design, this student had a much different opinion. "2.00B was awesome because you learn the design process, which is practical, and then you build something, which is real, and it's your own idea!" Project based classes have more opportunity for systems engineering and are thus more appealing to these types of students. The hands-on application of learned knowledge is also a cornerstone of the MIT education, one that needs to be implemented in more classes as is suggested further in chapter 6.

Several freshmen were interviewed in order to capture the thoughts that go into selecting a major and their self predictions of their career paths. One freshman in particular stood out since he is still deciding between course 2 and course 6, but has also lightly considered management or finance; this consideration entirely due to older students' peer influences. Peer influences are one of the strongest factors for students' academic course selections as younger students trust older students' opinions and will choose certain classes and even majors as a result. This particular student illustrates this claim when he said, "I had never thought about business management, consulting, or finance until I came to MIT and heard about it from the upper classmen that are doing those things. I would be surprised if I wound up in those fields, but I have lightly considered it, which I wouldn't have done unless I knew those upperclassmen." When asked how he thought freshmen choose their majors he said,

> I think people choose their major based on what they think the major is, which is much different from what it actually is. I think more people switch out of engineering than switch into engineering. Non-engineering is easier, has better pay and opportunities for leadership. Some people are afraid of being another

> person's grunt, stuck in a cubicle, and a management degree removes this fear since management's purpose is to be in charge of other people.

He highlights several key points including the misperceptions of engineering careers and curriculum, the fact that more students switch out of engineering than into it, mostly because the cost-benefit analysis suggests engineering is more difficult than management with less financial reward and less positional power. Another freshman expressed the same sentiment when he said,

> My Personal reasons for wanting to be course 15 is that it would be significantly easier than an engineering degree and that the dividends are larger. There are exceptions, but the cost-benefit analysis shows management is the better track. Why would I want to do all of the work myself for a businessman when I could be the businessman instead?

These sentiments from the freshmen are illustrative of how students select their majors and the misperceptions they have of the programs that they must choose between. It is my aim to correct these misperceptions and better support students prone to the systems engineering mindset.

5.4 The Existing Paths Do Not Train the Systems Engineers

In conclusion, this chapter has shown that students have difficulty selecting their academic major; especially systems engineers since no clear path for these students exist. Systems Engineers desire project based classes and often become discouraged by the introductory fundamental classes such as Mechanics of Materials (2.001) and Dynamics and Controls (2.003). On the other hand, these same students enjoy the flexibility of the alternative Mechanical Engineering major, 2A, and project based classes such as 2.00B and 2.009. The addition of this course has swung the balance of engineers versus management degrees back to levels typical of 1999. While more and more students are now earning degrees in either 2 or 2A, there are still many who do not select these majors that would, and this is due to misperception that engineering is entirely fundamental as represented by the first classes that these students come in contact with. In order to capture the students that would be engineers but are leaving the field, it is important to create a better defined, more applicable path for these students under the 2A structure and to better communicate this path to the freshmen class.

6.0 Proposed Systems Engineering Path: The Gordon Engineering Leadership Program

The Gordon Engineering Leadership Program is a new program at MIT that appeals to the Systems Engineers and can be used as an example of how a curriculum for Systems Engineers can be designed and implemented.

6.1 The Gordon Engineering Leadership Program

Disgruntled with engineering education, Bernie Gordon donated $20 million dollars to create a program at MIT to better prepare engineers for industry. The program aims to prepare a select few students to be engineering leaders, but to more importantly change the MIT culture of engineers so that they are more prepared to work in industry as members of engineering teams. This program is largely appealing to systems engineers since it offers opportunity to work with a diverse group of engineering students from all the different majors and learn the soft skills such as teamwork and communication through hands on experience.

A definition of the program from the Gordon Program's Website:

> Launched through a $20 million gift by the Gordon Foundation — the largest gift made to MIT's School of Engineering for curriculum development — the Program aims to create new approaches to prepare students for engineering leadership and to ensure MIT continues to lead the nation in developing effective engineering leaders.
>
> A core goal of the program is a set of improvements to education at MIT for all engineering students, with a laser-like focus on product development and project engineering.
>
> Housed in MIT's School of Engineering, the Program provides an integrated set of leadership-oriented, discipline-building, hands-on engineering activities, set in the context of the practice of engineering, designed to develop outstanding MIT students as disciplined, future leaders in the world of engineering practice.
>
> ...through project-based learning, extensive interaction with industry leaders, hands-on product development, engineering leadership labs, and authentic leadership challenges and exercises, the program transforms a highly motivated group of undergraduate students into engineering leaders who will fuel America's technology engine.
>
> What's important in engineering education? Making universities and engineering schools exciting, creative, adventurous, rigorous, demanding and empowering environments is more important than specifying curricular details.

From this description it is clear that the program addresses the need for engineering leaders, which I have defined in this paper as Systems Engineers. While this program has a strong focus for a select group of students, almost all of these courses can be taken by any student at MIT, and the Leadership Labs, which are only for a select group of students, could be expanded. In only three years of existence, the Gordon Program has expanded rapidly from having an initial class of 5 students to now having admitted over 60 students for the upcoming class. This program is enjoying this success as a result of its popularity with the many engineers that have discovered the program, mostly due to peer influences. Systems Engineers from Mechanical Engineering and the other engineering disciplines are discovering the Gordon program and finding it complementary to their fundamental engineering education.

A Sloan Professor, Tom Kochan voiced his opinion of the Gordon program in the following review:

> To me, the Gordon-MIT Engineering Leadership Program rediscovers MIT's culture of Mens et Manus. It builds on the momentum of many fine departmental educational efforts as well as on the broad support among MIT leadership and faculty for contextualizing learning. The Program represents the kind of educational innovation for which MIT has become renowned, and is on a scale that few other peer schools can embark on (Gordon Website 2010).

With very little effort, the Mechanical Engineering Department has the opportunity to support the Gordon program by creating a 2A concentration in systems engineering based on the classes necessary for the already existing Gordon program. This recognition of such a path would allow for systems engineers that would otherwise switch to another major, or another career to instead remain in the engineering curriculum and profession.

6.2 How the Mechanical Engineering Department Can Better Support Systems Engineers

Supporting the Systems Engineers through a concentration in the course 2A program could be easily done by recognizing the classes for the Gordon program as the electives necessary for the concentration. Also, the Mechanical Engineering department should continue to create and advertise classes such as Toy Design (2.00B).

7.0 Future Works

Many aspects of this thesis are only the beginning of the analysis that could have been done and the suggestions made are introductory at best. This thesis is important to the Mechanical Engineering department because it concerns the retention of the department's students and the effectiveness of those students in their careers, hopefully careers in engineering.

A more rigorous analysis of the factors affecting student major selection, and students switching majors should be conducted. A complete set of this data is held by a combination of the office of the provost and the registrar and would offer the opportunity to do a regression model revealing the affect of different variables on results such as student major selection or student major retention.

Another opportunity for future works is to look into more opportunities for project engineering classes, especially interdisciplinary classes involving students from all the departments within the school of engineering, and even beyond.

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8.0 Appendix

8.1 Bernard M. Gordon –MIT Engineering Leadership Program Affective Capabilities Definitions

Bernard M. Gordon-MIT Engineering Leadership Program

Capabilities of Effective Engineering Leaders

Draft v 3.2
Sept 2009

Engineers design and build things that meet the needs of customers, beneficiaries and ultimately society. These tasks can only be accomplished by the concerted action of many people aligned and rallied by effective leadership. The Bernard M. Gordon-MIT Engineering Leadership Program is dedicated to empowering MIT students to make the very most of their talents and to help them set and achieve personal goals, including the leading or founding of teams and organizations which tackle and solve the problems of the market and society that can be addressed (at least in part) by technical solutions.

Specifically, we seek to educate and develop the character of outstanding MIT students as the potential future leaders of engineering practice and development. In this program, *engineering leadership* is defined as the technical leadership of the *innovative* conception, design and *implementation* of new products/processes/projects/materials/ molecules/software/systems, supported by the *invention* of enabling technologies, to meet the needs of customers and society.

We start with the assumption that many students entering university have already demonstrated leadership potential. At the same time, we observe that with a focus on engineering science, many engineering curricula do not adequately emphasize the development of engineering leadership. In this program, our educational task is to provide opportunities for all engineering students to further develop, deepen, and broaden their engineering leadership attitudes and skills.

We believe engineering leadership can best be taught and developed by linking in a timely and systematic way:

- Coursework that provides the analytical concepts and frameworks for understanding engineering leadership;
- Opportunities on and off-campus to experience and practice leadership,
- Opportunities to reflect, discuss, and gain feedback from peers, faculty and experienced engineering mentors on lessons learned from leadership activities.

We want students to graduate having developed the *attitudes* of leadership: core values and character. They need to have developed the *skills* of leadership, represented below under the headings of relating to others, making sense of complex situations, creating transformational visions and realizing the vision. Finally, in order to be effective engineering leaders, they of course need to have developed a deep understanding of the underlying *knowledge* of engineering, science and technology.

In some greater detail, these leadership capabilities can be described as presented below (see notes on sources at the end).

1. **The Attitudes of Leadership - Core Personal Values and Character:** as a foundation for effective engineering leadership, students should further develop these personal capabilities and values. For effective engineering leaders, these include:

    - Initiative – Ability and willingness to assess risk and to take initiative, to create a vision and course of action, without the help or advice of others. [2.4.1]

    - *Decision Making in the face of Uncertainty* –Ability and willingness to make decisions informed by the information at hand, factoring in risks and uncertainty.

    - Responsibility, *Urgency and Will* to Deliver – Determination to accomplish one's objectives, in the face of constraints or obstacles. Commitment to the absolute responsibility to persevere and deliver on time, pursuing necessary follow-up. Focus on the tasks at hand with passion, discipline, intensity. [2.4.2]

    - Resourcefulness and flexibility – Ability and willingness to approach problems, tasks and situations making ingenious use of the resources of the situation and group. A willingness to embrace various views, be adaptable, and maintain and take alternative courses of action when necessary. [2.4.2]

    - Ethical Action and Integrity– An adherence to ethical standards and principles, and demonstration of the courage to act ethically and with integrity, and to practice according to the norms of professional responsibility. [2.5.1](f)

    - *Trust and Loyalty* – Commitment to actions that will instill trust, and to the principle that loyalty to the team yields loyalty to the leader and vision. Working to empower those around you, to make the people around you successful.

    - *Equity and Diversity* – Commitment to treat others as equals, regardless of status or background, and to embrace diversity in organizations

    - *Vision and Intention in Life* – Determining a pathway to one's eventual contribution to and impact on society, and how engineering plays a role in ones intentions. Committing to a personal vision, and the intention to inspire others.

- Self-Awareness and Self-Improvement – Awareness of one's own personal, interpersonal and professional skills, and strengths and weaknesses. [2.4.5] Proactively planning for one's continuing education, self-improvement, and future career. [2.4.6, 2.5.3, 2.5.4] (i)

2. **Relating:** developing key relationships and networks within and across organizations, including listening to others to understand their views, and advocating for your position. For effective engineering leaders, these specialize to:

    - *Inquiring* and *Dialoging* –Listening to others with the intention of genuinely understanding their thoughts and feelings. Creating constructive dialog, and recognizing the ideas of others may be better than yours.

    - *Negotiation, compromise and conflict resolution.* Appreciating the need to identify potential disagreements, tensions or conflicts, and being able to negotiate to find mutually acceptable solutions.

    - *Advocacy* – The ability to clearly explain one's own point of view or approach, advocate a position, and explain how one reached their interpretation and conclusion. Proactively assessing the extent to which you are understood. Being able to do so to those with and without technical backgrounds, and from different cultures.

    - *Diverse Connections and Grouping* – Appreciating, engaging and connecting widely with those with different skills, cultures, and experiences. Building a sense of group within direct participants, and building extended networks of those that can help achieve the goals and technical solution.

    - Interpersonal Skills – Understanding and respecting the needs of individuals and the group, and the resources that individuals with different backgrounds can bring to an organization. Coaching and teaching, and the essential elements of gracious professionalism necessary to be an effective engineering leader. [3.1] (d)

    - Structured Communications – Being able to create a strategy and structure to formal communications, and present information orally, in written and graphical form to both engineers and non-engineers in a clear and concise manner. [3.2, 3.3] (g)

3. **Making Sense of Context:** making sense of the world around us, and coming to understand the context in which the leader is operating - making a mental map of the complex environment, and explaining it simply to others. For effective engineering leaders, these specialize to:

    - Awareness of the Societal and Natural Context – An awareness and understanding of the world's problems, challenges, and opportunities, and the historical and contemporary role of engineering in addressing them. An understanding of the natural context, and the need for sustainability. Specifically identifying opportunities for new (or previously not implemented) engineering solutions and systems to address these needs. [4.1] (j, h)

    - Awareness of the Needs of the Customer or Beneficiary – An understanding of the specific needs of those who will benefit from the envisioned engineering solution: the customers who will buy it, the users who will use it, the beneficiaries who will directly or indirectly benefit from it. [4.3.1]

    - Enterprise Awareness – Understanding the goals and culture of the enterprise in which one works, the shared beliefs, goals and strategies of the enterprise, and norms for working successfully and bringing about change. Literacy in broader business concepts and analysis, and in particular engineering project finance. [4.2]

    - *Appreciating New Technology* – Understanding the emergence and implications of new science and technology, and how they might enable or enhance new solutions and systems.

    - Systems Engineering – Thinking holistically. Possessing an ability to view complexity, focus on critical features, identify inter-relationships and emergent qualities, and create abstractions and models that simplify comprehension. [2.3]

4. **Visioning:** creating purposeful and compelling images of the future, and identifying what could and should be. For effective engineering leaders, these specialize to:

    - Thinking Creatively and *Imagining Possibilities* – Understanding how to create new ideas and approaches. Creating and communicating visions for new technical products and systems, and new engineering-based enterprises, that deliver new capabilities. [2.4.3]

    - Defining the Solution – Identifying a vision for the solution, and setting achievable goals for performance, budget and schedule. These are guided by the views of the customer, reflect the possibilities of technology, meet regulatory and political constraints, and consider competitive forces. [4.3.1]

- Creating the Solution Concept – Creating and selecting the concept and architecture for the technical solution, which might be innovative or evolutionary, and then defining the specifications and interfaces of the solution so that realization can be effective. [4.3.2, 4.3.3]

5. **Realizing the Vision:** leading transformation by designing processes and approaches to realize the vision, to move from abstraction to innovation, invention and implementation, i.e., to get the engineering done. For effective engineering leaders, these specialize to:

   - Building and Leading an Organization *and Extended Organization* – Building an organization by recruiting key players with complementary and superior skills, defining team processes, roles and responsibilities, and creating incentives. Lead an organization by employing appropriate modes of leadership under various conditions, and leading group decision-making. Assess organizational and individual performance. Observe, reflect and build on the leadership qualities of others. Develop approaches to incorporating competence outside of one's enterprise in an extended organization. Understand how to manage change. [4.2.4] If desirable, create a new engineering-based entrepreneurial enterprise. [4.2.3]

   - *Planning* and Managing a Project to Completion – Devising a plan of action, and alternative plans if needed, to achieve the goals and deliver on time. Managing and apportioning the resources of the team, to achieve the desired outcome within the human, time, financial and technological resources available. Controlling and managing program risk, configuration and documentation. Understanding the financing and the economics of the project. [4.3.4]

   - *Exercising Project/Solution Judgment* – Questioning and critically evaluating and applying judgment to solutions proposed by others, and to corroborating inputs. Understanding alternatives that may be developed or are being developed by others, including competitors. Taking into account the evolution of existing systems when proposing new systems.

   - Innovation – Designing and introducing new goods and services to the marketplace. Based on goals and concept, design a solution with the appropriate balance of existing and new technology, reuse and new development, and flexibility and adaptability. Consider current and future competition. Consider sustainability in the design and implementation. Validate the effectiveness of the outcomes. [4.4] (c)

   - *Invention* – Imagining possibilities based on emerging technology or science, and inventing a practical device, material, process or way of working that enables or enhances a new good or service. Adhere to and exploit intellectual property regimes.

- Implementation and Operation – Applying the methods of engineering development to implementation of engineering outcomes and systems. Consider quality and variability. Operate the solution effectively in such a way that the needs of the customer and society are met. Design, implement and operate the project, product or system [4.5, 4.6], or model, manipulate and make the material or bio-molecule.

6. **Technical Knowledge and Critical Reasoning:** Essential to the effective execution of engineering leadership is a deep working knowledge of a technology or discipline. While normally developed in the standard curricular course of study, this knowledge is no less essential for an engineering leader. It includes an ability to understand, decompose and recombine different elements of a technical problem through application of a deep understanding of technical knowledge [1.0] (a,k), engineering reasoning and problem solving [2.1] (e), critical thinking [2.4.4] and the approaches to inquiry and experimentation that may be necessary to develop or refine a new technology needed for a product, process or system [2.2] (b).

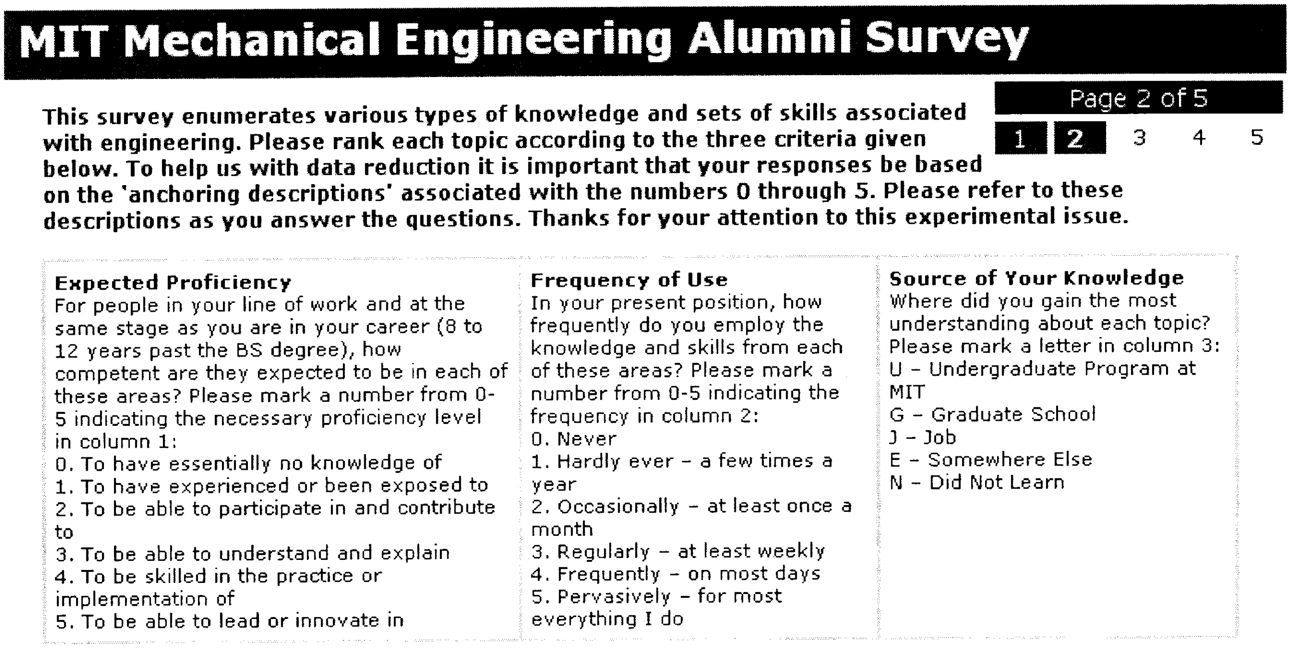
Notes on Sources:
The important inputs for this description of capabilities are:

1. The MIT Sloan Leadership Model, reflected in the Harvard Business Review article "In Praise of the Incomplete Leader" by Deborah Ancona, Thomas W. Malone, Wanda J. Orlikowski, and Peter M. Senge (February 2007). The topical organization of the above capabilities into Sensemaking, Relating, Visioning and Realizing the Vision (called by them Inventing) is due to this work.
2. The "CDIO Syllabus, a Statement of Goals for Undergraduate Engineering Education" a taxonomy of desirable engineering knowledge, skills and attitudes of engineers, originally presented in a report by Edward Crawley in January 2001 (see www.cdio.org) and later included in the book Rethinking Engineering Education, the CDIO Approach by Edward Crawley, Johan Malmqvist, Soren Ostlund, and Doris Brodeur, Springer, 2007. The notations in [square brackets] above correlates topics with the CDIO Syllabus, and notations in italics show significant additions to the topics in the CDIO Syllabus.
3. The accreditation standards for engineering education, contained in ABET 2000, as described in "Criteria for Accrediting Engineering Programs: Effective for Evaluations During the 2000-2001 Accreditation Cycle," Revised March, available at http://www.abet.org. The notations in (parentheses) above correlate topics to the ABET requirements section 3 a-k.
4. The deliberation for the Bernard M. Gordon - MIT Engineering Leadership Program on 18 December 2007, and subsequent development of summary documents by the group.

8.2 Kristen Wolfe's Thesis
From the Introduction:
The purpose of this research is to understand more clearly what knowledge and skills graduates of the MIT Mechanical Engineering Department make use of in their professions.
From Chapter 3: The process.

> The survey was sent to all MIT Mechanical Engineering graduates from the classes of 1992 through 1996. On March 29, 2004, these 676 graduates were contacted by email, told the vision and mission of the research and asked for their participation. In the email they were provided with a link to the online survey.

Below is a screen shot of a section of the online survey showing the presentation of the directions, which were shown at the top of every page:



MIT Mechanical Engineering Alumni Survey

This survey enumerates various types of knowledge and sets of skills associated with engineering. Please rank each topic according to the three criteria given below. To help us with data reduction it is important that your responses be based on the 'anchoring descriptions' associated with the numbers 0 through 5. Please refer to these descriptions as you answer the questions. Thanks for your attention to this experimental issue.

Expected Proficiency
For people in your line of work and at the same stage as you are in your career (8 to 12 years past the BS degree), how competent are they expected to be in each of these areas? Please mark a number from 0-5 indicating the necessary proficiency level in column 1:
0. To have essentially no knowledge of
1. To have experienced or been exposed to
2. To be able to participate in and contribute to
3. To be able to understand and explain
4. To be skilled in the practice or implementation of
5. To be able to lead or innovate in

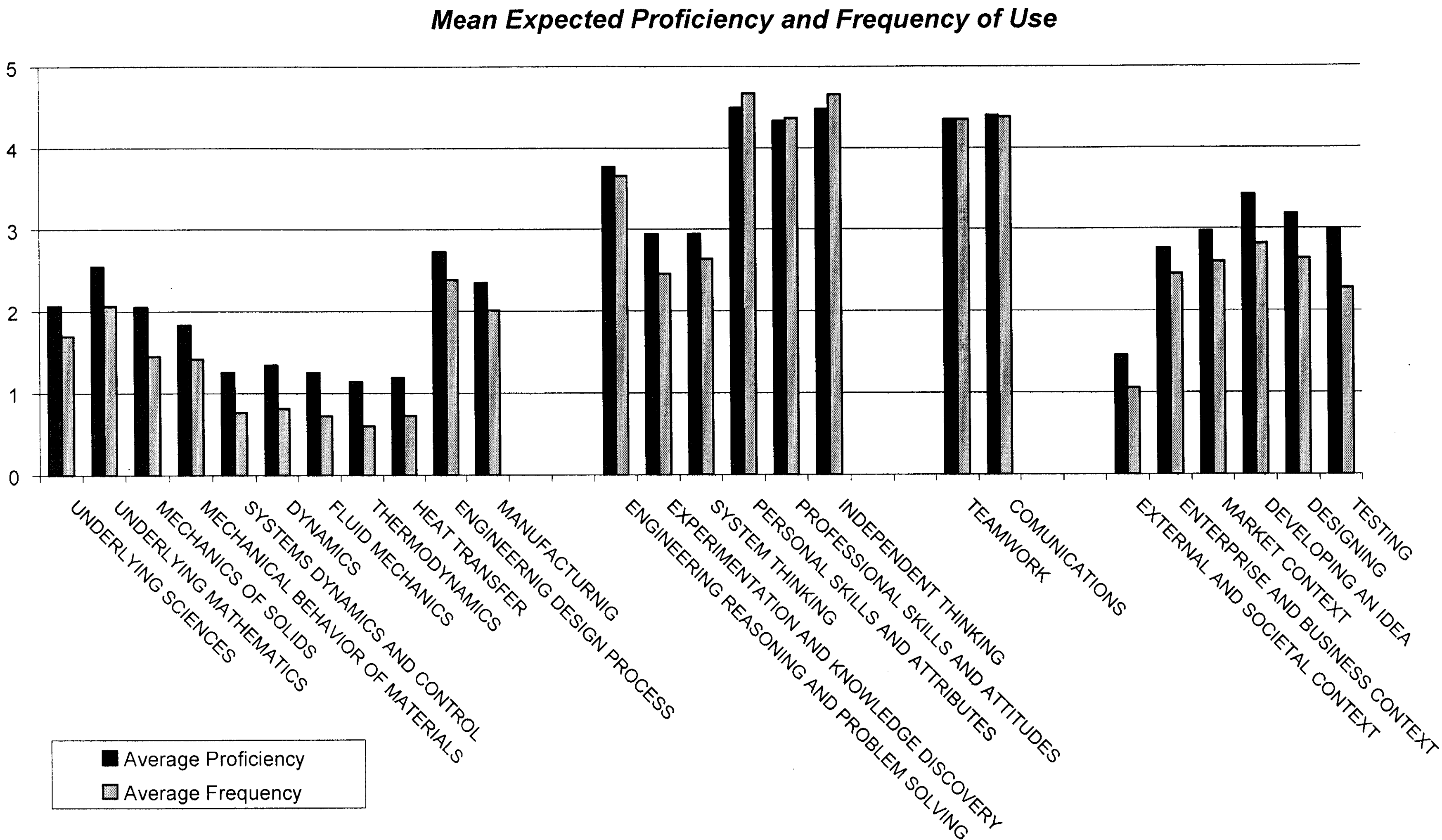
Frequency of Use
In your present position, how frequently do you employ the knowledge and skills from each of these areas? Please mark a number from 0-5 indicating the frequency in column 2:
0. Never
1. Hardly ever - a few times a year
2. Occasionally - at least once a month
3. Regularly - at least weekly
4. Frequently - on most days
5. Pervasively - for most everything I do

Source of Your Knowledge
Where did you gain the most understanding about each topic? Please mark a letter in column 3:
U - Undergraduate Program at MIT
G - Graduate School
J - Job
E - Somewhere Else
N - Did Not Learn

From Chapter 5: Interpretation of Results and Conclusions

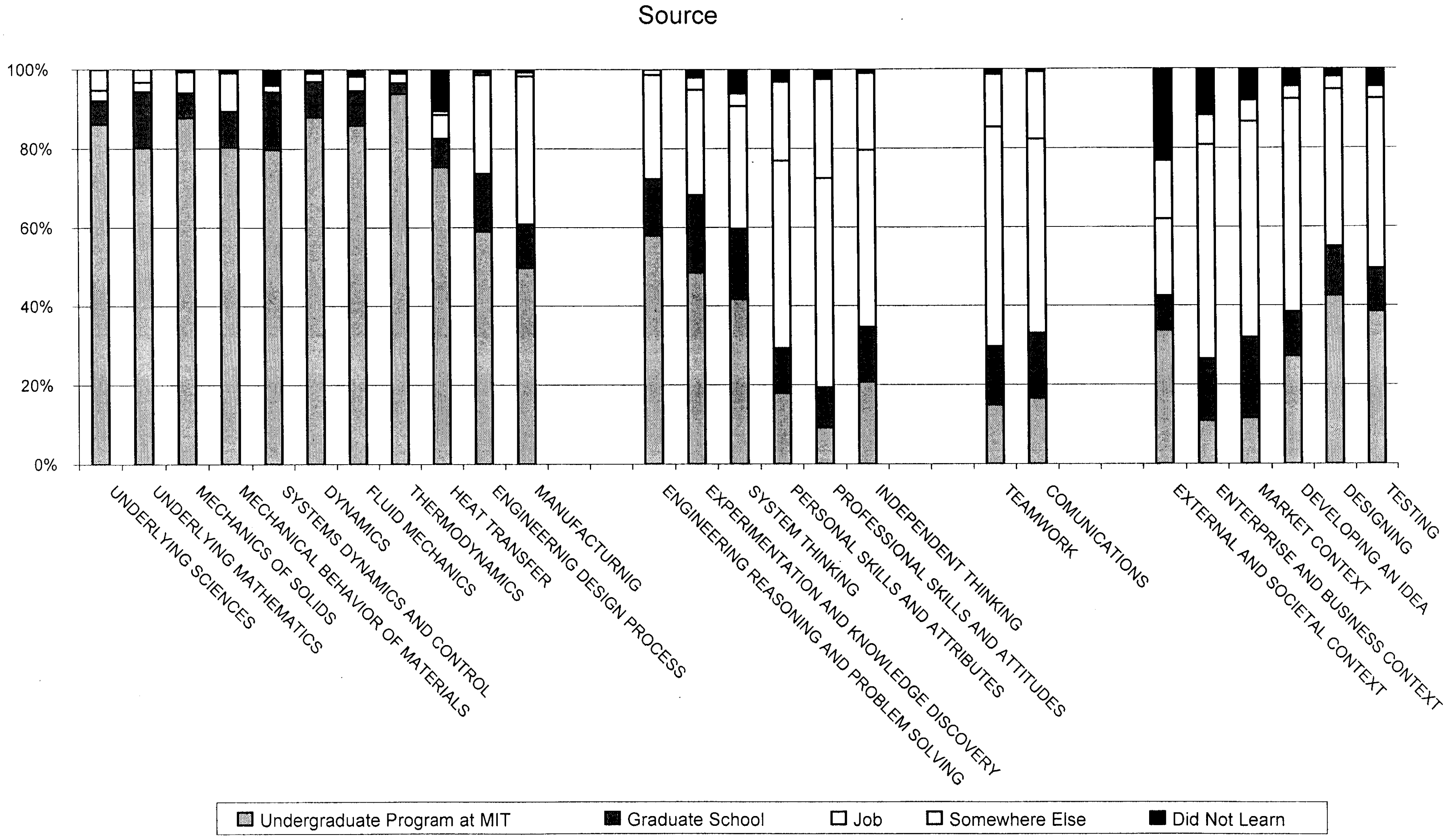
The data and charts presented in the previous chapter speak largely for themselves. I present them in this thesis as a stepping point for further discussion and research on the mechanical engineering curriculum. In this chapter I will offer my thoughts on the interpretation of the results, with the understanding that I am not an expert in the curriculum apart from my personal experiences as a student and my limited training in education.

There are two charts that I believe deserve the most attention: average proficiency/frequency and source. These are replicated on the next pages for ease of reference with the discussion that follows.


Mean Expected Proficiency and Frequency of Use

Expected Proficiency: 0 To have essentially no knowledge of, 1 To have experienced or been exposed to, 2 To be able to participate in and contribute to, 3 To be able to understand and explain, 4 To be skilled in the practice or implementation, 5 To be able to lead or innovate in.

Frequency of Use: 0 Never, 1 Hardly ever - a few times a year, 2 Occasionally - at least once a month, 3 Regularly - at least weekly, 4 Frequently - on most days, 5 Pervasively - for most everything I do


Source
100%
80%
60%
40%
20%
0%
UNDERLYING SCIENCES
UNDERLYING MATHEMATICS
MECHANICS OF SOLIDS
MECHANICAL BEHAVIOR OF MATERIALS
SYSTEMS DYNAMICS AND CONTROL
DYNAMICS
FLUID MECHANICS
THERMODYNAMICS
HEAT TRANSFER
ENGINEERNIG DESIGN PROCESS
MANUFACTURNIG
ENGINEERING REASONING AND PROBLEM SOLVING
EXPERIMENTATION AND KNOWLEDGE DISCOVERY
SYSTEM THINKING
PERSONAL SKILLS AND ATTRIBUTES
PROFESSIONAL SKILLS AND ATTITUDES
INDEPENDENT THINKING
TEAMWORK
COMUNICATIONS
EXTERNAL AND SOCIETAL CONTEXT
ENTERPRISE AND BUSINESS CONTEXT
MARKET CONTEXT
DEVELOPING AN IDEA
DESIGNING
TESTING
▨ Undergraduate Program at MIT
■ Graduate School
☐ Job
☐ Somewhere Else
■ Did Not Learn

One might hastily conclude in looking at these charts that there is little value in the core mechanical engineering courses because of their low levels of proficiency and frequency. However, as discussed before, this is an artifact of the specialization of the engineers at this stage in their careers. One might also hastily conclude the need to add classes to address the development of personal and profession skills, teamwork and communication. I do not believe this is the way to interpret the data or to achieve the desired outcome of better preparing our graduates.

Instead, I believe the charts show a need for integration of other topics into the existing core classes. My experiences in 2.001-6 have shown me that these classes are largely or entirely content knowledge based. The emphasis, from my viewpoint, is on knowing the material. I believe the department does a good job of providing the students with a very broad range of technical knowledge and reasoning. This is also evidenced on the source table with around 80% citing MIT as the primary source of their knowledge in these areas.

One disconnect I see is in the area of engineering reasoning and problem solving. Only 60% report their primary source as MIT. I assume that most professors believe the problem sets they assign are addressing this area. However, I'm not sure that is what students get out of such an exercise. I believe that for students to effectively learn engineering reasoning and problem solving they must be directly taught how in the class. As Prof. Seering pointed out in a presentation to the Engineering Committee on Undergraduate Education, most Professors cannot verbalize their problem solving method [9]. Yet students are for the most part expected to figure it out on their own. I know from experience that some do not figure it out and only learn to recognize patterns in problems and map them onto other problems at test time. I believe this is an area that needs to be given serious attention if students are to be successful in a real world engineering environment.

Another disconnect I see is in the area of experimentation and knowledge discovery. Less than 50% report their primary source as MIT. I assume that most professors believe the labs are addressing this area. However, I do not believe that students get this experience from the labs. The labs students are given in the various course 2 classes have explicit set-ups and desired outcomes. Students aren't so much discovering knowledge as they are following a prescribed set of instructions. Real experimentation is being given a problem or question and experimenting to discover the answer. It would be a challenging thing to replicate in the class environment, but perhaps the only way to give students the necessary background in experimentation and knowledge discovery.

The largest disconnects are in the areas of personal skills, professional skills, independent thinking, teamwork and communication. These areas received the largest scores for proficiency and frequency and the lowest for learning at MIT.

For the most part I believe professors assume the students will pick these up by virtue of the MIT experience. I propose there is a better way. For students to gain competence in these areas they need to be exposed to them and practice them regularly. I believe it requires a deliberate integration of these topics into the core curriculum. Currently, the written and oral communication aspects of course 2 are mainly through 2.671 and 2.672. I have not taken these classes, but have spoken with those who have. My concern is that this is an artificial environment. The students are learning how to communicate through fabricated experiments, which remain the same year after year. Communication is kept as an isolated component of the undergraduate education. I believe that a deliberate integration of personal skills, professional skills, independent thinking, teamwork and communication into each of the core engineering courses would serve the students much better. The difficulty comes in determining how best to integrate these areas into individual classes and the curriculum as a whole.

The structure of the core classes at this point makes any integration of such topics almost impossible. The core classes are already overflowing with their content knowledge and the work that accompanies it. There is little time for the students to process the knowledge and learn how to apply it with confidence. In order for change to occur, professors must recognize the downfalls of the “fire hydrant” approach and work to find the most effective way of enabling the students to learn. (Notice, I did not say the most effective way of teaching. I believe the job of a professor is to enable the students to learn. I think that this is very different from the commonly held view of what it is to teach.)

Conclusions:

Please accept these interpretations as my own. I am sure many will disagree with some or all of what I have said. I hope that the data I have compiled will be thought over carefully with much discussion. Making changes is never easy and determining the right changes to make is even harder. I leave this discussion to those who have made engineering education their career and are better equipped to recognize the changes that need to be made. Some may say that the curriculum is fine as it is because our alumni have accomplished so much in such a wide variety of professions. But I hope the department is never content with its program and is constantly striving for ways to make improvements so that MIT graduates will continue to go on to be leaders in all aspects of life.