

Experiments in Service Learning

by

Amy Banzaert

B.S., Mechanical Engineering (1998)

Massachusetts Institute of Technology

Submitted to the Department of Mechanical Engineering
in Partial Fulfillment of the Requirements for the Degree of
Master of Science in Mechanical Engineering

at the

Massachusetts Institute of Technology

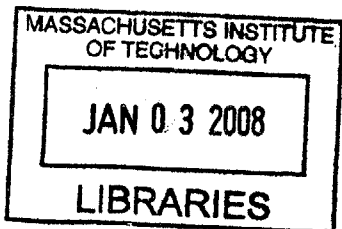
September 2006

© 2006 Massachusetts Institute of Technology
All rights reserved

Signature of Author _____
Department of Mechanical Engineering
August 12, 2006

Certified by _____
David R. Wallace
Associate Professor of Mechanical Engineering
Thesis Supervisor

Accepted by _____
Lallit Anand
Professor of Mechanical Engineering
Chairman of the Committee on Graduate Students



BARKER

Experiments in Service Learning

by

Amy Banzaert

Submitted to the Department of Mechanical Engineering on August 12, 2006
in Partial Fulfillment of the Requirements for the Degree of
Master of Science in Mechanical Engineering

ABSTRACT

Service learning, an educational method that involves the application of academic work to projects that benefit under-served communities, was explored in two complementary forms.

First, the development of an alternative form of charcoal made from sugarcane agricultural waste is discussed, including product and process characterization and improvement. The motivation for the project is to establish an alternative cooking fuel that is less detrimental than existing options based on three criteria: health risks, environmental impact, and affordability. A method for improving the speed and safety of a critical process step is presented, and initial test findings demonstrate that the product generally matches the cooking parameters of the benchmark, the wood charcoal that this project seeks to replace.

Second, the introduction of service learning pedagogy into three core mechanical engineering classes at MIT – 2.002 Mechanics and Materials II, 2.006 Thermo-Fluids Engineering II, and 2.009 Product Engineering Processes – is explored. Curricular materials, service projects, and assessment methods were developed and implemented. Based on initial research, the pedagogy is effective when integrated into the class well, meaning a project was chosen that was academically rigorous and matched both the curricular goals of the class and the needs of the community partner. In addition, positive social, career-oriented, and cognitive outcomes for students are evident, particularly for women and minority students. Use of service learning in 2.009 is also explored over four years, and positive results from interviews studying the interest in service learning by MIT mechanical engineering faculty are presented.

Thesis Supervisor: David R. Wallace

Title: Associate Professor of Mechanical Engineering

ACKNOWLEDGEMENTS

I would like to gratefully acknowledge the financial support of the National Science Foundation, under NSF Grant No. EEC-0431784, the Lord Foundation, and the Hugh Hampton Young Fellowship, which made portions of this research possible.

In addition, I would like to thank my advisor, David R. Wallace, for his incomparable support, helping me to pursue such diverse topics.

Amy B. Smith has provided amazing encouragement and support to me over the past five years, with my work in service learning and charcoal.

Sumedha G. Ariely generously offered me continuous support and advice for engaging in pedagogical research and assessment analysis.

Shawn Frayne, Gerthy Lahens, Victoria Fan, and Alia Whitney-Johnson have been wonderful collaborators with whom I worked on the charcoal project.

John Duffy, Camilla Shannon, and Sally Susnowitz have all provided me with inspiration and support throughout my work on integrating service learning into core engineering classes.

So many others – my friends, family, and colleagues – have offered wonderful inspiration and support during this process.

Finally, I would like to thank my husband, Stephen Banzaert, for his incredible support, humor, and patience with all my endeavors, including this one.

TABLE OF CONTENTS

OVERVIEW	7
CHAPTER I: SUGARCANE CHARCOAL	9
1. INTRODUCTION	9
1.1 Motivation	9
1.2 Background	11
2. Process Improvements	17
2.1 Grinding and Binding	17
2.2 Binder Ratio Optimization	21
3. Briquette Characterization	25
3.1 Briquette Performance Goals	25
3.2 Briquette Testing Methods	25
3.3 Briquette Characterization Results and Analysis	26
4 Conclusions & Future Work	28
SECTION II: SERVICE LEARNING IN THE MECHANICAL ENGINEERING EDUCATION CORE	31
1. Introduction & Motivation	31
1.1 Research and Reporting Methods	32
2. Faculty Views of Service Learning in Mechanical Engineering at MIT [53]	33
2.1 Background	33
2.2 Faculty Survey Method	34
2.3 Results and Analysis	35
2.4 Faculty Interview Conclusions	41
3. Integration of Service Learning into Core Mechanical Engineering Classes	42
3.1 Class Descriptions	42
3.2 Service Learning Projects	44
3.3 Service Learning Integration Process	45
3.4 Research Methods	48
3.5 Research Outcomes	49
3.6 Analysis and Lessons Learned	63
4. Longitudinal Study for One Core Mechanical Engineering Class [68]	66
4.1 Introduction	66
4.2 Class Description	67
4.3 Development of a Service Component in 2.009	68
4.4 Research Approach	72
4.5 Research Outcomes	73
4.6 Conclusions	80
5. Overall Conclusions and Future Steps	81
REFERENCES	82

OVERVIEW

The pedagogy of service learning, the integration of academically-relevant community service projects and experiences into the curriculum of a credit-bearing activity, has been used in liberal arts education for decades, but it is only more recently that it has been adopted in engineering education [1]. In engineering departments, service learning is typically used for elective classes, such as in Purdue's widely-adopted EPICS program [2], or in capstone classes, such as in the civil engineering department at the University of Utah [3]. While use of the pedagogy is expanding in engineering education, the use of the practice in core classes, where the oft-cited benefits of student motivation and understanding of course material [4-6] might be most significant, is rare.

In this thesis, service learning is explored in two complementary ways. In Chapter I, a specific service learning project is presented, namely, the development of a charcoal fuel made from sugarcane agricultural waste. The work encompasses two areas: process improvements and product characterization. In Chapter II, the investigation of how this type of service-oriented project can be integrated into core engineering classes is presented. Curriculum was developed, adopted, and assessed for three core engineering classes at the Massachusetts Institute of Technology.

Chapter I: Sugarcane Charcoal

1. INTRODUCTION

A largely unrecognized problem in many developing countries is that of cooking fuel. Cooking fuel, a seemingly simple basic human need, creates and exacerbates problems for inhabitants in many developing countries that can be lumped into three areas: environmental devastation, poverty, and health. This work seeks to develop an alternative cooking fuel that is less detrimental to its users in these areas, and can readily be adopted by users with minimal capital costs or changes to cooking habits.

One possible solution to these problems is the use of charcoal made from agricultural waste. Charcoal is nearly smokeless, significantly reducing health problems created by the direct burning of raw biomass, and if it is made from agricultural waste that lacks nutritive value for soil replenishment, will not lead to deforestation; in fact, it can encourage reforestation efforts, as farmers will be more inclined to plant crops if agricultural waste charcoal can offer an additional revenue stream from the same plant material. While the concept of making charcoal from agricultural waste is not at all novel [7-9], there is very limited information on doing so at the grass-roots level: most rigorous documentation is focused on mass manufacture, while small-scale efforts are described only vaguely, without sufficient information for replication. Small-scale charcoal production, requiring capital costs of less than \$100, is the focus of this research because this method is most likely to provide economic benefits to the targeted recipients, and will be most effective in regions like Haiti, where country-level production would be untenable currently due to political instability.

1.1 Motivation

For the 2.4 billion people in the world who cook using biomass (wood, dung, crop waste, and charcoal), these fuels can cause severe health, environmental, and economic problems [10, 11].

Environmental Devastation: A significant portion of the world uses solid fuel – often wood or charcoal derived from wood – as their sole source of cooking fuel; usage rates range from 16% in Brazil to 96% in Ghana [12]. Historically, wood has been a very convenient option: a seemingly limitless supply of free cooking fuel has been available by walking to the nearby woods and gathering branches or cutting down a tree. Alternatively, biomass conversion to charcoal offers a cleaner-burning fuel whose temperature profile is more controlled, allowing for improved cooking parameters. However, as the world population has grown and, in turn, the world's wood resources have been depleted (for fuel, to make room for agricultural crops, for building materials), wood as a source of cooking fuel is becoming less and less viable, and more and more expensive [12]. Despite these drawbacks, wood and wood charcoal are still used, since they're the only affordable, accessible option. One extreme example is Haiti, where 46% of the population uses wood and 49% uses charcoal as their sole cooking fuel [12], despite the fact that, as of 2000, Haiti is 97% deforested [13]. This level of deforestation, increasing annually primarily because of the need for cooking fuel, has led to severe environmental problems: soil erosion leads to floods that kill thousands of people and to the destruction of marine

environments, decimating the livelihoods of people who rely on fishing for food and as a source of income. Given this level of environmental devastation, wood-based fuels are rapidly losing viability as a fuel option.

Poverty: In many developing regions, it is becoming commonplace that people who used to gather wood are now forced to purchase it, since wood can no longer be found in their villages [12]. In Haiti, wood charcoal costs more and more each year as the deforestation becomes more and more extreme, forcing the poorest families, who typically make less than one dollar per day [14], to make the terrible choice between food and cooking fuel. For many families, cooking fuel can be 5% of their annual budget [12]; for comparison, in the U.S., the average cost of all energy used per family is approximately 0.25% of the budget, while the poorest 20% of the country spends approximately 1% [15]. Note that for most in the U.S., energy expenditures include electricity and water heating as well as cooking fuel, while in developing regions, the expenditure is typically solely for cooking fuel. In developing regions, the poorest families have income of less than one U.S. dollar per day, meaning that they have no flexibility in purchasing choices. A fuel that is at least as affordable as wood and wood charcoal were before deforestation led to rampant price increases is a critical need.

Health: One novel, non-wood-based fuel is cow dung. This product has the benefit of being free and readily available in many places, but causes severe respiratory disease exacerbated by the fact that many people cook indoors. Using any cooking fuel in its raw form, from dung to wood to other biomass, can cause severe respiratory illness. In fact, acute respiratory lung infection is the leading cause of death worldwide for children between the ages of one and five, causes more than one million deaths per year; most of these deaths can be linked to inhalation of smoke from burning raw biomass in kitchens. Another 600,000 adults also die from respiratory illness each year, typically women, who spend the most time tending to cooking [10].

Alternative Fuels

The use of charcoal can largely reduce respiratory illness caused by cooking, but there are few alternatives to the environmentally-damaging wood charcoal available in most regions. Wealthier families can use liquid natural gas, propane, or biogas, which cook more cleanly, but these are expensive options out of the reach of the poorest people in the world, and can also be risky to use. While government or large non-governmental political and economic intervention could make these fuels more affordable, this type of effort is unlikely in the foreseeable future. Further, these products are likely to become more expensive as the world supply of fossil fuels is depleted, making this option less viable for many more people.

One common solution that has been proposed to solve these issues is a solar cooker; however, this product has a number of limitations that have prevented its widespread adoption. First, the device requires users to cook outside, which many people object to, for privacy and cleanliness reasons. Second, the device can only be used during the middle of the day, when the sun is at its hottest, and many users need to cook in the mornings and evenings. Third, the device is excellent for cooking slow-cooked meals like stews, but much more limited when frying or sautéing, limiting the types of cooking that can be done on the stove. These three issues are extremely significant: there are volumes written on development and appropriate technology projects that have failed because the technology introduced did not fit into the lifestyle of the

users sufficiently. Finally, the device can be only truly useful in regions on the equator, where one can expect strong sunlight year-round.

Another method that is less common is agricultural waste densification, in which agricultural waste is extruded into dense briquettes. However, this process does not eliminate the dangers associated with inhalation of raw biomass smoke, and also requires relatively expensive equipment.

Table 1 shows a comparison of the main fuel options that are available and commonly used in developing regions. Using an A-F academic-style grading method, the limitations of each of these fuels becomes evident. Wood and wood charcoal have multiple grades for affordability because the cost of these fuels varies depending on the level of deforestation in a given region.

Given the limitations of all of these fuels, a new option that does not cause the environmental devastation that wood creates, is affordable for the poorest people in the world, can be introduced and adopted rapidly at low cost, does not create health problems, and is tailored to meet the cooking needs of its users must be developed.

Table 1: Overview of Fuel Options in Developing Regions

	Health	Environment	Affordability	Usability
Wood	F	F	A/C	A
Wood Charcoal	C	F	B/C	A
Dung	F	C	A	A
Crop Residue	F	C	A	A
LNG/LPG	B	C	F	C
Solar Cooker	A	B	C	F

1.2 Background

1.2.1 Charcoal History

Charcoal making is an extremely old human endeavor: there is evidence that charcoal was made from wood as early as 6,000 years ago. While the chemical processes involved in carbonization are reasonably complex, in its most basic form, charcoal-making can be quite simple. Organic material is heated until it reaches 400 to 1300°C (the temperature depends on the type of process being used and the quality of carbon that is desired), allowing the volatile compounds in that material to burn off. Then, the material is contained in an environment in which the oxygen supply is severely restricted, and the remaining organic material is converted into carbon [16].

In traditional charcoal-making a direct method of carbonization is used in which the organic material to be carbonized is ignited directly in order to reach carbonization temperatures. In the past 500 years the carbonization process has been industrialized, leading to a number of key process innovations. An alternative carbonization method known as the retort method was developed, which involves placing the material that is to be carbonized into an oven, for which a

distinct material provides the heat source. Overall, improvements have driven more efficient carbonization methods with better yields that can also produce valuable condensates [16, 17].

In developing countries, charcoal is typically made from wood, and the process often remains highly rudimentary. A tree is cut down, placed in a wide hole, and a structure is built over the hole to form a tube. The tree is lit on fire and eventually the tube is covered with earth, enclosing the tree in a low oxygen environment in which carbonization can take place. The efficiency of the process is extremely limited, but it is a highly affordable, accessible way to make a living for many people: while doing so is illegal in many places, the only investment is a machete or chainsaw, a fire source, and time. In areas where unemployment and underemployment can reach 66%, it is one way to make a living [18].

While wood charcoal is the most common form of charcoal, it can also be made from other materials, primarily from agricultural waste. The prevalence of non-wood-based charcoal is poorly documented, but total usage of biomass energy generally is known. Worldwide, fuel from non-wood biomass consists of 4% of the world's total energy usage – this number includes raw biomass, dung, and carbonized biomass. For comparison, 14% of the world's energy stems from all forms of biomass. In the U.S., 4% of energy used is derived from biomass, almost as much as from nuclear power, while developing countries use an average of 38% biomass; this rate is about 90% in certain countries, including Haiti [19].

1.2.2 Relevant Literature on Agricultural Waste Charcoal and Briquetting

Charcoal from Agricultural Waste

A wide variety of waste agricultural materials have been used to make charcoal, both for production purposes and in laboratory settings. Chardust Ltd., a Kenyan briquetting company, primarily creates charcoal from charcoal dust and fines¹ that accumulate in charcoal-sellers' storage areas [20]. While they started a venture to create briquettes from carbonized bagasse in 2002 [21], the "CaneCoal" project was abandoned, due to a number of economic and logistic factors: the bagasse drying time, the smokiness of the carbonization operation, the poor performance of the briquettes, as compared to wood charcoal, and the fact that the briquettes required specialized cookstoves [22].

In the 1970s, the government of Indonesia and USAID developed a method and equipment for creating charcoal briquettes from rice husks. While the process was reasonably effective, achieving 85% of the absolute heat output of standard charcoal – a rate deemed acceptable by the report – it does not seem that the program has continued into the present, at least on a documented scale [9].

A number of experimental efforts testing the viability of different forms of agricultural waste can also be found in the literature. Along with collaborators, Zandersons, Katyal, and McCauley each explored the viability of charcoal made from bagasse [8, 23, 24]. Koser et al. studied the carbonization of water hyacinths and cotton stalks, also performing an economic analysis focused on the Sudan [25]. Demirbas et al. explored the efficacy of carbonizing and briquetting hazel nut shells [7, 26, 27], while Karaosmanoglu and Culcuoglu both investigated making charcoal from rapeseed [28, 29]. All of these studies showed promising results in terms of these waste products being used for charcoal production; however, most were contained to laboratory experiments. Those that explored opportunities for implementation all focused on a vision of production at a much larger scale than what is considered in this work.

Briquetting

In addition to these documents, there is literature on the briquetting of a variety of non-carbonized materials. While not directly applicable, the documents offer insight into briquetting methods, binder options, and tradeoffs between factors in briquetting. The United Nations Food and Agriculture Organization documented a conference on a number of briquetting techniques and findings in 1995 [30]. Beker explored briquetting of lignite using a variety of binders and additives [31, 32], while Richards documented the briquetting of peat [33]. Rahman et al. explored how size and shape affects briquettes' performance [34].

1.2.3 MIT Charcoal Project

The impetus for this work stems from the MIT Charcoal Project, founded by MIT Senior Lecturer Amy Smith in 2001, which seeks to develop an alternative form of charcoal made from agricultural waste that can compete with wood charcoal in terms of selling price and cooking behavior. The goal of the project is to develop an agricultural-waste-based charcoal-making

¹ Charcoal fines are very small fragments of charcoal

Then the bagasse is lit on fire near the bottom of the drum. A half-cupful of kerosene or similar liquid fuel is typically used to light one piece of bagasse, which is used as a long match to light the entire volume of material. While the bagasse is burning and approaching carbonization temperature, water can be boiled by using the residual heat at the top of the oil drum, which can be used for a future step. This step is quite smoky, because of the high levels of volatiles in the raw material that burn off. After about 10 minutes, the smoke changes from a deep yellow color to nearly clear, indicating that the volatile compounds have been burned off. At this stage, the water is removed and previously-made briquettes are loaded into the top of the oil drum in baskets. Then, after lifting the oil drum off of the rocks, the oil drum is sealed using rocks, sand, and mud. After two to three hours, the carbonization cycle is complete, and the oil drum can be uncovered to reveal sugarcane charcoal fines.

The charcoal fines are removed from the drum and crushed by hand to form a charcoal powder. Concurrently, cassava,² which is used as a binder for holding the charcoal briquettes together, is grated, dried, and mixed with the water that was boiled during the carbonization process to make a porridge.³ The charcoal powder is mixed by hand with the cassava porridge, which binds the powder into a material with the consistency of wet sand.

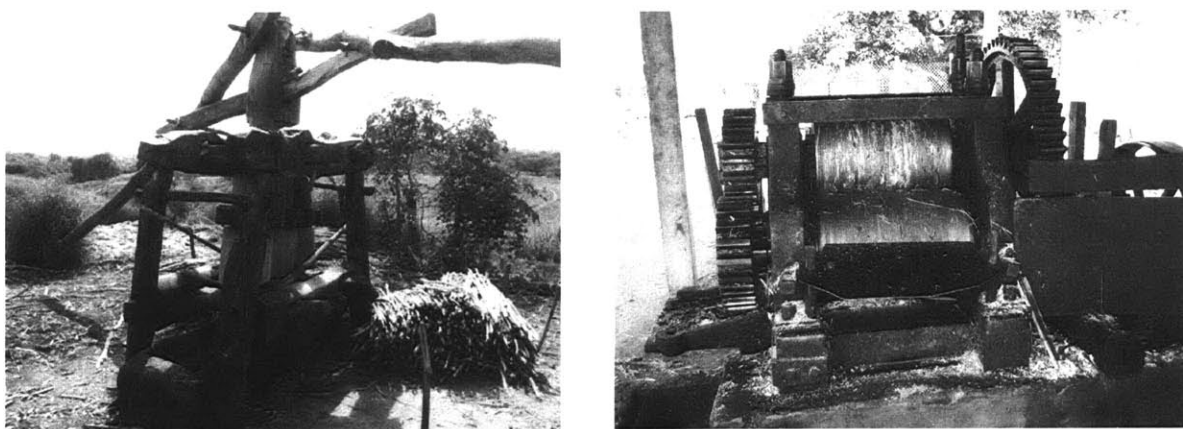


Figure 2: Small-Scale Sugarcane Processing Equipment

² Cassava is an extremely starchy root vegetable also known as yucca or manioc that is a staple in many developing regions, and can grow in a wide variety of climactic zones and soils.

³ Although using the residual carbonization heat to boil the water is most energy efficient, doing so requires that a batch of bagasse be carbonized while briquettes are being made. If this timing is too challenging, the water can be boiled on any stove. Further, although using warm binder results in easier mixing, moderately cooled binder is also usable, reducing the need for exact timing.

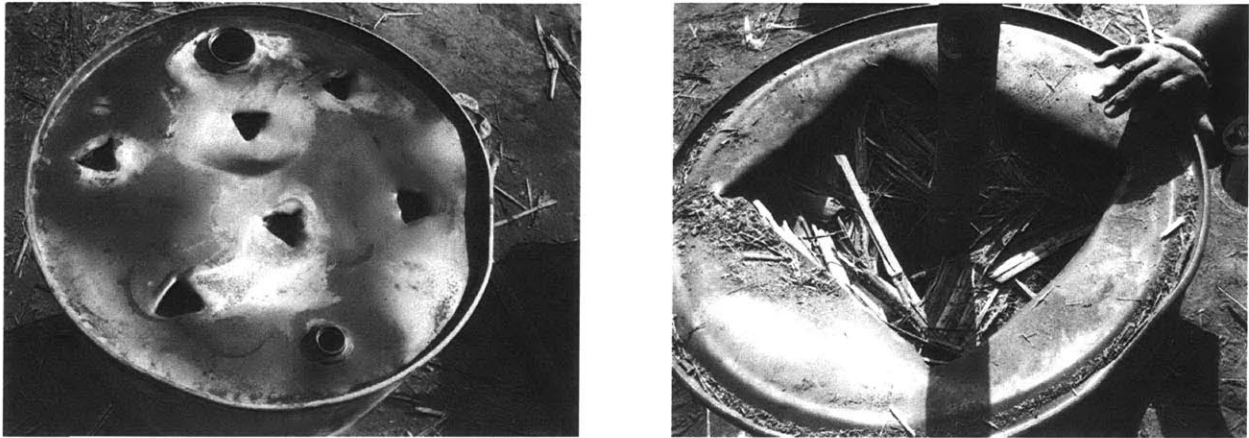


Figure 3: Modified Oil Drum - Holes in Bottom and Top Loaded with Bagasse

In the next step, briquettes are impact-formed using a simple device that was developed by Jessica Vechakul for her senior thesis in mechanical engineering at MIT [36]. The resultant, cylindrical briquettes are 2" in diameter, and approximately 1"-2" tall (briquette height varies depending on the amount of raw material used). The briquettes are dried in the sun for one-three days, depending on environmental conditions and then baked in order to harden them. The baking step can be done during the carbonization of another batch of charcoal, by placing a metal basket of briquettes in the drum prior to sealing it, as shown in Figure 4. After baking, the briquettes are ready for use.



Figure 4: Loading Briquettes into a Hot Drum for Baking

While this process was effective, a number of process improvements were needed to improve the efficiency, cost, and safety of the manufacture of charcoal briquettes so that it would be

production-ready. Additionally, little was known about the process and product, including what the correct ratio of binder to charcoal fines was, whether the particulate and gas emissions of the sugarcane charcoal were comparable or better than that of wood charcoal, the strength of the briquettes and whether they could survive transport, and whether the heating characteristics of the charcoal were comparable to wood charcoal.

This work addresses a number of these open questions; other students at MIT who have also investigated certain areas of this project include Jessica Vechakul, who worked on the design of a simple briquetting device [36]; Victoria Fan, who focused on the best methods for crushing and agglomerating the charcoal [37]; Dexter Ang, who investigated an extruder for briquette-making [38]; Andres Ramirez, who performed an initial study comparing the emissions released from sugarcane charcoal to those of wood charcoal [39]; and Lynn Kamimoto, who studied the economics of this project [40]. Additionally, much of the work on the project is documented at <<http://web.mit.edu/d-lab/portfolio/sugarcanecharcoal.htm>>.

2. Process Improvements

Two key improvements were needed to optimize the sugarcane charcoal manufacturing process – crushing the charcoal fines and mixing them with the binder, known as the “grinding and binding” step, and optimizing the quantity and processing of the cassava used in the binding porridge.

2.1 Grinding and Binding

One critical area affecting both process efficiency and safety involved working with the charcoal fines. After carbonization, the bagasse fines are an inhomogeneous composition of powder and semi-rigid material. In order to create briquettes, all of the fines need to be crushed into a powder (grinding), and then mixed with the cassava porridge (binding). This step creates two main problems.

First, it is quite time-consuming, requiring about an hour to perform both operations. This length of time is problematic because it results in the operation becoming a bottleneck for the entire process; ideally, the carbonization step should be the limiting factor. Second, and most importantly, any agitation of the charcoal powder creates airborne particles that pose a significant risk to human health.

2.1.1 Charcoal Fines Airborne Particle Risk

Ambient airborne particles can pose significant harm to human health, damaging the cardiovascular and respiratory systems, leading to a wide range of life-threatening ailments, including acute respiratory infection, chronic obstructive pulmonary disease, asthma, and lung cancer, as well as low birth weight from exposure during pregnancy [10, 41, 42].

Because of these dangers, the U.S. Environmental Protection Agency has set National Ambient Air Quality Standards for airborne particles in two key size ranges: those between 2.5 – 10 microns in diameter, called PM₁₀, which can clog larger respiratory passages, and those that are

equal to or smaller than 2.5 microns in diameter, known as PM_{2.5} [43]. The EPA standards are shown in Table 2. This table shows the specific guidelines for the maximum number of particles that should be in the air on an **average** day over the course of a year; the EPA also has a general guideline for the maximum number of particles that should be in the air on **any** day over the course of a year for PM_{2.5}.

Table 2: EPA Standards for Airborne Particles

	Maximum average exposure over any full day during the year (micrograms/cubic meter)
PM ₁₀	50
PM _{2.5}	15

The airborne charcoal dust that is created during the crushing of sugarcane charcoal fines has significant numbers of particles in the PM₁₀ and PM_{2.5} ranges, as shown in Figure 5. These measurements were taken indoors when crushing charcoal in a laboratory; comparable results were found when crushing was performed outdoors. Measurements were taken for 30 minutes, and then extrapolated to 8 hours, a standard work day. As is evident from this table, the particles produced during crushing produce hazardous levels of PM₁₀, and noticeable levels of PM_{2.5}. Although the PM_{2.5} level is not above the EPA threshold, both of these PM levels are deceptive, as they do not reflect the baseline level of particulate matter that people are exposed to on a daily basis. Given that this method is intended to be used in developing countries, where typical ambient particulate levels already are dangerously high due to the use of biomass-based cooking fuels [10, 42, 44], additional PM exposures at the levels shown in Figure 5 are unacceptable. Fundamentally, since the workers making the charcoal are likely to be exposed to extremely high levels of airborne particulate matter already, a safe process should not increase significantly workers' exposure to particulate matter.

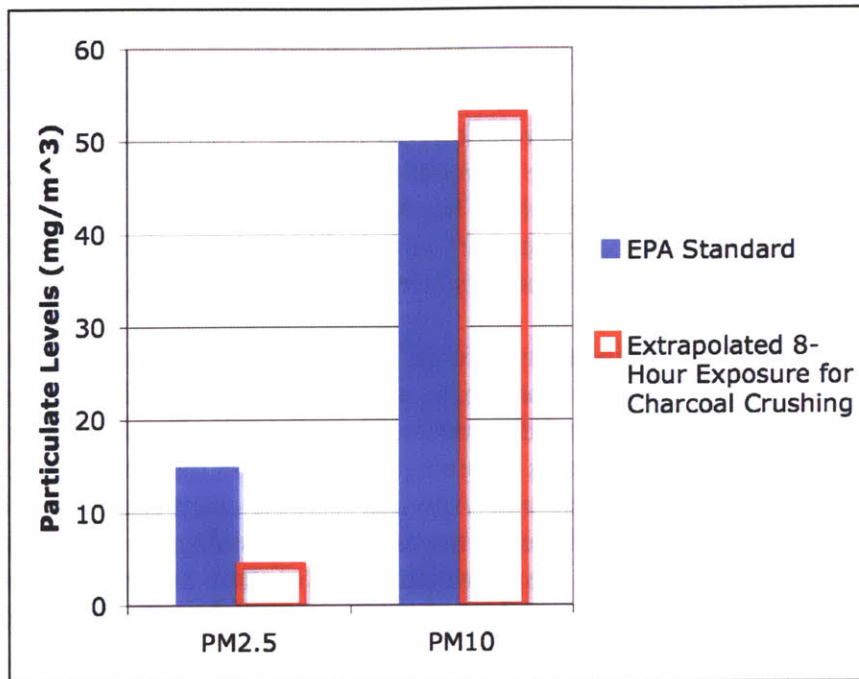


Figure 5: Comparison of EPA Particulate Standard to Ambient Particles During an 8-Hour Charcoal Crushing Process

2.1.2 Process Requirements

Process requirements for the grinding & binding steps were established through informal conversations with other people working on the project. The key requirements are as follows.

- Speed: more than twice as fast as the 2-hour carbonization step, so that a full batch of briquettes can be made while a new batch of raw material is carbonized
- Safety: no special personal protective equipment (PPE) required in order to perform the processes. The original grinding & binding process necessitated the use of respirator masks to prevent inhalation of charcoal particles ... masks are too expensive and have limited availability in the regions where this device is targeted. Ideally, no measurable particle exposure is warranted.
- Labor: 1-3 people; since unemployment is severe where this process will be implemented, labor is readily available and highly affordable.
- Ease of use: high, as unskilled labor will be used.
- Robustness / reparability: high, as it is to be expected that availability of parts and funding for repairs will be limited
- Composition: locally available materials and construction
- Capital costs: <\$20 (entire process <\$100)

2.1.3 New Grinding & Binding Method

Given the constraints outlined in the previous section, the solution needed to be extremely simple. As any perturbation of the fines created dangerous charcoal particles, minimizing

movement and interaction of the particles was of utmost importance. Hence, the new method involves leaving the charcoal fines in the kiln drum in which they were made.

To crush the charcoal, three large rocks, approximately 6-10 inches in diameter are placed into the drum. Then the drum is sealed, as described in the next paragraph, and rolled for approximately eight minutes at about 40 rotations per minute. Then, after letting the drum sit unperturbed for two minutes, to allow the charcoal particles to settle, the rocks are removed and the porridge binder is poured into the drum. The drum is rotated again for an additional four minutes, to incorporate the binder into the charcoal powder. Once the binder is mixed in, the charcoal powder is no longer airborne, and it is safe to interact with and perturb the mixture.

The sealing method requires additional drum modifications beyond those required for the drum to be used as a kiln: welding three bolts onto each end of the drum, and then placing a cap on top of each end of the drum, using bolts and the nuts to secure the cap. Between the caps and drum ends rubber and/or cardboard is placed as a compressible medium that seals the drum's holes, preventing the charcoal fines from escaping. Alternatively, the drum caps can be held together by running a rope between two small holes in the cap, and tightening the rope with a stick twisted around the rope and used as a simple winch. Each of these methods should cost less than U.S. \$10, although a finalized cost accounting would depend on the country where this process is implemented.

Rolling can be accomplished simply by rolling the drum on the ground, although this method is quite tiring on uneven surfaces; by wrapping the drum with a rope, allowing one or two people rotate the drum back and forth with moderate effort; or by placing the drum on a structure that allows for rolling the drum in place. These different methods, shown in Figure 6, work equally well in terms of crushing efficacy and offer process implementers options in terms of capital investment versus labor requirements.



Figure 6: Three Methods for Drum Rotation - Rolling on the Ground, with a Rope, and with a Stand

Figure 7 displays the process improvements offered by the new grinding and binding methods. The operation time is reduced from 70 minutes to 15 minutes, and the health risk, as defined by the percentage of the EPA PM_{10} daily limit that is reached per batch, is reduced from 56% to

1.8%. This new method offers marked improvements for speed and safety, with limited capital costs.

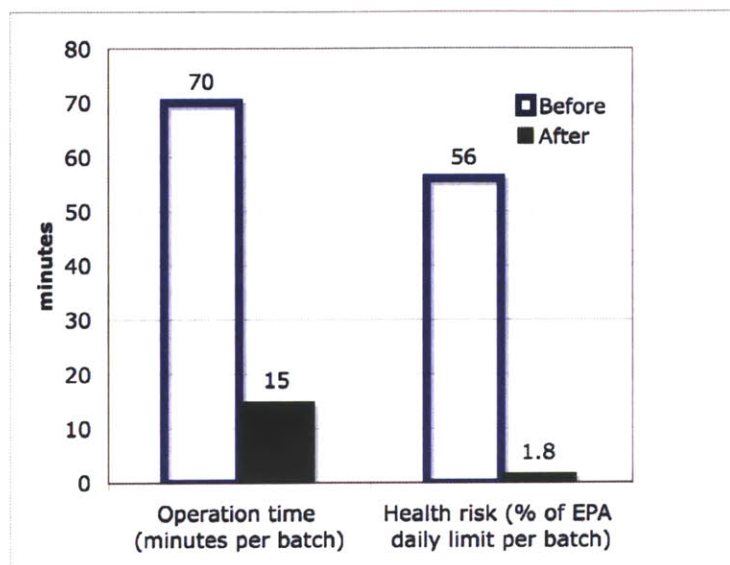


Figure 7: Process Improvements Achieved

2.2 Binder Ratio Optimization

Another aspect of the process that needed to be improved was optimizing the amount of cassava used in the binder porridge and identifying acceptable processing methods for the root vegetable. Cassava strengthens and hardens the briquettes, and having a reasonably hard briquette is important for two reasons. First, briquettes that are too delicate will fall apart when transported even a short distance, reducing significantly their salability. Second, when first encountering these new charcoal briquettes, it seems to be universal that people’s first instinct is to squeeze the briquette – this has been true in the U.S, El Salvador, Haiti, and Ghana. People tend to be impressed with briquettes that retain their integrity, and extremely unimpressed with weaker ones that break. As weaker briquettes tend to explode in compression, sending charcoal powder everywhere, it is critical that the briquettes be strong enough to be acceptable to users and to survive transport. Hence, using a significant amount of cassava is preferable for hardness.

However, minimizing the amount of cassava used is also desirable, as cassava is a staple food that adds cost to the product. In addition, if this type of briquette is used widely, the use of cassava could create pressure on food supplies in regions where there is no safety net for increases in food scarcity and expense. Therefore, the goal of this aspect of the work is to identify the minimum amount of cassava that can be used to create a briquette that is acceptable in terms of strength and hardness.⁴

⁴ A final reason to minimize the amount of cassava used is that, as cassava is not entirely carbon, the cassava will cause the briquette to smoke. In small quantities, the smoke is not significant, but at higher levels, the resultant output is undesirable both in terms of user preferences and from

Cassava processing methods were also of interest, because cassava can be processed in numerous ways, with tradeoffs in labor requirements, level of starch output, and whether, after processing, cassava meat remains that can be eaten. The simplest processing method is just grating the cassava and using it directly. Labor requirements are extremely low, but no cassava meat remains. The remaining four methods involve squeezing the grated cassava meat through a cheese cloth. This can be done just once, and then use the squeezings for the porridge, leaving the meat for cooking. Another option is to reconstitute the meat with water, and squeezing a second time, allowing more starch to be extracted. In addition, when the juice is left to settle, the starch partially separates from the liquid, and either just the liquid or just the starch can be used. In the original process, only the starch was used. While using just the liquid raised concerns because it seemed that too little starch would remain in the juice, if this method does work, the starch sediment that remains is tapioca starch, which can be sold.

2.2.1 Testing Methodology

In order to determine the appropriate amount of cassava to be used, and to understand what types of methods of cassava processing are acceptable, two testing variables were identified: the ratio of charcoal powder to binder used, and the formulation of the cassava. For testing, a modified fractional factorial design was used, as shown in Table 3. All methods of cassava processing were tested at a baseline level, which was identified in earlier work as an amount of cassava that worked well, consistently. The squeezing once and twice methods were also tested at a low and high level of starch, as these methods seemed most promising for balancing labor costs with usable by-products and strong briquettes. For each test run, five briquettes were made, allowing for two types of strength tests, the metric by which the briquettes were judged. Although using more briquettes for each test run would have been preferable, the availability of carbonized sugarcane was quite limited, necessitating these testing parameters.

Table 3: Cassava Testing Methodology

	Level of Starch Used		
	Baseline	Low	High
Just grated, no squeezing	X		
Squeeze once	X	X	X
Squeeze twice	X	X	X
Only starch sediment	X		
Liquid only, no sediment	X		

The two tests used were a hand crushing test and a more traditional compression test. The compression test, following ASM standards [45], provided a rigorous evaluation of briquette compression strength. However, the hand crushing test was also necessary to provide calibration, defining a baseline strength level for whether briquettes are acceptable.

a health standpoint. However, testing the relationship between cassava levels and briquette smoke output was beyond the scope of this study.

2.2.2 Results of Briquette Strength vs. Cassava Formulation Tests

The results of the hand crush and compression tests are shown in Figure 8. On the y-axis, the different types of cassava formulation are defined, and are grouped into three sections: single squeezings, double squeezings, and other methods of processing. The amount of starch used is denoted by the color density of each bar, with low levels of starch denoted by a light hue, and vice versa. If a particular run passed the hand crush test, the bar is green with a solid border; if it failed, the bar is red with a dashed border. Finally, the x-axis defines the average compressive strength of each run, with the purple lines at the end of each bar showing the range of briquette compressive strengths. The dotted line at 600 kN/m^2 specifies a baseline strength that was determined based on correlating the compression and hand crush tests: briquettes that can withstand 600 kN/m^2 of pressure should pass the hand crush test.

2.2.3 Analysis of Briquette Strength vs. Cassava Formulation Tests

The results of the hand crush and compression tests offer two main contributions to the charcoal project. First, there are four cassava processing methods that result in sufficiently strong briquettes: squeezing twice, grating, using only the starch sediment, or using only the liquid without sediment. That the final option is acceptable is a bit surprising – the initial hypothesis was that removing the starch sediment would not leave sufficient starch in the liquid to create strong briquettes. Hence, it is recommended that further testing be performed if the liquid only formulation is preferred in certain regions, to confirm these findings. Regardless of this concern, the fact that four distinct methods create acceptable briquettes provides a real benefit to implementers of this process: depending on labor, capital, and cassava availability, as well as regional preferences, the cassava can be processed differently without affecting the strength of the briquette. This flexibility is highly desirable for this type of process.

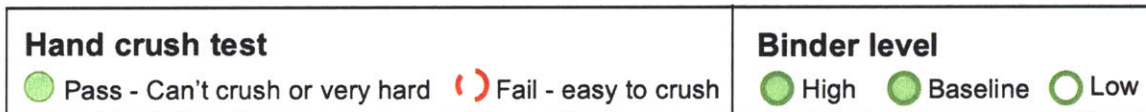
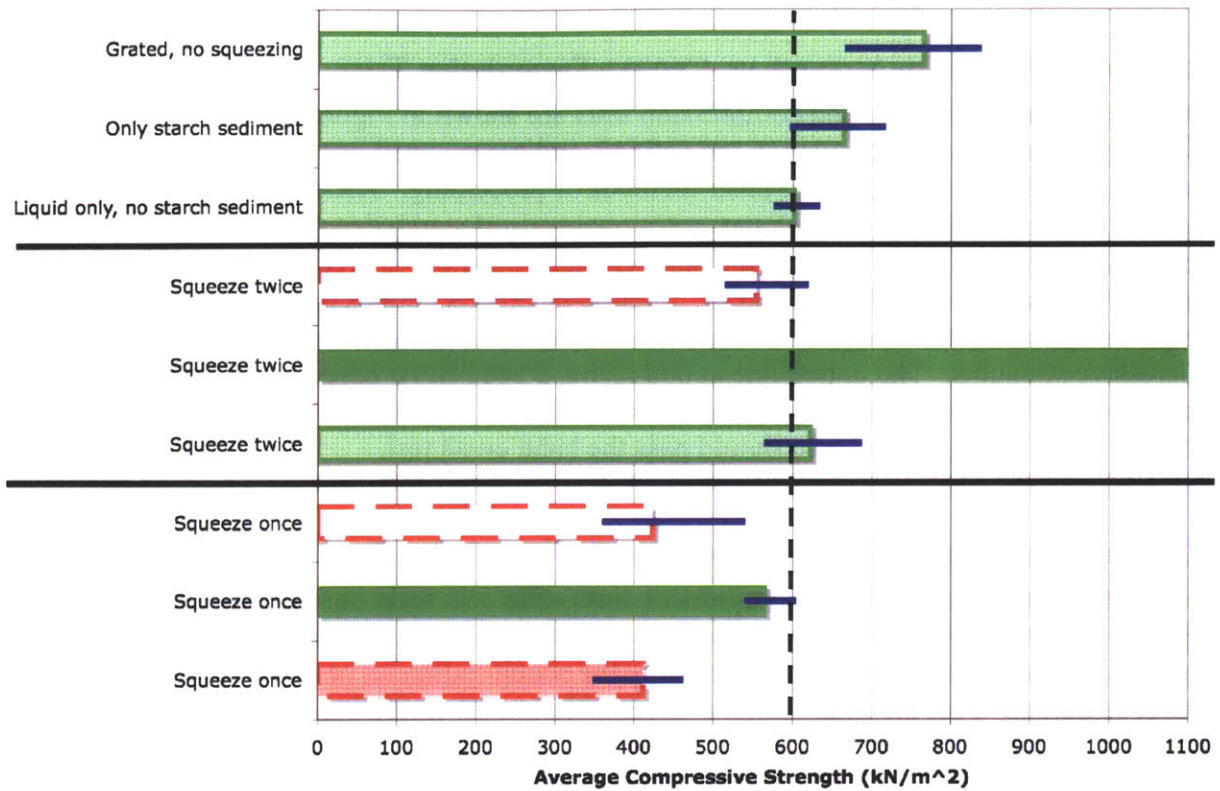


Figure 8: Briquette Compression Strength Test Results

The second crucial outcome from this test is the finding that the baseline level of starch identified originally is very close to the minimum amount of starch acceptable: all versions of briquettes tested with the lowest level of binder failed. As the goal is to minimize the amount of cassava used, these results confirm that the level chosen is not excessive. While more detailed investigation might demonstrate that a further, modest reduction in cassava is acceptable, given the lack of quality control anticipated for real-world use of this process, it is recommended that a “safety factor” be included in the minimum amount of cassava used, so that variations will yield some briquettes that fail the strength requirement. In addition, it is clear that modest increases in the amount of cassava used create significant improvement in the strength of the briquette, so end users can increase cassava usage if harder briquettes are desired.

Based on the tests outlined in this chapter, Table 4 provides recommendations for the formulation of cassava in sugarcane briquettes.

Table 4: Cassava Formulation Recommendations

Processing method	Cassava (ml)	Water (ml)
Starch sediment only	25	475
Squeeze twice	50	150 (for squeezing) 300
Just grated	50	450
Liquid only	250	250

for all options, 500 g of charcoal powder is used

3. Briquette Characterization

Apart from process improvements, the goal of this work was to characterize the sugarcane briquettes to assure that they meet the needs defined by researchers working on the charcoal project and the end users.

3.1 Briquette Performance Goals

Sugarcane briquettes should be comparable to wood charcoal based on three criteria: briquette strength, emissions during cooking, and burn characteristics during cooking. These performance goals for the briquettes were identified through conversations with other researchers working on the charcoal project and informal interviews with potential users in Haiti and Ghana.

3.2 Briquette Testing Methods

Based on the briquette performance goals, a number of testing methods were identified for characterizing the briquettes. For strength testing, three tests were used: the compression tests described in section 2.2, a drop test, and a douse test. The drop test consisted of dropping briquettes from a height of 4' onto a linoleum over concrete surface and was used to verify that if a user dropped a briquette (where it would typically be dropped onto dirt), the briquette would not break. The douse test was developed because it is a common practice that, if wood charcoal remains after a meal has been cooked, the chef will douse the briquettes in water to save them for another meal. Since sugarcane briquettes are bound with a water-soluble binder, there was concern over whether this practice would be feasible with this type of briquette.

For emissions and burn characteristics, three tests were used: a profile of combustion gases, a temperature profile, and particulate monitoring. For particulate monitoring, a Met One® 531 Aerosol Particulate Profiler was used, while a Bacharach ECA 450 Combustion and Environmental Analyzer was used for temperature and gas emissions profiling. For this series of tests, equal weights of wood charcoal from El Salvador and sugarcane charcoal were burned. The fires were started with a tablespoon of paraffin wax and covered with a chimney that allowed capture of combustion gases, as required by the combustion analyzer.

3.3 Briquette Characterization Results and Analysis

As described in section 3.2, a range of tests were performed to characterize the sugarcane briquettes.

3.3.1 Strength Tests

The compression tests, described in section 2.2, confirmed that the briquettes are sufficiently strong, as long as sufficient cassava is used. All ten briquettes that were dropped passed the drop test. As for the douse test, while a reduction in briquette volume occurred when burning briquettes were doused, the remains were large enough that they could easily be reused. It is recommended that users consider covering the fire, rather than dousing it, to prevent this volume reduction but, as end users are often reluctant to change their habits, the dousing method is a viable option.

3.3.2 Emissions Tests

Table 5 displays results for sugarcane charcoal gas emissions, as compared to wood charcoal. The percentages were calculated by taking the total of all emissions measured for all tests over a set amount of time for each test. Figure 9 shows a representative graph of emissions for sulfur dioxide. The spike at the start of this graph, and the subsequent temperature profile in Figure 10, is due to the use of paraffin wax as a fire starter.

Table 5: Comparison of Sugarcane and Wood Charcoal Emissions

Gas	Total sugarcane charcoal emissions, compared to wood
CO	4% worse
NOX	40% better
SO2	36% better

Overall, sugarcane charcoal is superior to wood charcoal in terms of emissions; the slight increase in carbon monoxide emissions is offset by the decreases in nitrogen oxides and sulfur dioxide. The results are very promising for assuring that using sugarcane charcoal will not exacerbate the health risks that wood charcoal users currently face.

Figure 10 shows temperature profile results comparing sugarcane and wood charcoal from El Salvador. As is evident from the graph, sugarcane charcoal produces approximately 80% of the heat of wood charcoal over a standard 100-minute cooking period. These results are concerning, as cooking behavior is a key characteristic about which end users are very sensitive. However, other tests done by the lead researcher on this project, Amy B. Smith (unpublished), have found the sugarcane charcoal to have a superior temperature profile to Haitian wood charcoal.

These contradictory results may have a number of causes, including:

- The quality of Haitian and El Salvadoran wood charcoal may differ
- All versions of the charcoal may vary from piece to piece
- Because only one combustion analyzer is available, tests cannot be run simultaneously; hence, weather variations may cause differences in behavior.

Further investigation is needed to better understand the reasons for these variations in outcomes, and to understand if the sugarcane charcoal is an acceptable substitute for local wood charcoal, based on the temperature profile. At present, it is not known how much temperature variation is acceptable for end users.

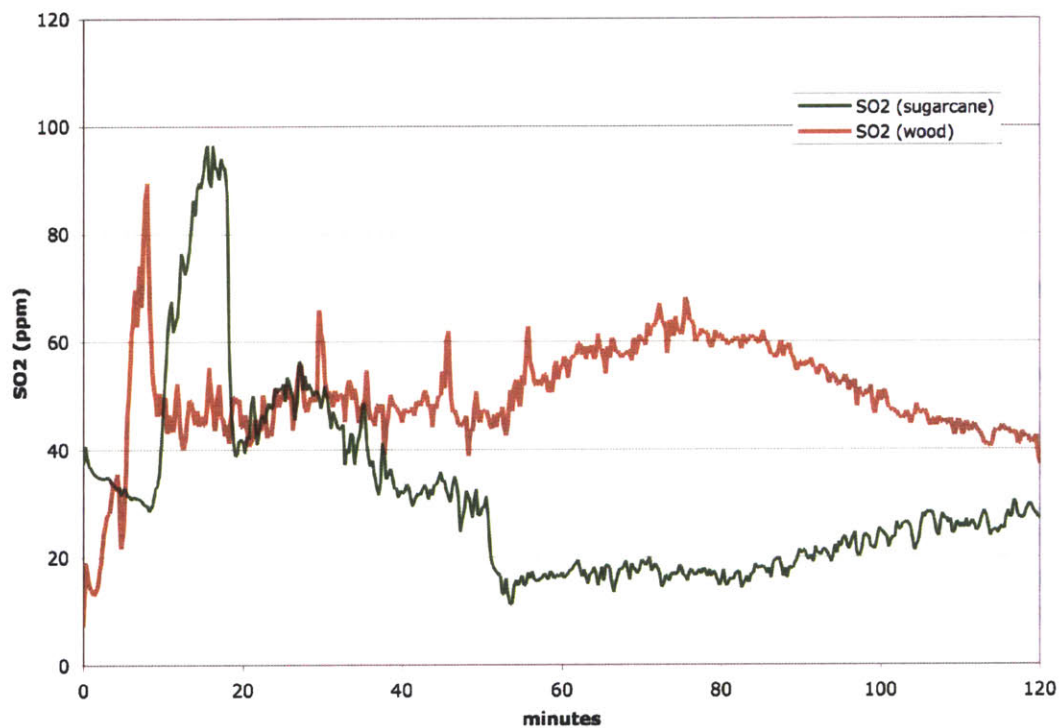


Figure 9: Sulfur Dioxide Emissions

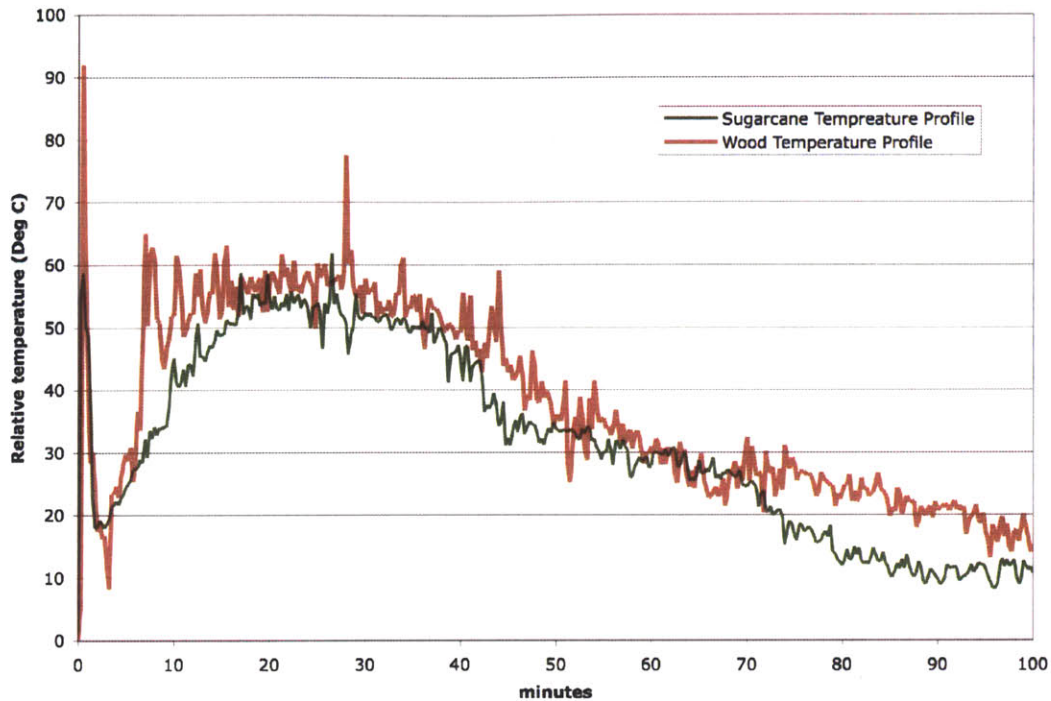


Figure 10: Temperature Profile Comparison of Wood Charcoal to Sugarcane Charcoal

3.3.3 Particulate Tests

Because testing time in the field was limited, tests for particle measurements and emissions measurements were performed simultaneously. This testing set-up led to highly unreliable results, since all particles were sent up the chimney used to capture emissions gases. Hence, depending on wind conditions, the particle measurements varied by orders of magnitude, yielding unusable results. Further testing is needed, in order to characterize briquette particulate emissions.

4 Conclusions & Future Work

The development of a charcoal briquette made from sugarcane has promising initial results. An improved method for crushing charcoal fines has been designed, built and tested, significantly improving the rate and safety of the original process. In addition, the briquette binder ratios and method for cassava processing have been identified and optimized. Finally, an initial characterization of sugarcane charcoal has been completed, although further work remains for understanding the temperature profile of the briquette and its particulate emissions, as compared to wood charcoal.

It is recommended that additional work on this project include two key steps. First, this method of making sugarcane charcoal should be disseminated in countries that might benefit, particularly Haiti but also countries such as Ghana and Guatemala, so that this work will leave the academic realm and offer benefit to those who need it most. Second, the investigation of other agricultural waste, such as corn cobs, rice and coconut husks, and palm fronds is recommended. Ideally, this

process should be expanded to accept as many types of agricultural waste as possible, so that variations in waste availability will not reduce the viability of agricultural-waste-based charcoal. In summary, sugarcane charcoal should be promoted as a viable alternative cooking fuel that can be processed in a novel way, allowing for minimal capital investment.

Section II: Service Learning in the Mechanical Engineering Education Core

1. Introduction & Motivation

Service learning is a pedagogy in which academically relevant community service projects and/or activities are integrated into the curriculum of a credit-bearing activity, helping students reinforce and synthesize key learning concepts. Features of service learning include a clear service objective that is tied directly to what students are learning, direct communication between students and one or many community partners, and reflection opportunities throughout the service learning portions of the class, to help students understand the impact of their work on their education and on society [6, 46].

A tremendous number of benefits to students are identified for service learning experiences, enhancing understanding of course concepts, especially within the greater context of the field; motivation to learn subject material; teamwork and communication skills; and relationships with other students and faculty members. It may also impact students' career aspirations, interest in community service, and knowledge of the ethical responsibilities of their chosen profession. For community partners, the benefits include receiving specialized help from disciplines that they are less likely to be able to access, and making connections with universities. The university can benefit by using service learning to help recruitment and retention, and to improve town-gown relations [1, 4-6]. It is important to note that the quality of the service learning project, as defined in the first paragraph, is crucial for these benefits to be imparted [47, 48].

Given these positive benefits, service learning has been a relatively common practice in liberal arts education for decades [1], but it is only recently that it has been introduced formally into engineering education, and the practice is much more common in design-focused electives than in core engineering classes required of all students [49]. For example, Purdue University created the EPICS Program (Engineering Projects in Community Service), which has been a great success for engineering-oriented service learning at Purdue, and has since expanded to thirteen universities within the US, and two internationally [26]. However, students in EPICS classes are typically given elective credit for the experience, and the skills explicitly taught are primarily softer skills: team work, project management, communication, and leadership. Likewise, service learning is reasonably common for capstone classes, such as in the civil engineering department at the University of Utah [3], but rare for earlier courses focused on specific discipline areas. While use of the pedagogy is expanding in engineering education, the use of the practice in core classes, where the oft-cited benefits of student motivation and understanding of course material [4-6] might be most significant, is rare. While these experiences are certainly beneficial and of merit, a gap exists for the use of service learning in standard engineering classes.

There are a variety of reasons for this difference, but one reason often given is that faculty are not aware of community service projects that could augment the curriculum of technical engineering topics like thermodynamics or solid mechanics. A second key concern is often that course time is limited, given the number of concepts typically taught in an engineering class, and service learning may distract from, rather than enhance, the learning objectives of the class. A

third common concern is that faculty time is very limited, preventing significant effort into redesigning a class, finding community partners and projects, and learning best practices for service learning so that the faculty member feels able to use the pedagogy. Hence it is understandable that service learning is more common in elective subjects, where time is less tight and there is more curricular flexibility, allowing for a broader set of projects.

However, if it is possible to mitigate the challenges for service learning in engineering cited by faculty, service learning could be integrated into core classes in engineering curricula, and the impact of service learning could be much greater, for students, community partners, and the university. More students would be reached, enhancing the outcomes mentioned above. If service learning projects can be structured so that they augment rather than detract from the course objectives, the pedagogy can provide a highly efficient way for students to learn course material, apply it, and gain the “softer” skills needed for engineering proficiency [50], but difficult to introduce into traditional engineering classrooms.

Further, study of outcomes of service learning for engineering students specifically is rare, despite the fact that the educational methods and goals for undergraduate engineering are typically quite distinct from a liberal arts education [51]. While it is hoped that the benefits will translate, particularly for those often under-represented in engineering disciplines – women and minorities – documentation of these specific benefits is needed.

Hence, curriculum was developed for three core classes in the mechanical engineering department at MIT: 2.002 Mechanics and Materials II, 2.006 Thermo-Fluids Engineering II, and 2.009 Product Engineering Processes. The curriculum was implemented over the 2004–2005 academic year and assessed using pre- and post-survey instruments to determine whether the pedagogy has benefit for students. A four-year longitudinal study was also performed for use of service learning in 2.009 specifically.

Additionally, faculty in the mechanical engineering department were interviewed to ascertain their interest in and concerns about using service learning in the classes they teach, since working to increase the use of service learning pedagogy in the department is sensible only if faculty believe the practice has merit.

1.1 Research and Reporting Methods

A limitation of the research with students is that random selection and use of control groups was not possible, because such efforts would have posed pedagogical problems. Students were compared by gender, ethnicity, and service learning participation. For ethnicity, students were lumped into two categories: all Caucasian students were considered non-minority, and all others were considered minority students. For most ethnic groups, this categorization is reasonably straightforward. However, for Asian students, who are not considered underrepresented minorities at MIT, this method is a bit more complex. Asian students were put into the underrepresented minority category because, in the U.S., they remain underrepresented, and, within MIT, there have been reports of discrimination that suggest that they may have an experience at MIT more similar to underrepresented minorities than do Caucasian students.

Throughout this chapter, a variety of statistical tests were performed to compare outcomes for different groups, and are reported using APA guidelines [52]. For example, t-tests are denoted using a lowercase t, while ANOVAs use a capital F. For both tests, that letter is followed, in parenthesis, by the degrees of freedom. A 5% significance level was used for most tests, unless otherwise noted, and the exact significance value is given following the letter p.

2. Faculty Views of Service Learning in Mechanical Engineering at MIT [53]

At MIT, service learning was first used deliberately in a mechanical engineering class in the spring of 2002. Subsequently, faculty attitudes toward service learning were measured informally: we found that when the project matched the class curriculum well and the community partnership was strong, the faculty were very pleased with service learning; when either or both of these criteria were not met, faculty were understandably much less enthusiastic.

Therefore, as part of a planning process to develop an infrastructure and curriculum for the broader integration of service learning in the mechanical engineering department, we sought to better understand faculty knowledge of, enthusiasm for, and concerns about service learning. To this end, structured interviews were conducted to gain insight into MIT mechanical engineering faculty's perception of service learning.

2.1 Background

Studies of faculty attitudes about service learning are reasonably rare. Driscoll suggests that a significant body of research is needed in order to increase the adoption of service learning [54]. A small number of studies examine the reasons that faculty elect to employ service learning as part of students' curricular educational experiences. Hammond completed one of the most comprehensive studies that focused solely on faculty who were already using service learning; the study found that faculty are motivated primarily to use service learning in order to improve student learning [55]. Hesser [56], as well as McKay and Rozee [57], completed similar surveys of faculty, with similar findings. However, only Hammond's study includes research-focused institutions, and the study does not address similarities or differences between attitudes at those schools and other types of universities. Further, it is not clear if these studies include surveys of engineering faculty.

It is not necessarily the case that general findings are applicable to engineering programs or research-focused institutions. Abes et al. completed a more recent, comprehensive study that also included research universities (N=86, 40% of the study) and "math, engineering, computer sciences" faculty (N=5, 18% of the study) and found significant differences between these variables on certain measures [58]. This study also found that faculty adopted service learning primarily because of student educational benefits, and secondarily for benefiting the communities served. Faculty who did not use service learning reported that "time, funding, and logistical concerns" were most critical, followed by "curricular and pedagogical concerns."

While a number of studies survey engineering faculty exclusively, none include questions about service learning that focus on more general education topics, such as ability to teach engineering

teams [59], teaching styles [60], and time spent improving teaching [61]. As the Abes et al. study has such a small sample size for engineering, there is a clear need to study engineering faculty's interest in service learning given the paucity of data that exists currently.

Despite the limited data on faculty using service learning in engineering classes, the practice is slowly increasing in engineering educational settings, in part because it can help instructors meet many of ABET's EC 2000 Criterion 3 accreditation requirements [1]. The literature published thus far focuses on implementation methods for service learning in engineering education rather than on faculty attitudes [6, 49, 62-64]. These papers provide mainly anecdotal evidence that engineering service learning activities have been well-accepted by students and faculty alike. Based on the positive educational experiences described, many authors propose the implementation of service learning in other engineering educational programs. Yet, adoption is slow, and it is suggested that faculty attitudes and perceptions about, and lack of support infrastructure for, service learning in engineering education may be one important factor in adoption rates. Hence this study of such attitudes is an appropriate one, since it expands knowledge about factors that might facilitate or hinder adoption.

2.2 Faculty Survey Method

Faculty were surveyed using a brief (ten minute), structured, one-on-one interview. This method was chosen because faculty have been far more willing to take ten minutes to be interviewed in person than to respond to a paper or an electronic survey, especially because many were unaware of service learning and were less likely to comment on an unfamiliar practice in writing. Previous paper service learning surveys given to MIT mechanical engineering faculty for gauging interest and for evaluation following service learning classes resulted in a typical response rate of under 5%, but through a variety of in-person interactions, it was clear that faculty were generally interested in service learning. While issues of demand characteristics and good subject biases can be pronounced for interview formats particularly [65], care was taken to encourage all responses and minimize social desirability effects. Interview instructions indicated that the interview was not only trying to gauge knowledge about and interest in service learning but also to understand concerns about and limitations of the practice. The open-ended format of questions and structured probes for both positive and negative aspects of service learning were used to encourage expression of all attitudes. Additionally, the method was deemed necessary in order to get feedback from as many of the faculty as possible.

Considerable persistence was required to reach most of the 75 faculty members in the department at the time of the study. As shown in Figure 11, half of the interviewees, 27 (36%), were reached after one or two emails requesting interviews; another 27 were reached by subsequent emails, phone calls, and unscheduled visits to their offices. Four faculty (5%) requested interview times far in the future. Six (8%) explicitly declined to be interviewed, and 11 (15%) were never reached. In total, 64 faculty (85%) were contacted, and 54 (72%) were interviewed at the time of the study.

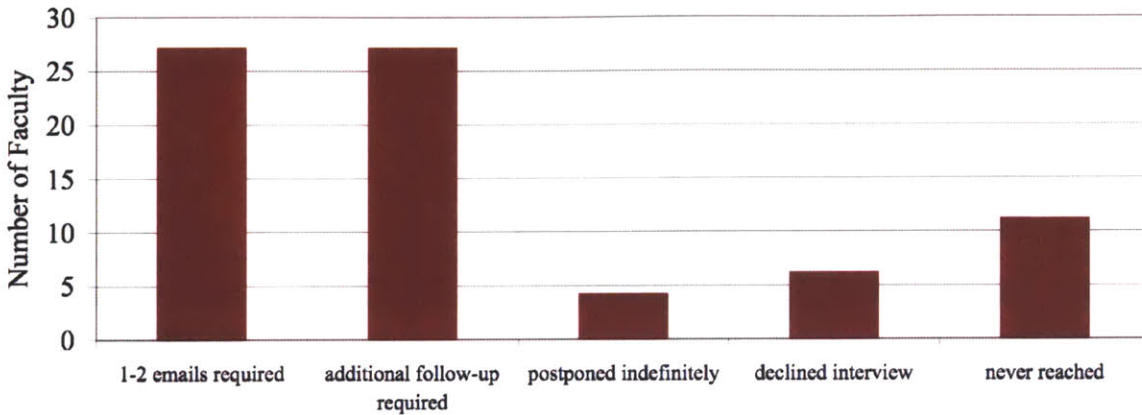


Figure 11: Faculty Response to a Request for an Interview

Because of scheduling constraints, seven people were involved in carrying out the 54 interviews, though the majority were given by two primary interviewers. All interviewers were instructed on how to perform the interviews, and all used structured interview questions to standardize the interview procedure. While interviewers took hand-written notes, audio-tapes of the interviews ensured comprehensive collection of interview data.

The interview questions were organized into a number of parts. First, faculty’s awareness and general impressions of service learning were ascertained. Then the interviewer defined service learning, giving some examples specifically appropriate for engineering classes. Next, faculty were asked to discuss in more detail what they liked and disliked about the practice, their openness to trying service learning in classes they teach, and what classes in the department they believed were most appropriate for service learning. At the conclusion of the interview, handouts on service learning at MIT and the associated service learning grants program were given to increase faculty awareness of the resources available at MIT for such work.

Most of the questions allowed for an open-ended response; however, a quantitative scale was used to ascertain faculty’s future behavior: “On a scale of 1-10, with 1 being not at all open, and 10 being completely open, how open are you to trying service learning in classes you teach?”

2.3 Results and Analysis

The 54 faculty interviewed for the project were a representative sample of the 75 faculty in the MIT mechanical engineering department based on three factors: tenure status, gender, and department division (faculty in the department are divided into three divisions: I - mechanics and materials; II - fluids, energy, and transport; and III - design, manufacturing, systems, controls, and information). Figure 12 compares demographics for all faculty in the department to their interview status.

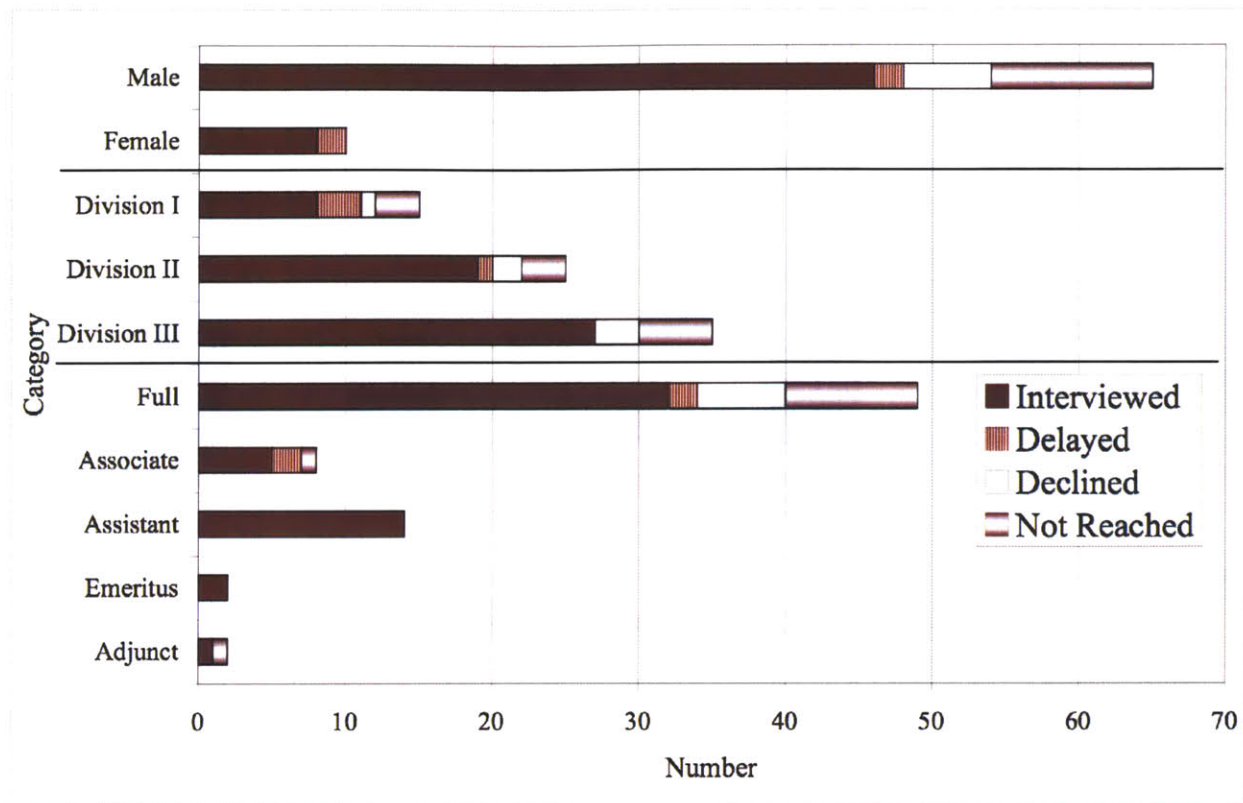


Figure 12: Demographics for Faculty Interviewees

We hypothesized that tenure status, gender, and departmental division might be influences on whether a faculty member agreed to be interviewed, especially because the principal investigator on the grant funding this study is in the design division (III), and because the most well-known service learning class in the department is a design class. We considered the four who delayed their interview to be part of the interviewee group for this analysis because they were willing to be interviewed. We grouped those whom we were unable to reach into the “declined” group: since we tried multiple methods of reaching them repeatedly, it is likely that they would decline to be interviewed were we able to reach them.

To test the relationship between tenure status and whether a faculty member agreed to be interviewed, a Yates chi-squared test was performed, comparing full professors to all others. The difference was barely significant, with $p=0.049$. We hypothesize that perhaps professors still working toward full tenure might be more interested in new teaching methods and/or more willing to collaborate to build relationships. For gender, a one-tailed Fischer exact probability test was performed because the number of women was not high enough to use a chi-squared test. The t-test showed no significant difference, with $p=0.085$. For division, faculty in division III were compared to those in either divisions I or II, using a Yates chi-squared test, with $p=1.0$, showing no significant difference between the groups.

The faculty interviewed were varied as to whether they had heard of service learning previously: 28 (52%) had heard of the practice, 22 (41%) had not heard of it, and four (7%) were not sure whether they had heard of it. All but one of those who had heard of the practice were aware of it

through MIT – either colleagues had mentioned it, service learning staff had reached them directly or indirectly, or they were aware of a service learning class in the department.

All 54 interviewees were asked to define the term “service learning” regardless of their familiarity with it. As shown in Figure 13, 23 (42.5%) said they were not sure, ten (18.5%) gave a definition quite different from how it is generally used [1], 16 (30%) were generally able to define it, but did not emphasize the criticality of both service and learning, and five (9%) defined it in a way that it aligned well with the definition given in the introduction of this paper, the one used by MIT’s service learning program. Following that question, all interviewees were given the definition used by MIT’s service learning program and were asked to consider the remaining survey questions using the given definition.

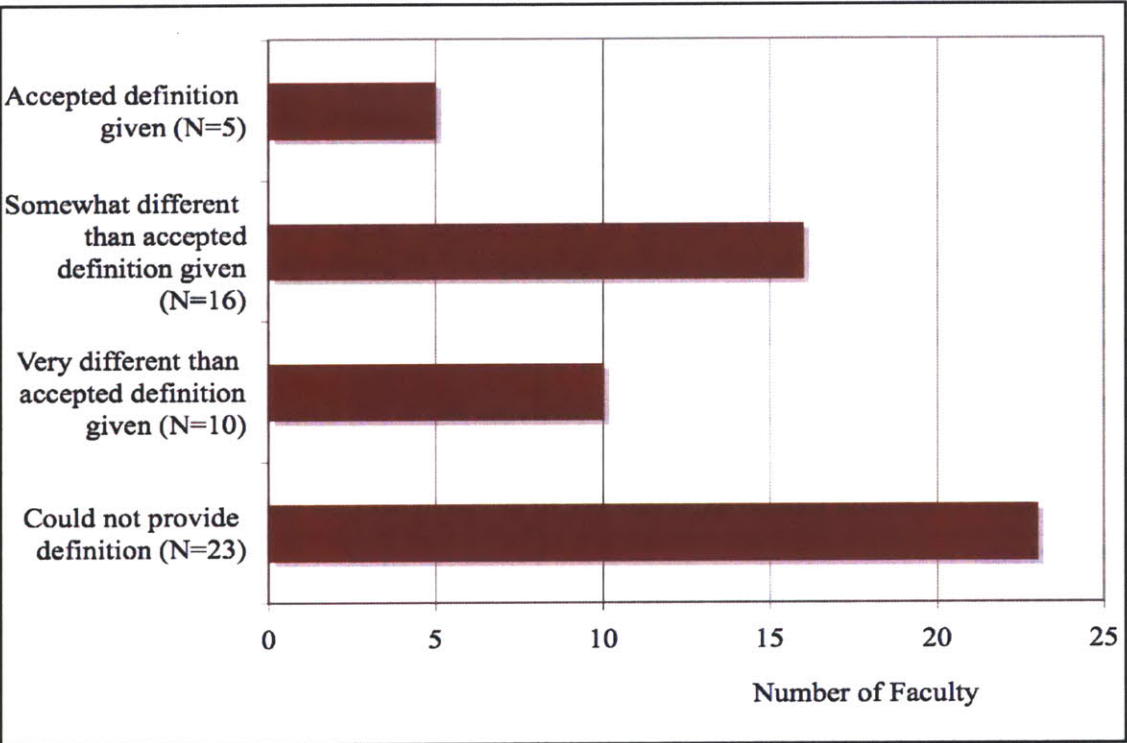


Figure 13: Faculty Definitions of "Service Learning"

Of the 28 faculty familiar with service learning, 18 (64%) had a “good” impression of it, 1 (4%) had a “bad” impression of it, and 5 (18%) had “mixed” impressions of it. The remaining 4 faculty (14%) did not report an impression. Faculty were asked to provide a rationale for their positive or negative impressions in terms of the possible benefits or concerns for service learning implementation in the mechanical engineering curriculum. Table 6 and Table 7 present these results.

Table 6: Faculty beliefs about the benefits of service learning (N=54)

Benefit of Service Learning	N	%
Provides service to a community	29	53.7
Motivates students	19	35.2
Helps students develop experience and skills to help society	16	29.6
Helps students contextualize their learning	13	24.1
Helps students understand course material	9	16.7
Is an efficient, good use of student time	6	11.1
Helps MIT's reputation	4	7.4
Helps students consider the ethical issues of engineering	3	5.6
No Benefit	2	3.7

A majority of faculty interviewed considered service learning beneficial because it provides service to a community, and many believed that it motivates students and helps them to develop skills that will allow them to help a community. A quarter believed it could help students to contextualize their learning. These findings do not align well with earlier published faculty studies described in the background section, in which faculty adopt service learning primarily because of student educational benefit. A key difference in these studies may explain the contradiction: almost all of the faculty surveyed here have never tried service learning, whereas the faculty documented in the other surveys were ones using service learning.

Table 7 displays the logistical and pedagogical concerns about the concept of service learning.

Table 7: Faculty concerns about the practice of service learning (N=54)

Concerns	N	%
Difficult to find an appropriate project	30	55.6
Class curriculum too tight to fit in service learning	28	51.9
Possible conflict between service and learning goals, leading to negative effect on academic rigor	22	40.7
Time-intensive to revise the course curriculum	18	33.3
Challenges of working with off-campus community partner	14	25.9
Potential harm to or disappointing community partners	9	16.7
Logistical headaches	8	14.8
Need training to do service learning well	8	14.8
(Some) students don't like service learning, especially if done poorly	5	9.3
Liability and safety concerns for the student and/or community partner	3	5.6
Not efficient use of student's time or way to provide service	2	3.7
Service could distract students from course material	2	3.7
Against MIT entrepreneurial spirit	1	1.9
No concerns	1	1.9

The top concern faculty had about service learning was finding an appropriate project, followed closely by class curriculum constraints. Faculty also worried that the service would negatively

affect academic rigor. These concerns are highly understandable: finding appropriate service learning projects for engineering classes is challenging, as we found in previous MIT pilot projects and, without an appropriate project, it is very likely that the service project goals and a subject’s learning goals will conflict. Concerns about the effort to revise the course curriculum and interact with an off-campus community partner were also commonly cited. Many of the concerns mentioned by faculty aligned well with results published in the service learning literature and prior interactions with MIT faculty. Additionally, it is no surprise that MIT faculty face serious constraints on their own time and on the course content.

Figure 14 displays how faculty responded to the question, “On a scale of 1-10, with 1 being not at all open, and 10 being completely open, how open are you to trying service learning in classes you teach?” Two sets of data are shown, since 18 faculty (33%) gave two responses to the question – a lower response for a worst-case scenario, and a higher response for a best-case scenario. For faculty who gave a single response, that response is included in both categories.

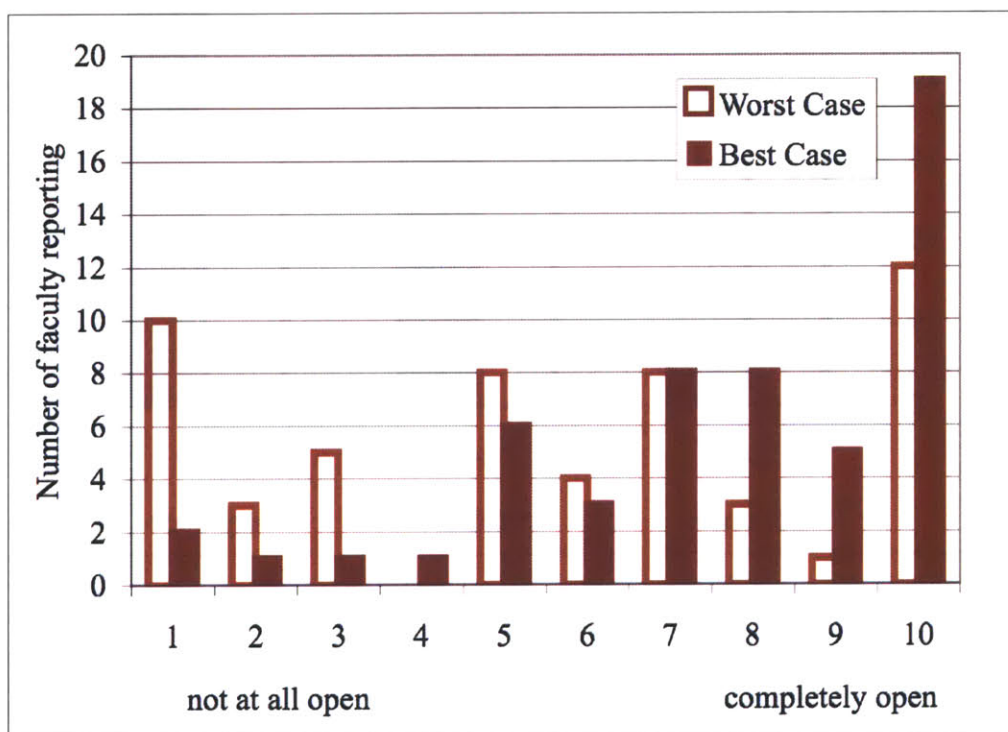


Figure 14: Openness of faculty to trying service learning in classes that they teach, N=54

The worst-case scenarios discussed included not having enough time, not finding the right project, or teaching a class particularly ill-suited to service learning. The best-case scenarios included teaching an appropriate class, having a highly appropriate project, and receiving sufficient support from the service learning staff at MIT (despite outreach efforts, few faculty were aware of the available support). For the worst-case scenario, faculty’s average response was 5.6 (scale 1=not at all open, 10=completely open, standard deviation +/- 3.3). For the best-case scenario, the average was 7.6 (standard deviation +/- 2.5). Overall, the average was 6.6 (standard deviation +/- 3.1).

As shown in Figure 15, dividing the responses into three categories – scores of 1-3, 4-7, and 8-10 – it becomes clear that given the worst-case scenario, faculty are evenly split in their openness to service learning (18 not open versus 16 highly open), and in the best-case scenario, the majority (32) are open to the practice. While there are four faculty who are clearly not interested in the practice, and for some faculty their worst-case scenario is the most realistic, many are open to the practice regardless of the challenges.

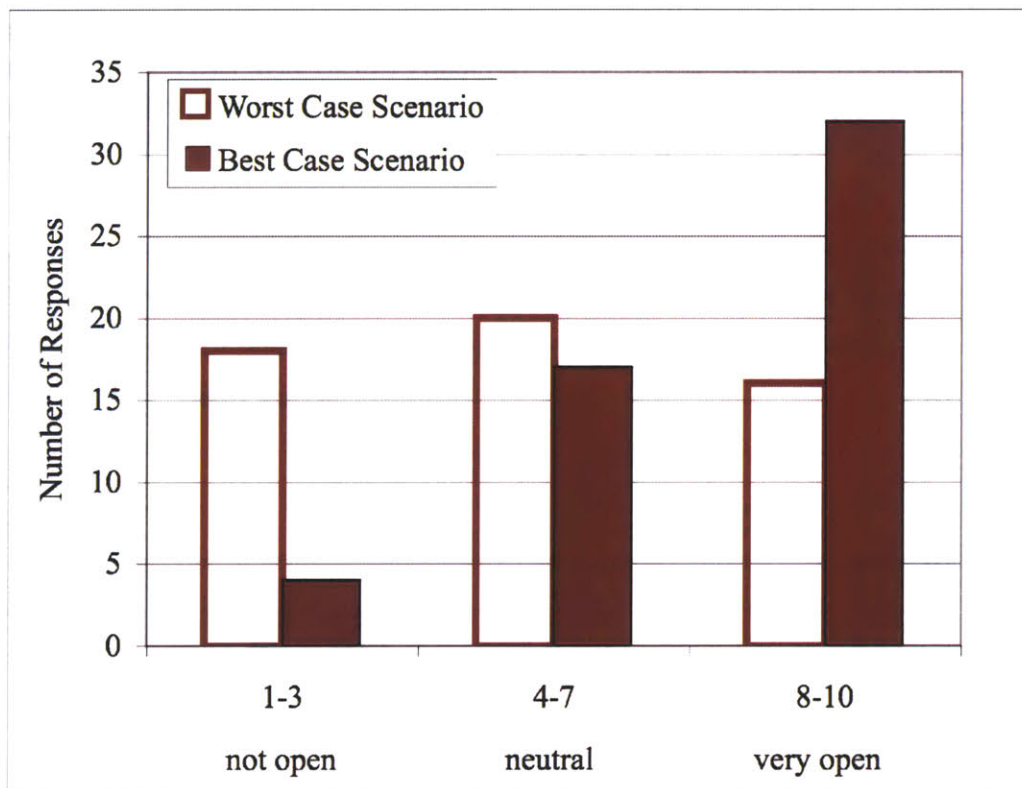


Figure 15: Lumped Faculty Openness to Using Service Learning (N=54)

Table 8 shows the list of undergraduate classes that faculty believe are best suited to service learning. By far, most faculty consider design-focused classes to be most suitable, with the top four most-suggested classes being design classes. While part of this overall effort is to integrate service learning into more theory-focused classes, this finding is entirely unsurprising. 2.009, the class that 94% of the faculty mentioned as being appropriate for service learning, is the mechanical engineering class at MIT that has done the most service learning, so it is what most faculty are aware of when they think of the practice. The majority of service learning engineering classes that have been written about, and cited in the background section of this paper, focus on engineering design. Further, it is likely that the survey itself caused faculty to think of design as most appropriate, since the service learning examples given were primarily design examples, an unfortunate error in survey design. However, some faculty mentioned other classes and many were open to using service learning in classes they teach, even though

they do not teach design classes.

Table 8: Faculty Beliefs of MIT Classes Most Suited to Service Learning (N=54)

Class Number	Class Name	Div	# Faculty Mentioned	% Faculty Mentioned
2.009	The Product Engineering Process	III	45	94%
2.007	Design & Manufacturing I	III	32	67%
2.008	Design & Manufacturing II	III	21	44%
2.72	Elements of Mechanical Design	III	16	33%
2.006	Thermal-Fluids Engineering II	II	12	25%
2.005	Thermal-Fluids Engineering I	II	9	19%
2.002	Mechanics & Materials II	I	7	15%
2.001	Mechanics & Materials I	I	6	13%
2.670	Mechanical Engineering Tools	N/A	6	13%
2.671	Measurement & Instrumentation	N/A	6	13%
2.672	Project Laboratory	N/A	6	13%
2.THU	Thesis	N/A	6	13%
2.003	Systems, Modeling & Dynamics I	III	3	6%
2.004	Systems, Modeling & Dynamics II	III	3	6%
2.41	Advanced Thermal-Fluids Engineering	II	3	6%
2.14	Analysis & Design of Feedback Control Systems	III	3	6%

2.4 Faculty Interview Conclusions

A survey of 72% of the MIT mechanical engineering department showed a moderate level of awareness of service learning and inconsistent views of the definition of service learning. However, after hearing an accurate definition, most faculty expressed interest in using service learning, regardless of their gender, position, or research discipline. Key hesitations about the pedagogy included finding appropriate service projects and service learning limiting the number of curriculum objectives they could fulfill.

The results of this survey also suggest that faculty understanding of service learning pedagogy and its benefits is highly varied and incomplete. Faculty saw the value of service learning primarily as a way to provide service, and were less aware of how service learning can improve student learning, a key difference from other studies of faculty interest in service learning. To improve faculty awareness of service learning benefits and best practices, the survey results are being used to propose an infrastructure to support a broader application of service learning concepts. Faculty are interested in using service learning in their classes, but they need significant support in terms of training, curriculum development, and project identification. It is hoped that these findings will encourage both the mechanical engineering department and the service learning program at MIT to increase the level of support they provide in these areas.

The one-on-one, comprehensive interview approach was time-intensive, but it is recommended that other universities perform similar interviews if they are trying to establish similar

departmental-level integration of service learning, since such knowledge of a large department's interest in a teaching practice is quite rare. While many of the concerns we found were similar to those found in other surveys of faculty, some differences were evident, and having this confirmation of interest is highly encouraging, especially given the conventional wisdom that engineering faculty at research universities may be more resistant to education reform than most. The process also provided an additional benefit of increased interaction and information flow with departmental members, laying the groundwork for positive change.

3. Integration of Service Learning into Core Mechanical Engineering Classes

Three classes adopted service learning pedagogy during the 2004-2005 academic year: 2.002 Mechanics and Materials II, 2.006 Thermal-Fluids Engineering II, and 2.009 Product Engineering Processes, referred to subsequently by their class numbers. In this section, the classes, process for integration of service learning, and research outcomes will be discussed.

3.1 Class Descriptions

Descriptions for each class are summarized and excerpted from a Program Self-Study Report submitted by the department to the Engineering Accreditation Commission [66], course syllabi, and data from MIT's registrar.

2.002 is a required, sophomore-level class that focuses on the mechanical behavior of engineering materials and the selection of materials for engineering design. The course objectives are for students to gain:

- an awareness of the varied behavior that engineering materials can exhibit when subjected to mechanical and thermal loading
- an understanding of the fundamental physical mechanisms associated with design-limiting behavior of engineering materials, especially stiffness, strength, toughness, and durability
- an understanding of the mechanical behavior of engineering materials, the ways in which these properties characterize material behavior, and of the testing procedures that quantify these properties
- quantitative skills to deal with material-limiting problems in engineering design and a basis for materials selection for mechanical design

Class size is generally 35-60 students who all attend two one-and-a-half hour lectures each week, go to one of three or four two-hour laboratory sections each week, and are expected to spend about seven hours per week studying for quizzes and tests, completing problem sets, and writing laboratory reports. The class staff includes a professor who gives the lectures, different instructors for each lab section, two teaching assistants, and a laboratory technical instructor who sets up the experiments in the lab and helps all lab sections.

The laboratory portion of 2.002 is a primarily a combination of recitation-style content with small experiments that reinforce course material. Students quantify mechanical properties of

materials and structures, select materials for applications, and also investigate an area of relevant interest at the end of the term through a three-week team project.

2.006 is a junior-level, required class that “focuses on the application of the principles of thermodynamics, heat transfer, and fluid mechanics to the design and analysis of engineering systems.” The course objectives are for students to:

- develop the fundamental principles and laws of thermodynamics, fluid mechanics, and heat transfer and the implications of these principles for system behavior
- formulate the models necessary to study, analyze, and design thermal-fluid systems through the application of these principles
- develop the problem solving skills essential to good engineering practice in thermal-fluid systems
- develop an understanding of sound engineering design of thermal-fluid systems

Class size is generally 25-70 students who all attend four hours of lecture each week, go to one hour of recitation per week, and are expected to spend about seven hours per week of studying for quizzes and exams, completing problem sets, and working on a thermo-fluid design project. The class staff includes a professor who gives the lectures, different instructors for each recitation section, and three teaching assistants.

For the design project, teams of 4-10 students perform the paper design and analysis to develop a comprehensive thermal-fluid system, and present the project orally in class and complete a written report.

2.009 is a senior-level, required class that focuses on learning and experiencing the early phases of product development, from idea generation to the “construction of a high-quality, functioning alpha prototype” in a large team setting. The course objectives are for students to:

- improve creative ability
- improve expertise in constructing models for reasoning about design alternatives. These include: estimations, sketches, and sketch models; spreadsheets, geometric models, and mockups or prototypes
- improve engineering expertise and proficiency in techniques for building high quality product models and prototypes
- learn and experience structured methods for working in large teams on a project that requires teamwork to be successful
- improve presentation skills using a wide variety of media
- develop an understanding of, and enthusiasm for, the engineering activities involved with designing a new product

Class size is generally 70-95 students who all attend three one-hour lectures each week and, in teams of approximately 16-20, work in one three-hour lab session each week. Students are expected to spend, on average, six hours per week outside of class on team and individual assignments, most of which contribute to the development of the final alpha prototype that each team builds. The staff includes a professor who gives the lectures, different instructors and at least one industry mentor for each lab section, two teaching assistants, six laboratory staff, and one librarian.

For the design project, teams have a budget of \$6000 and develop a mechanical or electro-mechanical device that falls into a broad course theme; recent themes (and projects) include agriculture (a lentil sorter based on density), alternative energy (a backpack-based vaccine transporter), and remotely-controlled devices (a remote-controlled water-rescue flotation vehicle). During the semester, each team proposes six ideas and then narrows to one concept through a series of milestones involving sketch models and early prototypes. This class is described in greater detail in section 4.2.

3.2 Service Learning Projects

As the three classes that adopted service learning have very different structures and curricular goals, the types of service learning project varied widely, depending on the needs of the class. Discussion of how projects were developed for the class is presented in the following section.

2.002: A service learning project was offered to students as one of the options that they could choose for the three-week project portion of their laboratory work. The service learning option was to quantify experimentally the material properties of an innovative type of charcoal being developed at MIT for use in Haiti that does not promote deforestation, discussed in Chapter I. Students were also asked to determine the relationship between rudimentary process parameters and resultant charcoal properties.

Students learned about the service learning project during a set of presentations on possible projects. The lab section instructor and lab technical instructor gave most presentations. The service learning project was presented by two members of a team working on the charcoal project: a Haitian woman and an MIT student. If a team selected the project, the MIT student attended the team's lab section, to provide insight into the project from her perspective and encourage informal reflection. Students presented their work in a final presentation, attended by the Haitian woman and MIT student who presented the idea originally, which provided the opportunity for more formal reflection.

For comparison, a representative non-service learning project is the analysis of bolts of different hardnesses, to quantify experimentally how hardness changes strength and brittleness characteristics.

2.006: All students were required to work on the same service learning end-of-term project: the design of an essential oils distillation unit for use in Haiti. Students were asked to develop an entire distiller, including a steam generator, condenser, and separator, considering cost of manufacture in Haiti, cost of operation, and quality of distillation.

Students learned about the project in a presentation given by a Peace Corps volunteer serving in Haiti who was flown in to provide first-hand context for the need, including conditions in Haiti that warrant and constrain the device. Follow-up lectures were provided by the teaching assistants to help students with the technical aspects of the project. The Peace Corps volunteer was available by email throughout the semester for students to ask questions. A number of local

Haitians active in MIT's international development efforts attended the final presentations, which included a reflective component.

For comparison, a representative non-service learning project used in the class in a previous semester was the development of a jet injector for vaccine delivery that does not involve dermal contact. While this type of device has a service flavor, it is not a service learning project, given the lack of contact with potential community partners and lack of reflective activities.

2.009: All students worked in teams to develop polished prototypes; service learning projects were introduced through an ideas fair, in which community representatives presented a range of service-oriented topics within the course's theme of alternative energy. Each team had to consider at least one of the projects presented at the fair for their first assignment, but were not required to pursue any idea or choose a service-oriented one. In the end, four of the six teams worked on service learning projects, which were a parabolic solar collector-powered pump for use in Lesotho, a human powered battery charger for use with a low-power microfilm projector developed in 2.009 previously, a backpack refrigerator intended to carry and deliver vaccines in developing countries, and an extruder for creating charcoal from the byproducts of the sugarcane industry for use in Haiti.

For comparison, a non-service learning project chosen that term was an MP3 player that was powered by motion. While this last project has modest environmental benefit because it is an alternative energy device, it was not a service learning project because the team lacked contact with a community partner.

3.3 Service Learning Integration Process

Given the diverse nature of these classes, it is unsurprising that the process of adapting each class to include service learning practices varied widely. However, all classes were consistent in their interaction with MIT service learning support structures, which have been critical to the development of service learning at the Institute. The program was developed in 2001 by the MIT Public Service Center, which encourages and supports the MIT community in engaging in a wide variety of types of service, and The Edgerton Center, which focuses on academic innovation and educational outreach.

The program is run by MIT's service learning coordinator, who is supported by staff from both of these centers, and who works to support faculty who wish to use service learning by identifying and liaising with community projects and partners, helping faculty understand and adopt service learning pedagogy, helping revise curricula and develop service learning course material, and assessing the outcomes of service learning for students, faculty, and community partners. Apart from the coordinator, the service learning program provides a number of support systems for its constituents:

- grants for students to pursue service learning projects, typically of a few hundred dollars to one thousand dollars, that provide students with funding for materials and/or travel to develop projects that they started during a service learning class
- grants for faculty to integrate service learning into the curriculum, of up to \$2000, for materials, travel, student staff support, and/or lab supplies

- a database of community partners and projects that have been identified
- a library of service learning resources to help faculty get project ideas and understand best practices for service learning
- assessment reports sent to faculty following the conclusion of their service learning classes, to document how students benefited, and to recommend improvements for future years

For this effort of integrating service learning into 2.002, 2.006, and 2.009, since the position of the coordinator was in flux during the time of the study, the role of service learning coordinator was essentially covered by a faculty member in the department researching service learning, a graduate research assistant, a cognitive psychologist, and an engineering instructor at the Edgerton Center who has extensive knowledge of international community projects; it is more typical for the coordinator to lead the effort, and be supported by these types of resources. Conveniently, the graduate research assistant was previously MIT's service learning coordinator, so she had significant experience with service learning implementation.

It is important to note that, while the process outlined below for each of the three classes documents a reasonably quick development time, preparatory work was in progress for quite a bit longer. For 2.002, the engineering instructor had been informally brainstorming service learning projects for the class for about two years. For 2.006, the graduate research assistant (who, at the time, was the service learning coordinator) researched and proposed service learning projects to the professor for about two years: the professor did not feel that any of those proposed projects matched the class goals sufficiently. For 2.009, students worked on service-oriented projects informally for a number of years, and service learning had been formally introduced during the previous two years. The professor of the class used lessons from past years to shape the service learning methodology in the subsequent year.

2.002: In the fall of 2004, after brainstorming appropriate projects following a review of current lab projects, the service learning coordinator worked together to develop a possible service learning lab write-up for 2.002. The professor of the class provided positive feedback, indicating that he was interested in using service learning in the class, and felt that the project, with some revision, was appropriate for the class. The team then revised the project, working with the technical lab instructor. All aspects of the project were tested by the team prior to implementation in the class.

Three of the 15 laboratory groups in 2.002 chose to work on the charcoal project; each group was in a different lab section that met on a different day. While such breadth prevented competition for lab equipment, and having a high number of participants provided many subjects for research purposes, this distribution created a number of challenges. First, the service learning support team was stretched thin, because so many hours were required to support the three different teams. Second, each lab section was taught by a different section instructor, each of whom had a different attitude toward the salient features of the service learning project. While the service learning team had met with each professor prior to introducing the project, these differences did not become clear until the project began, leading to significant difficulties. One instructor was very enthusiastic about the project exactly as it was given. The other two encouraged the students to pursue the project in ways that deviated from the project description, leading to

confusion for the students, TAs, and service learning team. Prompt interim meetings with those instructors outside of lab time allowed the students to complete their work with reasonable success, but the process was challenging for all involved.

2.006: This class had been identified early on as a strong candidate for service learning, but finding an appropriate project had proved difficult. Eventually, thanks to a trip by a service learning team member to Haiti during the summer of 2004, the distiller project was identified. At the end of that year, the service learning team wrote up a brief project description and reviewed it with the 2.006 instructor. He was enthusiastic, so the team revised the description to match the course goals more closely, and also confirmed his willingness to use class time for a community representative to discuss the project in detail with the students.

During the semester, the course instructor was somewhat difficult to reach due to other commitments. There was a bit of confusion about when the project description would be given to students, and whether the lecture from the community partner would fit into the class schedule. However, both of these concerns resolved relatively easily.

2.009: During the summer of 2004, the service learning team worked with the course instructor, already enthusiastic about service learning in his class, to brainstorm possible themes for the class that would include service-oriented projects. Once the theme was chosen, the team worked to identify a range of community partners who could provide project ideas, offer student support, and attend the project ideas fair. Developing these partnerships is more challenging than for typical service learning classes for a number of reasons.

First, expectation management is critical for this class. The service learning staff warn every service learning community partner MIT works with that students may not be able to achieve the goals we hope for, although that is the intent. However, in 2.009, the process of narrowing down ideas from many to one, and the class structure that encourages students to consider an extremely wide range of ideas from many sources ensures that some community partners who attend the career fair will not be chosen by the students initially and other projects will not survive the project winnowing process over the course of the term. While this method has been extremely effective pedagogically, it exacerbates the challenge of making sure that community partners benefit from the interaction and do not gain false expectations from working with us. The structures developed to manage this challenge include a formal expectations letter sent to each community partner; conversations about these course limitations before, during, and after the project fair; and discussion about other ways the community partners can work with MIT, through MIT's Public Service Center, other service learning courses, and other outreach programs. In addition, all community partners are encouraged to interact with students through the class website, where all reviews of project process are documented with video on-line. This opportunity has proven to be popular with partners and helpful for the students.

The second challenge is that students work far more independently in this class than in others, meaning it is solely up to the students, following the project fair, to work with community partners. While those who do make the effort to have significant interaction tend to benefit highly from it, and increase the benefit to the partners, it is up to the students to take that initiative, and some do not.

Third, students often choose projects that focus on the needs of developing countries overseas, and it can be very challenging to identify and regularly communicate with appropriate partners. During this year, one team opted to use some of their budget and apply for a service learning grant to fly to Mali in order to get sufficient information about the product they were developing. While the trip was highly effective in meeting those goals, the expense is significant. Other teams had less success finding and working with community partners and faced much more difficulty developing appropriate projects.

An additional unique aspect of the class is the level of confusion that is created by the concept of service learning. In 2.002 and 2.006, the service aspect of the projects is very clear to the students, as is the lack of service integration in other projects done by other students in the class, or in classes in previous years. In 2.009, however, the theme of the class, alternative energy, inherently has a service orientation. However, as mentioned above, students may or may not work closely with a community partner, a key feature of service learning. Additionally, students work on modest business plans and market analyses as their projects develop. While investigating a non-profit model is allowed for this step, for those who focus on for-profit businesses, students often believe that a profitable venture cannot be considered service. Students have many opportunities to reflect on these perceived contradictions, in design notebooks, discussions with faculty during lab time, and in formal presentations. However, confusion often remains.

3.4 Research Methods

As part of this effort to introduce service learning into a range of mechanical engineering classes, surveys were administered to the students in each class at the start and conclusion of the term.

The main hypotheses tested were:

- students who participate in service learning will experience increases in motivation for learning and service orientation
- some of the benefits will be of particular benefit for women and minority students

The surveys collected information on topics such as demographics; career aspirations; attitudes toward the course, service project, MIT, teamwork, major, community service; and beliefs about engineering skills and abilities. Most questions used a scaled format, from 1-9. A few open-ended questions were also posed on certain instruments.

For all three classes, certain questions were identical, although class-specific questions were also asked. For 2.002, one lab section had no exposure to service learning whatsoever, so that section also had a somewhat shorter survey as compared to the other sections and other classes. Additionally, this year was used as an opportunity to explore different methods of investigation, so certain questions were posed in different ways on surveys for the classes.

Surveys typically required 5-10 minutes to complete and were either administered in class in paper form by a member of the service learning team, or were offered on-line, in which case students were asked by the class instructor to take the survey outside of class time. While on-

line surveys are much easier to use from a data collection standpoint, the logistics of some classes requires paper surveys, especially because the paper-based response rate is typically much higher.

Either student ID numbers or names were collected to correlate pre- and post-survey responses; following the correlation, the identifying information was removed, to assure anonymity of information. The two different methods were tried to determine whether students were more likely to respond to either request. All survey instructions explained that answering the survey was voluntary, that responses were confidential, and that anonymity would be assured for reported results.

In addition to surveys, informal conversations were held with a selection of course instructors, TAs, and students following the class, to gain further qualitative information about the use of service learning in these classes.

Table 9 displays the participation rate of those surveyed, and the demographics of the respondents. In 2.002 and 2.006, there were some logistical problems with survey distribution leading to relatively low numbers of students who completed both surveys.

Table 9: Service Learning Survey Participation and Demographics

		2.002		2.006		2.009	
		N	%	N	%	N	%
Survey Completion	Total class enrollment	44	100.0	64	100.0	95	100.0
	Just pre-survey	1	2.3	15	23.4	21	22.1
	Just post-survey	23	52.3	12	18.8	8	8.4
	Both pre- and post-survey	19	43.2	20	31.3	65	68.4
Gender of respondents	Male	30	69.8	35	74.5	58	71.6
	Female	13	30.2	12	25.5	23	28.4
Minority status of respondents	Non-minority	26	60.5	27	57.4	44	51.8
	Minority	17	39.5	20	42.6	41	48.2
Project focus of respondents	Service-oriented	12	27.9	47	100.0	61	64.9
	Not service-oriented	30	69.8	0	0.0	30	31.9

Analysis was performed using a variety of tests, depending on the type of data available. One-tailed t-tests were used, for paired samples and independent results; as needed, Welch's independent t-test was used. In addition, ANOVAs were performed when comparing multiple factors. Given the fairly low numbers of subjects studied, a value of $p=0.10$ will be considered significant for section 3.5.

3.5 Research Outcomes

2.002: For the pre-post questions asked, a few significant differences were found from the following question topics:

- happiness with major

- attitude toward MIT
- problem-solving ability
- creativity
- ability to test the mechanical properties of materials
- whether engineers should address social problems
- whether the student is concerned about social problems
- whether the student feels able to have an impact on problems affecting the local or global community
- whether the student has a meaningful relationship with a faculty member
- interest in community service and whether past community service activities have been meaningful

When asked about their perceptions of their ability to solve problems, on a 1-9 scale, students' perceptions increased significantly from 5.16 to 5.55 [$t(18)=1.662$, $p=0.057$]. For this question, women's initial mean responses were much lower than men's, and remained lower on the post-survey, but increased significantly more than did men [women: 4.44 to 5.17; men: 5.8 to 5.9; $F(1,17)=1.786$, $p=0.10$]. While this increase is heartening, it is a bit concerning that students' overall responses are so low, since 5 is neutral on the scale from much below average to much above average. The significant increase for women may suggest that the educational methods of the class are more beneficial for women, or that women generally enter the department with less confidence, but start to gain it with time and class experience.

When asked about their attitude toward MIT, overall, the mean student response decreased from 6.53 to 6.37, although not significantly. However, there was a significant difference for this question between students who completed a service learning project and those who didn't [$F(1,17)=2.252$, $p=0.076$]. The initial mean response for students who participated in service learning was much lower than for their peers; the former students' responses increased at the end of the class, while the mean for those who didn't decreased [service learning participants: 4.83 to 5.83; peers: 7.31 to 6.62]. One of the impetuses for developing service learning in the department is to help students better connect the highly theoretical engineering concepts they learn with little context in their initial mechanical engineering classes to real-world applications. This finding may suggest that the service learning experience was effective in doing so for service learning participants, since it is reasonable to imagine that a lack of clarity for why one is learning course material would lead to frustration with the university experience as a whole. In addition, since service learning participants were much less happy with MIT than their peers, and all students chose the projects they worked on, it may be that those who were less engaged with the theoretical material were more drawn to a service learning project.

One final significant difference on the pre/post questions was that women's initial mean response to a question about their interest in community service was much higher than men's, but at the end of the term, both sets of students' interests had grown more similar, with women decreasing in interest, from 7.44 to 6.89 and men increasing in interest from 5.40 to 6.10 [$F(1,17)=3.699$, $p=0.036$]. Generally, women in engineering tend to be more interested in service-oriented engineering than men [67]; this finding may suggest that exposure to service learning can increase students' interests in community service, but that the effect may be countered by the realities of being an engineering student in terms of time pressure and the necessity to focus on

schooling. Students were also asked about their involvement in community service, and the results, shown in Table 10, suggest a similar trend: as students get more involved in their studies during their sophomore year, the interest in community service remains, but they are less able to commit time to doing so.

Table 10: Frequency of responses to the question, “Choose the response that best describes your community service activities since coming to MIT.”

	Before	After
Community service has not been one of my priority choices	25%	30.2%
I am interested in community service activities, but have not had time while at MIT	30%	44.2%
I am involved in community service 1-5 hours per month	35%	16.3%
I am involved in community service 6-18 hours per month	10%	7.0%

A final question on both the pre and post surveys asked students to rank possible career choices. As shown in Figure 16, students’ career preferences changed very little over the course of the term, and students were most interested in professions and opportunities that are typically engineering-oriented like product development, research, and graduate school.

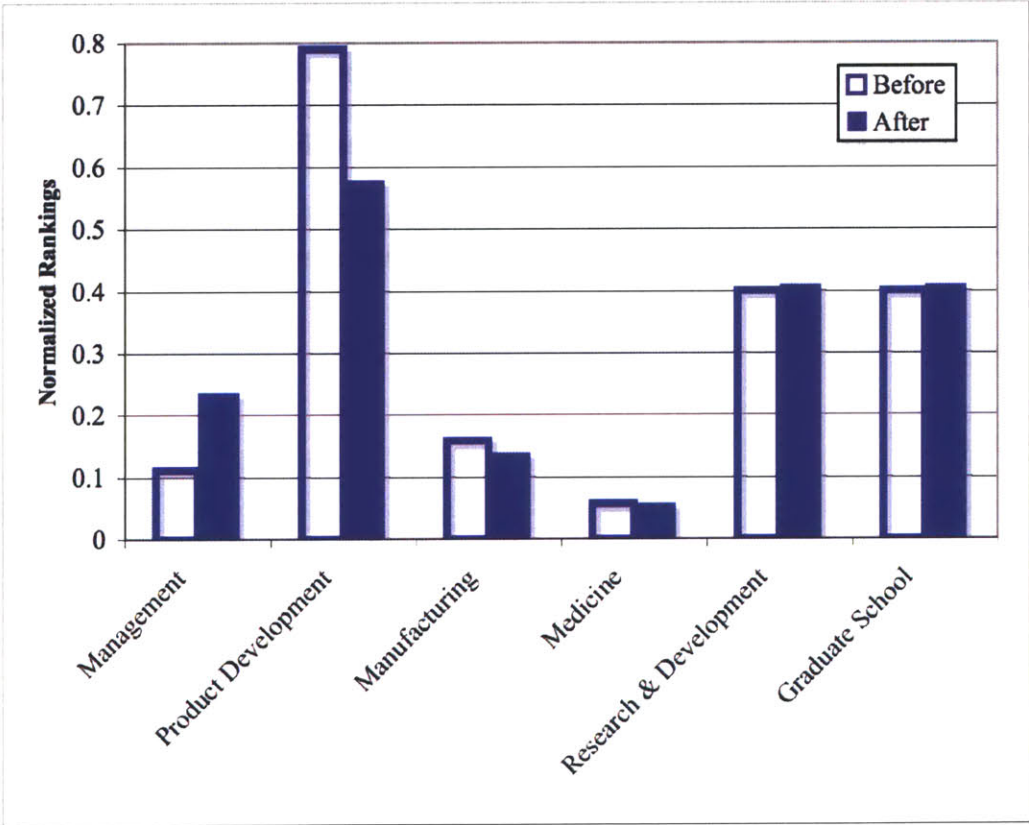


Figure 16: Students' First or Second Career Choices

Students were also asked a set of questions that were only on the post-survey, covering the following topics:

- the lab experience: interest, learning, satisfaction
- whether the class affected their thinking about career choices
- whether the project affected their relationships with other students or teaching assistants and professors
- whether the project affected their understanding of course material, ability to apply class concepts, ability to identify concepts that they didn't understand, motivation to work hard in the class, and attitude toward MIT
- whether the project was a good match for how they learn.

On every question but one, the mean response for males was higher than for females; for the question on whether the project affected their attitude toward MIT, the difference was significant [$t(39)=1.628$, $p=0.056$, with males showing a slight positive response (5.29), and women showing a slight negative response (4.54). Women responded more positively to whether the project affected their interest in community service, showing a slight positive response (5.77), while men disagreed slightly, on average (4.72) [$t(40)=-1.141$, $p=0.016$].

Comparing responses between students engaged in service learning projects and those who weren't, only one significant finding was evident: students working on service learning projects responded somewhat positively to whether the project affected their interest in community service (mean of 5.83), while their peers were somewhat negative (mean of 4.73) [$t(40)=-2.313$, $p=0.013$]. This finding is to be expected, but it is surprising that no other significant differences arose between these groups. The relatively short length of time that students spent on the service learning project, the low survey response rate, and the differences between how service learning was implemented in each section may have contributed to these limited findings.

However, there is a clear differentiation between these groups of students in terms of their reasons for choosing the project that they worked on, as shown in Figure 17.

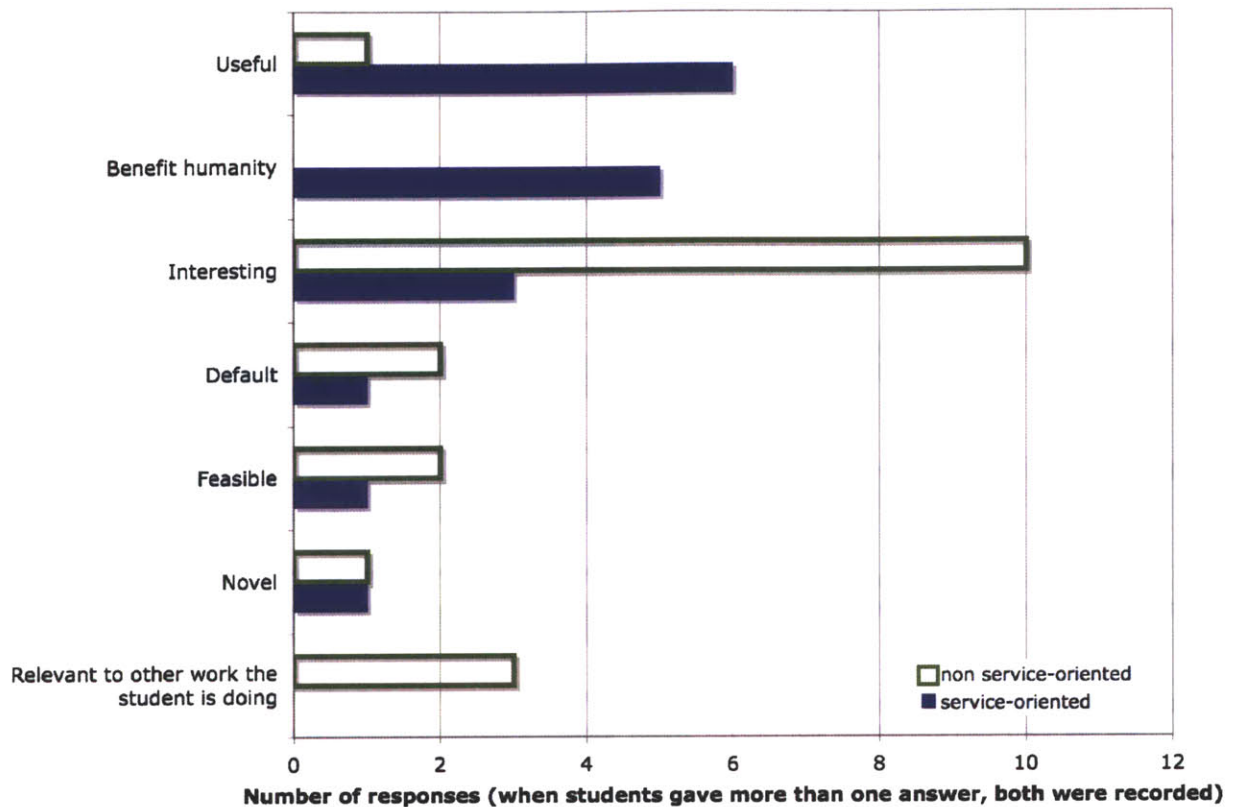


Figure 17: Reasons Students Chose their 2.002 Project, Split by Project Type

Students working on the service-oriented project were most taken by its potential to benefit humanity, or to be of use to others, while students working on the other projects were generally drawn to them because they seemed interesting. Furthermore, at the end of the class, students seemed to be happy with their choice. Of the eleven students working on service-oriented projects who responded to the question, “If you had to choose today, which project would you pick?” only two wanted to choose a different project (that would not have been service-oriented), and of the thirteen students who worked on non service-oriented project, only one expressed interest in doing the service-oriented project instead.

When comparing minority and non-minority students on their responses to the post survey questions, a number of significant differences arose, for which minority students were consistently more positive than non-minorities, as shown in Figure 18.

Finally, students were asked, “Is there anything else you would like us to know about service learning in 2.002 and/or at MIT generally?” on the post survey. Only two responded about service learning, stating:

“I feel that service learning is very important. I think the 2.002 project lab should always be a community service project. Have a real-life purpose for solving problems/testing data. It gives students more of a motivation and reason to work. Thanks!”

“Service Learning could play a far greater role in teaching and learning at MIT. In general, there should be far more self-motivated and hands-on projects than cookie cutter assignments, projects, or psets.”

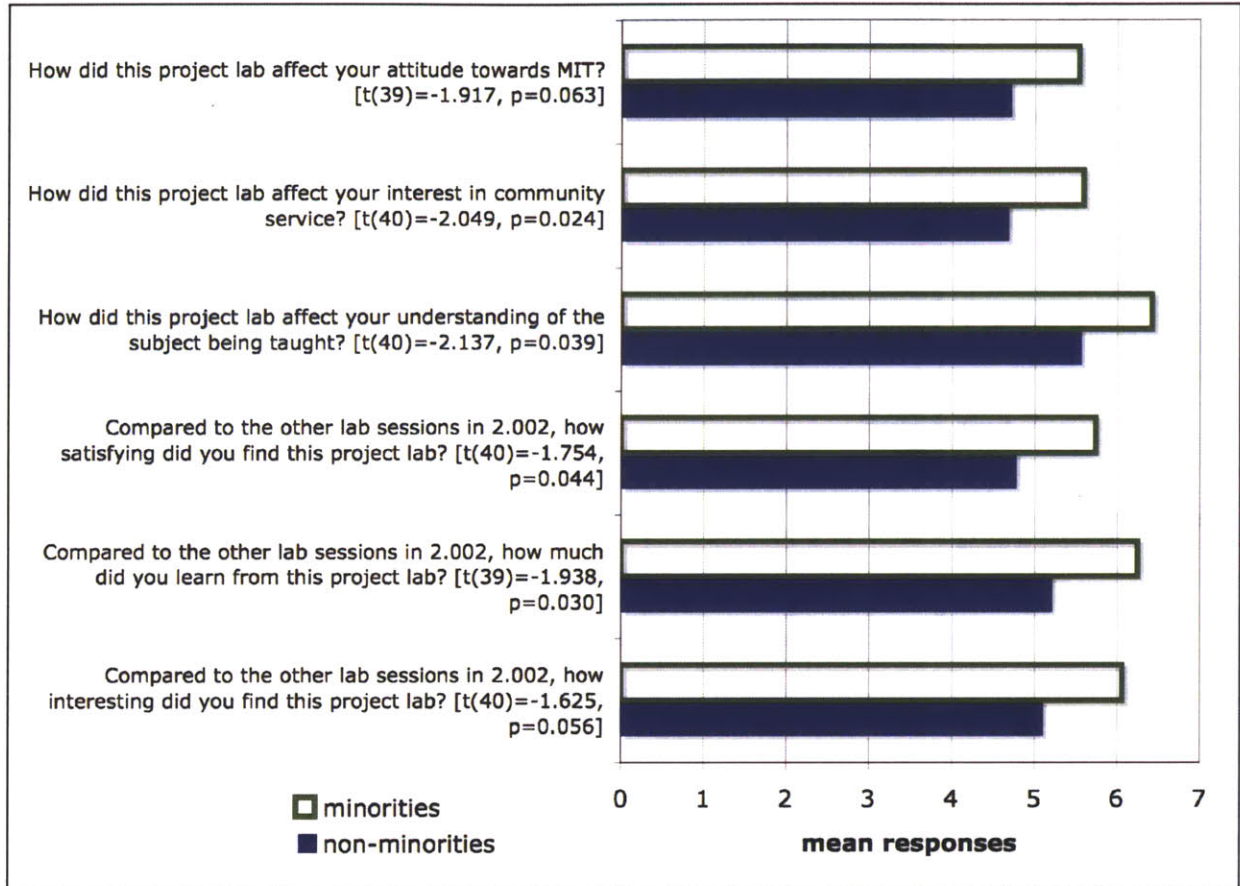


Figure 18: Significant Differences Between Minority and Non-Minority Responses to 2.002 Post Questions

2.006: Students were asked about the following topic areas in both the pre- and post- survey:

- happiness with major
- understanding of fundamental principles of thermodynamics, fluids, and heat transfer
- ability to design and formulate models for analysis of thermal-fluid systems
- general ability to set up and seek solutions for an open-ended engineering problem
- whether engineers should address social problems
- whether the student is concerned about social problems
- whether the student feels able to have an impact on problems affecting the local or global community
- whether the student has a meaningful relationship with a faculty member

Because this assessment was a pilot effort, the ranges for the scaled questions varied. On the set of questions about whether students understood the fundamental concepts of the class, the mean

of students' responses increased, significantly so for the topics of fluids [from 3.8 to 4.2 on a five-point scale, $t(19)=-2.179$, $p=0.021$] and heat transfer [from 3.5 to 3.95 on a five-point scale, $t(19)=-1.756$, $p=0.048$]. On average, students also increased on two similar measures, their ability to formulate models for analysis of thermal-fluid systems [from 3.15 to 3.45 on a five-point scale, $t(19)=-1.552$, $p=0.069$] and to complete a sound engineering design of a thermal-fluid system [from 2.55 to 3.25, $t(19)=-4.273$, $p=0.000$]. One final question with significant outcomes was whether students had a meaningful relationship with at least one faculty member. For this class, the pre-survey used a 5-point scale, while the post-survey used a 9-point scale; hence, the pre-survey responses were recoded to match the 9-point scale. The mean responses increased from 4.6 to 5.7 [$t(19)=-2.288$, $p=0.017$].

One perplexing result is that women, whom we hypothesized would benefit more than men from the service-oriented project experience, answered the statement, "Social problems are not my concern" more negatively than men did at the start of the class, but much less negatively at its conclusion [women from 2.14 to 3.57; men from 2.83 to 2.33; $F(1,17)=6.252$, $p=0.023$]. This outcome might suggest that women were turned off by the project experience, and hence less interested in social issues. However, on most questions, only included on the post-survey, asking about whether students perceived benefits from the project, women responded more highly than men did, though generally not significantly so, as shown in Figure 19. For the one response that was significant, the statistical outcome is shown.

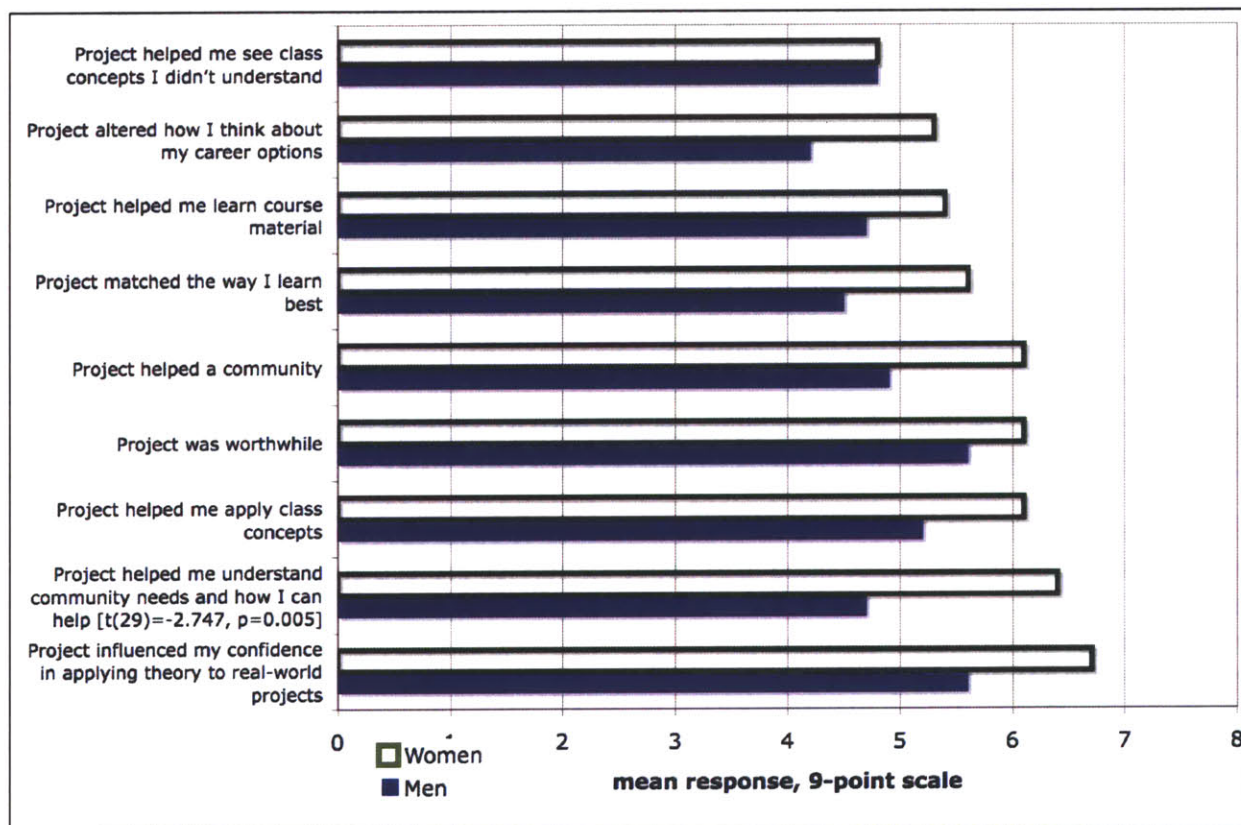


Figure 19: Comparison of Responses by Women and Men to Project-Related Post Questions

From these responses, it seems that women generally benefited from the project, and one possibility for the extreme change in response to the social concern question is that one woman, who responded with a 3 on the pre-survey and an 8 on the post-survey, creating most of the change, made a mistake in responding; she responded with a 7 or 8 on similar questions on the post survey, and may have misread the scale descriptions for this inverted question.

When comparing responses of minorities and non-minorities, a few differences arose. Minority students started out agreeing less than non-minorities to the statement, “Engineers should use their skills to solve social problems,” but ended the term increasing, from 7.29 to 8.00, while non-minorities average response decreased from 7.92 to 7.38, on a nine-point scale [F(1,18)=5.212, p=0.018]. A similar change emerged from the question about students’ general ability to set up and seek solutions for an open-ended engineering problem, on a five-point scale. Minority students’ mean went from 2.86 to 3.71, while non-minorities did not change, and remained at 3.62 before and after the survey [F(1,18)=3.569, p=0.038]. Minority students also responded more positively on almost every question on the post survey. However, minorities were more negative on the question, only included on the post-survey, about their overall attitude toward MIT on a seven-point scale: non-minorities were slightly positive about MIT (mean of 5.59), while minorities were somewhat negative (mean of 4.40) [t(30)=2.418, p=0.011].

The students in 2.006 responded similarly to students in 2.002 in terms of their overall interest in community service. While time certainly seems to affect students more and more in their academic careers, their interest in community service also seems to increase, as shown in Table 11.

Table 11: Frequencies of Responses to the Question, “Please let us know your experiences with community service activities since coming to MIT.”

	Before	After
Community service has not been one of my priority choices	35%	20%
I am interested in taking part in community service activities, but have not had time while at MIT	0%	15%
I have taken part in at least one community service activity while at MIT	25%	20%
I have taken part in two or more community service activities while at MIT	40%	30%

The series of surveys for 2.006 also included a number of open-ended questions for students to answer. When asked what they liked least about the service project, common responses included:

- the project was too time-consuming
- the project had too many unknowns
- the connection to the community was too limited or abstract

Anecdotally, the concern about time has been true for most 2.006 projects, with or without a service component. Additionally, the project is designed intentionally to include many unknowns, so that frustration for the students was to be expected. However, the concern about the limited connection to the community is one that we hope to address in future classes with

project like these, although the solution is not entirely evident. Since all the students are working on the same project, the class is relatively large, and there are limited community partners who can speak to such a specialized topic, it is difficult to provide significant interaction between students and community partners, apart from the lecture that was set up, and the email communication that was available. With care and practice, however, we hope to remedy this limitation.

When asked what they liked most about the service projects, students offered:

- the real-life aspect of the project seemed important and relevant
- it was satisfying to investigate one topic thoroughly
- it helped integrate the course material from the class
- it provided the opportunity to make a real difference

These outcomes are all ones we hoped would be evident, so it is heartening to see students respond this way. A final measure showing evidence for students' interest in a service-oriented class experience was their response to the question, "If it fit into your schedule, would you take another service learning class?" Nineteen students responded positively, five responded negatively, and four said maybe.

On the post survey only, students were asked about their career choices. Figure 20 displays a normalization of how students ranked the six career options given. Generally, the top choices align reasonably well with the students' choices in 2.002, with students preferring engineering-oriented careers to other options.

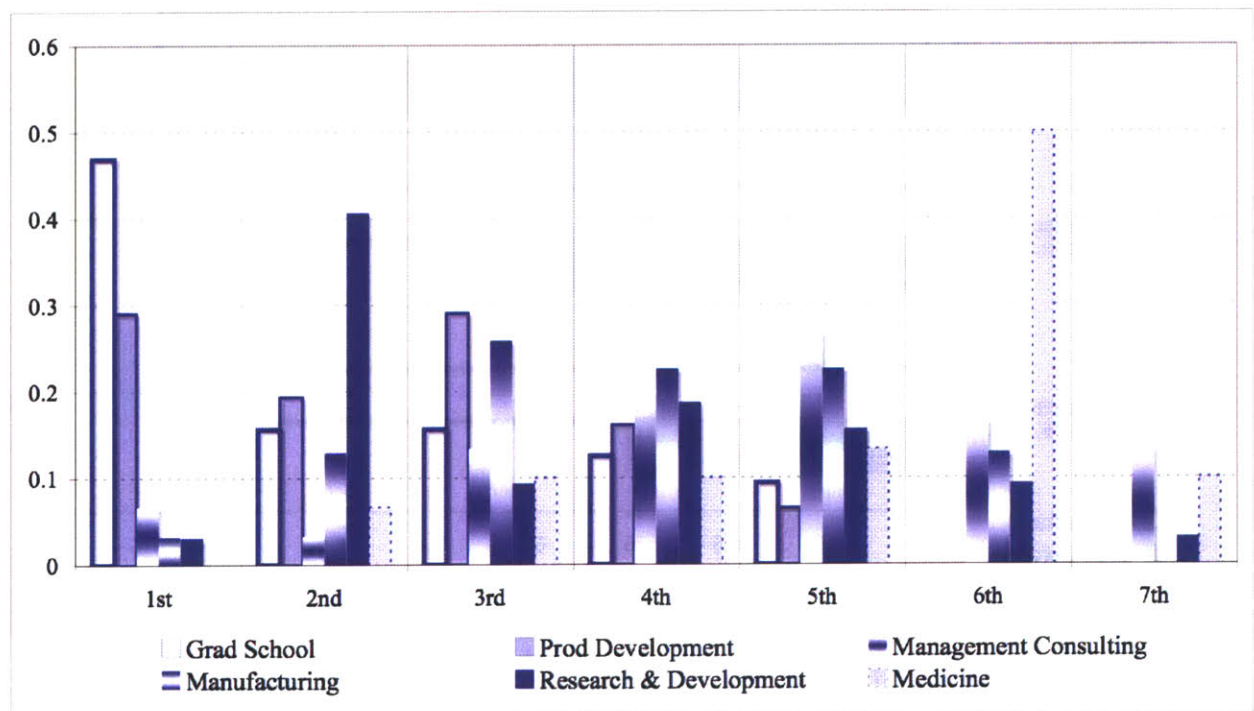


Figure 20: 2.006 Students' Rankings of Career Choices

2.009: The following types of questions were asked on the pre- and post-surveys:

- happiness with major
- self-perception of abilities in product design, problem solving, creativity, teamwork, and communication
- comparing the relative amount of time needed for different steps in the design process
- how much the student expected to, and then did, learn from team members
- interest in community service and global issues
- whether engineers should address social problems
- whether the student is concerned about social problems
- whether the student feels able to have an impact on problems affecting the local or global community
- whether the student has a meaningful relationship with a faculty member

On the questions relating to students' skills in product design, problem solving, and creativity, students responded significantly more positively at the end of the term than at the beginning, as shown in Figure 21. In addition, also shown in this table, students reported a significant increase in whether they have a relationship with at least one faculty member.

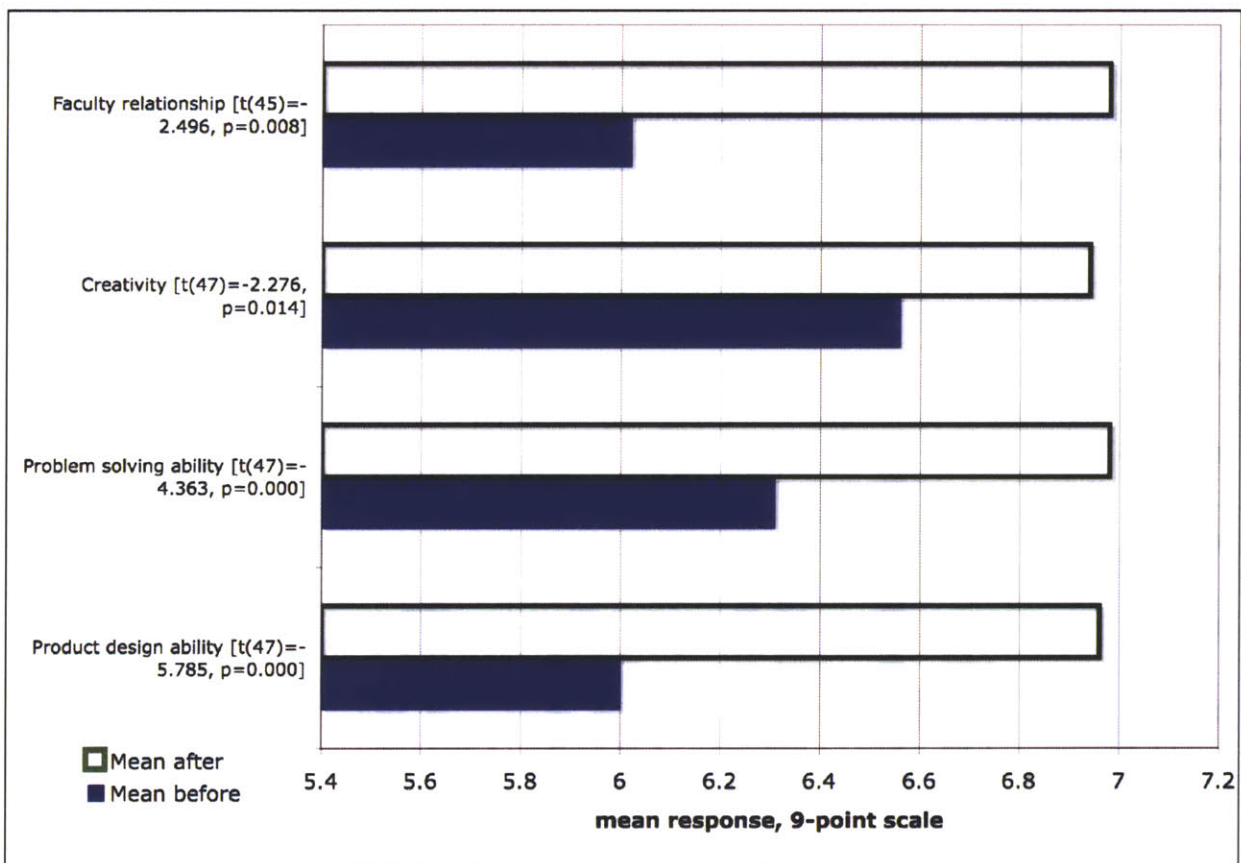


Figure 21: Significant Differences for Certain Questions on the Pre- and Post-Surveys in 2.009

When comparing students by gender, considering both pre-post and post-only questions, there were a few key areas where women differed significantly from men. Using a one-tailed t-test, women were significantly less happy with their major than men were (mean of 6.94 for women versus 8.09 for men; $t(19.812)=2.247$, $p=0.018$); women also reported a less positive attitude toward MIT than did men, though not significantly. Women also rated themselves less positively than men on their product design skills, although, over the course of the semester, they increased their perception significantly more than men did. Women's means increased from 4.9 to 6.6, while men's increased from 6.6 to 7.2 [$F(1,42)=7.605$, $p=0.009$].

However, women were more positive on a number of factors related to service orientation. When asked about their interest in global issues, women's means started slightly higher, and increased, from 6.71 to 7.57, while men decreased significantly, from 6.68 to 6.46 [$F(1,42)=7.605$, $p=0.009$]. Students were also asked whether "2.009 helped me better understand community needs and how I could help as an engineer." Women responded significantly higher than men did, with a mean of 7.22 versus 6.07 for men [$t(62)=-1.959$, $p=0.055$]. Women also reported spending more hours working with clients than men did: women's reported average was 21 hours, versus 13.12 for men. Women also perceived that their product helped a community more than men did, averaging 6.83 on a 9-point scale, while the average for men was 5.73. In addition, when asked to rank their relative interest in improving a hypothetical job in four areas, starting salary, positive society impact, innovation and creativity, or chance to have a managerial role, women were significantly more interested than men in improving the position in terms of positive societal impact [$F(1,62)=3.496$, $p=0.066$]. These findings point to the comparatively higher level of interest women seem to have in socially-oriented activities, suggesting that service learning may be of greater benefit to women engineering students.

When comparing responses by minority status, a similar, higher social orientation by minority students emerged, as shown in Figure 22. Minorities were significantly more likely to respond positively to the question, "Did working with real clients help you better understand difficult aspects of the design process?" [minorities had a mean of 7.42, versus a non-minority mean of 6.31, $t(60.055)=2.621$, $p=0.006$]. Minority students also responded more positively to the question about whether 2.009 helped students better understand community needs and how they, as engineers, could help [minorities had a mean of 7.03, versus a non-minority mean of 5.83, $t(66)=2.418$, $p=0.009$]. Further, minority students reported spending more hours working with clients (17.2) than did non-minority students (13.4), and were more optimistic about whether their project helped an under-served community, though not significantly so (mean of 6.56 versus 5.8). Finally, on the question about what job improvements are most important, minorities were significantly less interested in a salary increase than non-minorities were [$F(1,66)=6.959$, $p=0.010$].

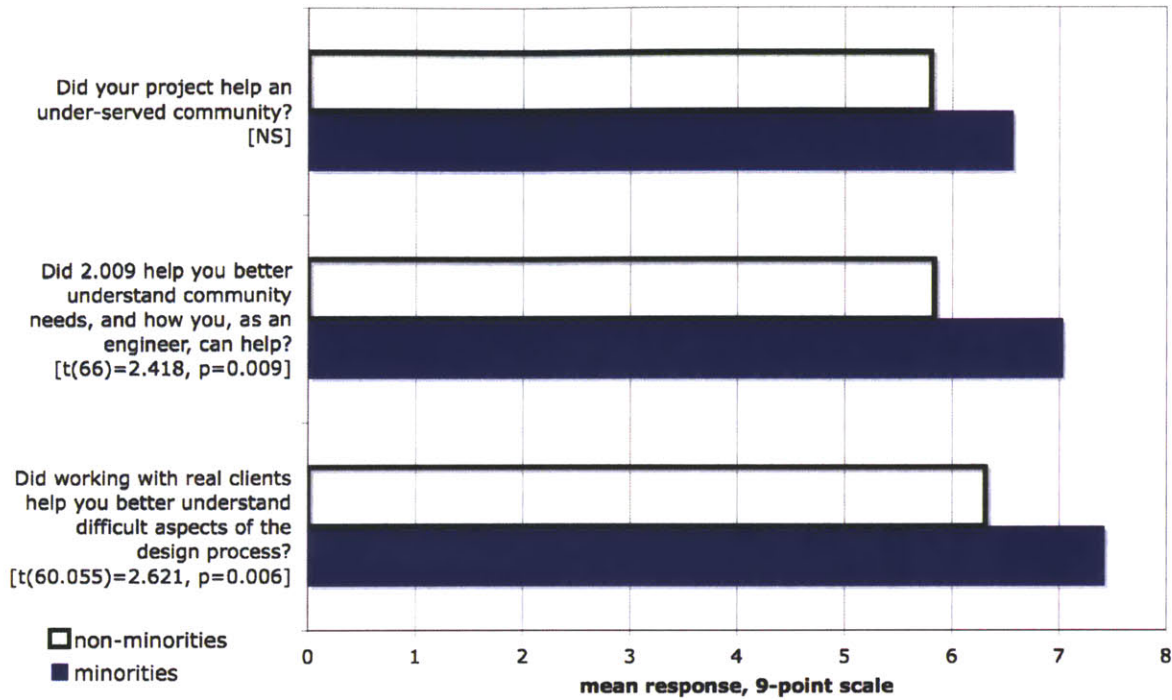


Figure 22: Differences Between Responses of Minorities and Non-Minorities to 2.009 Post-Survey

Differences between students who worked on a service-oriented project and those who didn't also emerged. Unsurprisingly, students who worked on a service-oriented project believed much more strongly that their project helped a community, with a mean of 7.82 versus 2.00 on a nine-point scale [t(69)=15.012, p=0.000]. They also reported spending more time working with clients, reporting an average of 17.68 hours versus 10.59 and agreed significantly more strongly that the class helped them understand community needs and how they could help [mean of 6.74 versus 5.45, t(31.999)=2.188, p=0.018].

In 2.009, students showed a dramatic shift in career interests from the start of the class to its end. As shown in Figure 23, students began the class most interested in management consulting, research, and medicine. The first and third of these professions are not ones that typically require a lot of traditional engineering knowledge, and it was disheartening to see that so many students were not intending to pursue engineering careers upon graduation. At the conclusion of the class, student interests had shifted significantly, so that their top interests were now working at a product development firm, going to graduate school, or working in research and development. 2.009 students were also surveyed when they graduated from MIT, and the trends for career interests changed little.

Combined Class Analysis: A number of questions on the class surveys were identical for two of the three classes, or for all of the classes. The data was pooled, to investigate themes across the three classes more closely, and to increase the sample size for analysis.

Students were asked about their problem-solving ability and creativity on surveys for 2.002 and 2.009: their perception of their ability to solve problems increased significantly from 5.99 to 6.57, overall [$t(66)=4.590$, $p=0.000$] and their perception of their creativity increased from 6.24 to 6.53 [$t(66)=1.980$, $p=0.026$]. While not significantly different, 2.009 students had higher means on both questions than 2.002 students (2.009 students' means increased from 6.31 to 6.98 for problem-solving and from 6.56 to 6.94 for creativity; 2.002 students' means increased from 5.16 to 5.55 for problem-solving and 5.42 to 5.50 for creativity), a positive sign that suggests that students are gaining confidence in key skill areas as they progress through their MIT careers. In all three classes, students perceived an increase in the existence of a relationship with at least one faculty member, with the mean response climbing from 5.36 to 6.25 [$t(84)=3.504$, $p=0.001$]. Similarly, students reported more and more of a connection with at least one faculty member as they progressed through the classes, as shown in Figure 24.

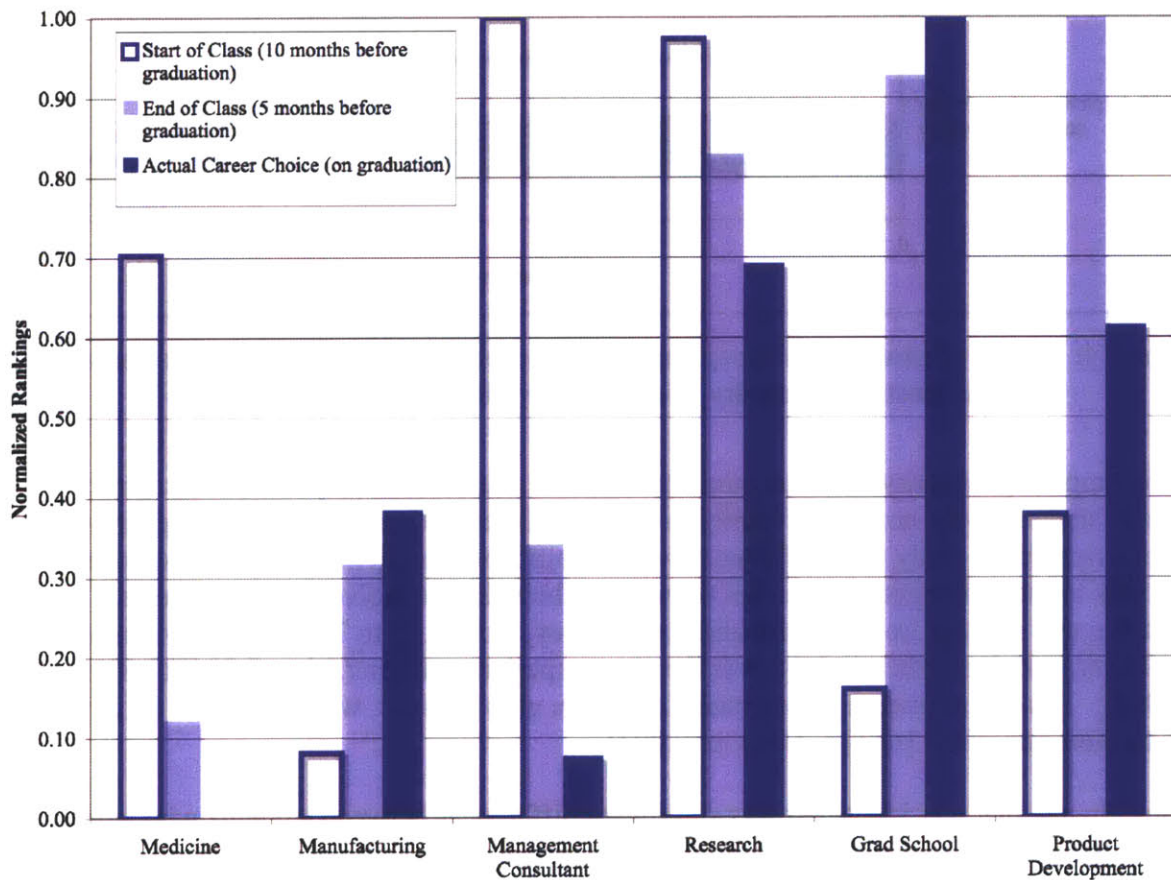


Figure 23: 2004 Career Choice Rankings for 2.009

There were no significant differences between men and women for questions given on both the pre- and post- surveys. However, generally, women's means were lower on questions about attitude toward MIT and reporting of their own engineering skills, and higher on their interest in

community service and social orientation. On the three common post-only questions, which also asked about service orientation, women were significantly more positive than men, as shown in Figure 25.

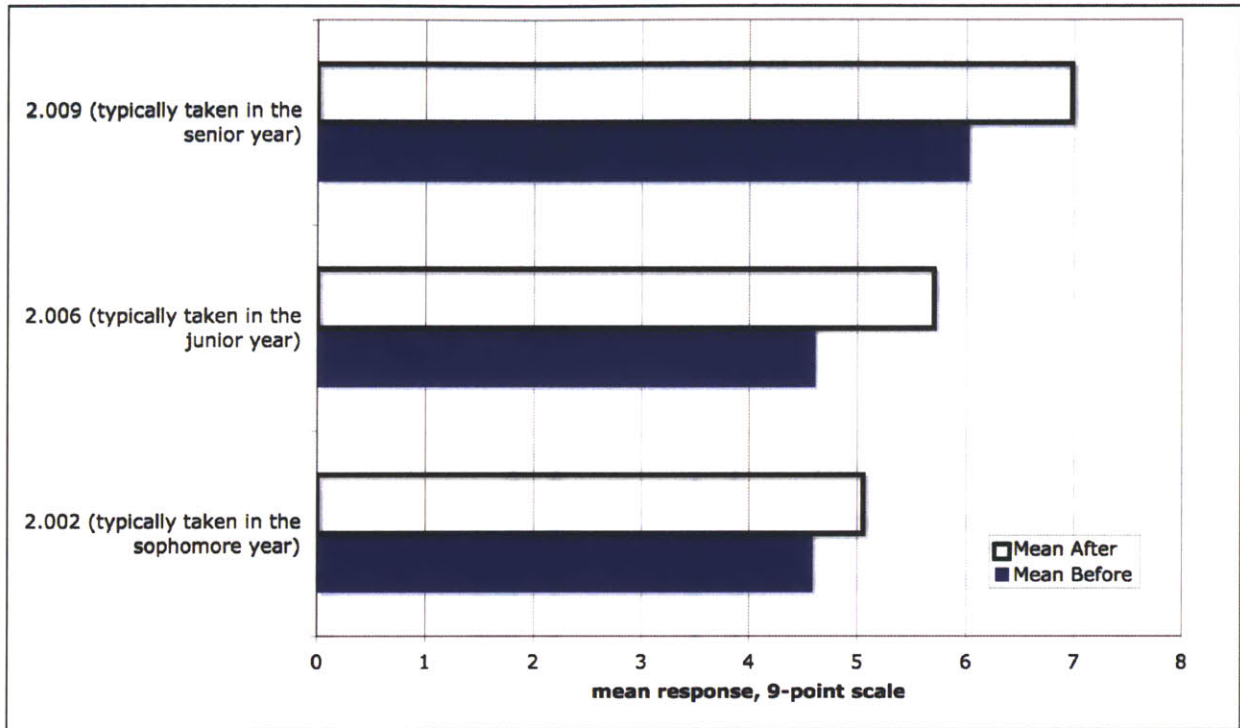


Figure 24: Means of Students' Perceptions of Whether they have a Close Relationship with at least One Faculty Member, for 2.002, 2.006, and 2.009

When comparing minority and non-minority students, there was a very similar outcome: minority students were non-significantly lower on self-perception of skills, and higher on a service orientation. Only two differences were significant: one, that minorities responded more positively to the statement, “Engineers should use their skills to solve social problems,” increasing this attitude from the pre- and post- survey, from 7.43 to 7.95, while non-minorities were lower, and decreased slightly over the class experience, from 7.14 to 7.09 [F(1,81)=3.429, p=0.068]. Two, minorities reported more interest in global issues, with a mean of 7.12, versus 6.00 for non-minorities [t(86)=-2.844, p=0.003].

A final change that was identified was significant differences between students who worked on service-oriented projects and those who didn't. As we expected, students who worked on service projects believed much more strongly that their work helped a community in need, with a mean response of 6.81, versus 2.31 for their peers [t(126)=11.303, p=0.000]. In addition, those involved in service projects believed they had a better understanding of community needs and how they could help, with a mean response of 6.23, versus 4.5 [t(50.866)=3.452, p=0.001]. In addition, overall, those who worked on the service-oriented projects were less positive about MIT at the start of the semester, but increased their perception from a mean of 6.43 to 6.64, while their peers became less positive about MIT over the semester, with the mean shifting from 6.68 to 6.18 [F(1,70)=2.970, p=0.089]. These common findings point to the possibility of

service learning providing benefit to most engineering students engaged in the pedagogy, regardless of implementation methodology.

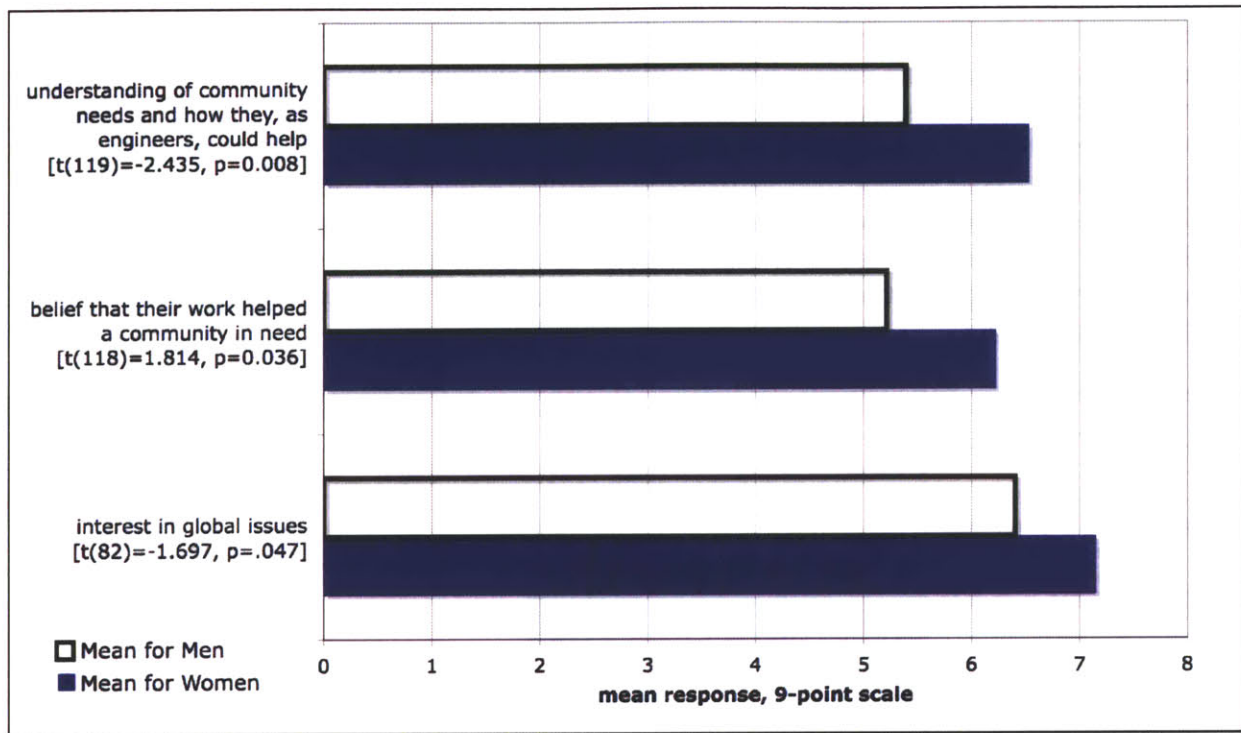


Figure 25: Gender Differences on Post Questions Common to All Three Classes

There were significant differences between the classes on two of the common post-only questions, as shown in Figure 26.

A post-hoc pairwise comparison revealed that for the first question, only 2.002 and 2.009 differed significantly ($p=0.013$), while for the second question, those classes differed significantly ($p=0.001$) and 2.006 and 2.009 differed significantly ($p=0.028$). Since the implementation of service learning into 2.009 affected much more of the class, and was done with more practice and experience, this outcome matches our hypothesis, that the service learning experience would have a greater impact in 2.009 because of the implementation method.

3.6 Analysis and Lessons Learned

In developing service learning projects in these three very different mechanical engineering classes, we have compiled a list of lessons learned, in the hope that others interested in adopting service learning pedagogy into core engineering classes will learn from our experiences.

- **A service learning project should never be forced.** If the project isn't right, because it doesn't fit the curriculum of the class, because it doesn't really meet the needs of the community partner, or for similar reasons, it's better to hold off until those issues can be resolved. Waiting, while frustrating, will improve the chances of the project being a success, providing positive outcomes for students and community partners alike. Service learning administrators at MIT have found that this cautious approach increases respect from faculty.

- Finding good, appropriate projects takes creativity and persistence.** Generally, community organizations do not consider how engineering projects might benefit them; tend to focus on the financial and managerial aspects of more typical community service. A phone call to an agency asking if they have any good heat transfer projects for university students is unlikely to be effective. A reasonably successful approach for finding projects is to start by brainstorming project ideas, getting a combination of people in the room with a variety of backgrounds: experience with local organizations, experience with development work internationally, and technical knowledge of the class content. When these knowledge areas overlap, those sessions are particularly fruitful. With a portfolio of project ideas, the service learning coordinator or course instructor can reach out to organizations much more effectively and the success rate is much higher. However, it is not unusual to make phone calls to twenty organizations before finding a project, or to have to wait a year before the right project arises.

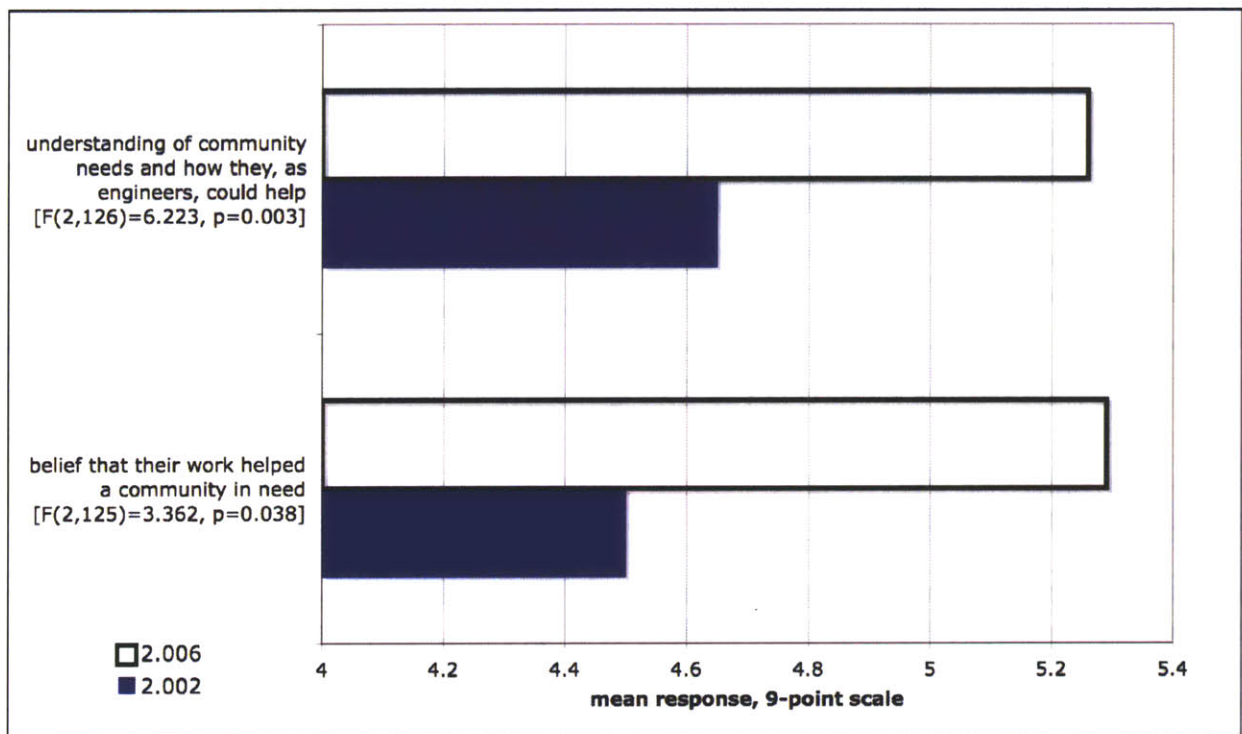


Figure 26: Mean Responses for Post Questions Common to All Three Classes

- Administrative support from people with technical knowledge is crucial.** Faculty have such restricted schedules that asking them to make the 20 phone calls that might be required for a service learning project is rarely practical. Additionally, faculty new to service learning pedagogy generally need support, guidance, and encouragement from someone in the role of service learning coordinator to be willing to try the pedagogy. Additionally, if the person in this role has a technical background, that knowledge is likely to be highly beneficial in two ways. First, some faculty can be skeptical of whether service learning projects may provide academic rigor; faculty seem to be more responsive to the idea of service learning when approached by someone who is technically knowledgeable. Second, developing projects, and

working with faculty and community partners alike, can be much easier with a technical background, especially for someone skilled at “translating” between highly technical and non-technical communication. Since it is daunting to find someone with experience and knowledge of service learning pedagogy and technical ability, MIT has chosen to hire a non-technical service learning coordinator, but has that person work closely with graduate students and instructors very interested in service learning to serve as technical counterparts.

- **Work with the team, not just with individuals.** While doing so can be challenging, setting up a meeting with all course organizers to discuss the project, from the instructor to the TAs to any other constituents can ensure that all members are on the same page. Meetings with individual constituents are much simpler to schedule, but this method can lead to confusion and miscommunication. Some classes have staff meetings, and it may be possible to attend one (or, preferably, many) of these.
- **Help students contextualize their work in a culturally appropriate framework.** A key feature of service learning pedagogy is reflection activities, which help students contextualize their work, and gain more from the experience. For use of service learning in the liberal arts, the concept and practice of reflection is common. For most engineering students and faculty, even the term is foreign and may seem “wishy-washy,” so encouraging this practice is a bit tricky. Some effective reflection methods developed for engineering students are:
 - not using the term “reflection,” but instead describing the activity without naming it
 - having students reflect in their engineering “notebooks”, rather than in “reflection journals”
 - integrating reflection assignments into class presentations

Key areas for reflection are how the service project connects to the academic material of the class; the ethical implications of the student’s work; if their work will be of value to the community partner they are working with; the different communication styles and expectations of the real world and the university environment; the reciprocal nature of service learning, wherein students and community partners are both learning from and being helped by each other; and whether a project can have the potential to be profitable, and still be considered “service.”

- **Provide resources to let the projects continue beyond the scope of the class.** This recommendation is important for two reasons. First, while the service learning program tries to ensure that students provide benefits to their community partners during the class semester, there is often more work that could significantly augment the benefits if students spent additional time on the project. Second, students often become absorbed in the project they are working on, and want to continue working on it after the class is over. Hence, the service learning program provides a wide range of ways to support this need, from offering funded individual student research opportunities, to providing funding for materials for senior theses, to service-oriented innovation competitions, that all provide outlets for further work. Occasionally, projects can be fed from one class to another, so that a different side of the project can be addressed, though this is a tricky prospect that requires excellent documentation and management.
- **Maintain relationships with community partners, during and after the class.** Doing so helps to ensure that problems are addressed reasonably quickly, that expectations for the relationship on both sides remain clear, and that the reputation of the university as a good partner is maintained. This communication also helps to make sure that students do not

overwhelm an organization. Additionally, once community partners have a positive experience with an engineering class, they are often much more open to working with ones in the future, and may even suggest engineering projects ideal for an upcoming class that would not have arisen otherwise.

- **Web surveys will generally have a lower response rate than paper surveys.** Unless the students are properly “trained” to take a web survey on their own time, in-class paper surveys will provide a much higher response rate. While paper surveys have the drawbacks of taking class time and requiring data entry on the part of researchers, we have found that students will almost always fill out a paper survey in class (as long as they attend the class). When told to take a web survey on their own time, however, the response rate seemed to be distressingly low, even with repeated email prompts, encouragement in lecture, and offers of \$5 gift certificates. In 2.009, which has a highly interactive website that students use on an almost daily basis for the class, web surveys were successful, so they can be effective in that situation. But without that type of environment, the drawbacks of paper surveys are much less than the drawback of having little data.
- **Finally, be prepared for the unexpected, and expect to be flexible.** While many of the issues that arose could have been mitigated with improved planning, a feature of service learning is the unpredictable nature of the work, providing students with real-world experiences. Thus, community partners, often under-funded and over-worked, may not respond as quickly as you might like, or your contact at an organization may leave during the middle of a semester. The project students are working on may turn out to be harder than anyone anticipated, meaning the community partner will not receive help as quickly as one would have hoped. These challenges are not uncommon, and can be very frustrating, but also provide a rich learning opportunity for students that will serve them in the workforce.

4. Longitudinal Study for One Core Mechanical Engineering Class [68]

4.1 Introduction

2.009: Product Engineering Processes, more briefly described in section 3, is a senior-level, required, semester-long mechanical engineering class at MIT, in which students unify their foundations in the design process by developing refined product prototypes. The course has been offered in the department for many years and, while students often note that the class has a demanding intensity and workload, it is highly-rated by students and considered to be effective at introducing and reinforcing a wide range of skills, including creativity, teamwork, communication, fundamental product design ability, and prototyping.

Over the past four years, the course has been evolving through an effort to adopt a service learning teaching approach, introducing service-oriented design themes into the class. Adopting a service learning approach in 2.009 was undertaken for two key reasons: research has shown that a service learning approach can improve student motivation and help them to master the skills that the class seeks to transfer [1, 4-6], and faculty were interested in helping students be more aware of the potential for the humanitarian impact of engineering practice and innovation. In addition, many problems that plague under-served communities offer a rich source of material for novel, challenging, user-centric product design. During this transformation, assessment of

the student experience as well as conversations with the instructors and community partners has provided insight into the benefits and challenges of this approach for students and instructors alike.

4.2 Class Description

2.009 provides students with a semester-long experience in the early product development process, progressing from opportunity identification through design ideation to a fully functioning, aesthetically-finished prototype of a novel mechanical or electro-mechanical product. Six large teams of 16-20 students work within a project theme chosen by the course instructor; examples of past themes include wireless remote-control, alternative energy and energy conservation, agriculture, and independently-living elderly. Product prototypes that have been created include a motion-powered mp3 player; a rehabilitation device for patients who underwent knee surgery; and a remote-controlled snow thrower. Representative photos are shown in Figure 27.

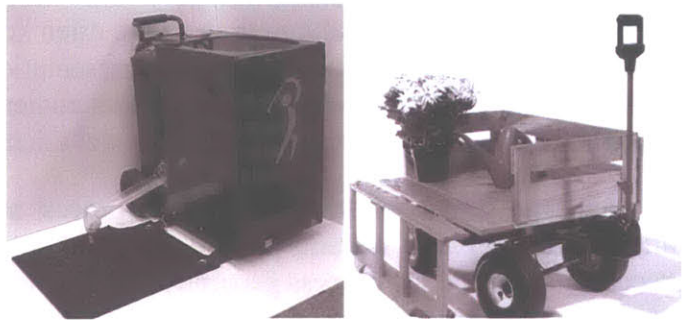


Figure 27: Representative 2.009 Prototypes: a Golf Teeing Device and a Powered Garden Cart that Follows the User

Students in 2.009 attend three one-hour lectures and one three-hour lab each week.

Lectures cover a wide range of topics including the overall product development process, design techniques, product definition, team management, engineering estimation, visual communication, and physical modeling. Each lab section has two instructors who guide the teams throughout the process; students also have the support of a class librarian, industry mentors, communications experts, and two teaching assistants. Lab sessions are held in a teaching-oriented machine shop, supported by six technical instructors who provide instruction on machining and fabrication. Students are expected to spend additional hours working in the lab outside of class time, and are given sufficient space in the lab to work on reasonably large projects. In 2.009, both individual and team-based milestones are defined, all of which help students toward the team goal of developing an alpha prototype. In-class exercises involving real-time data collection and feedback create a high level of interaction for this large class.

A key feature of the class is a comprehensive website, <<http://web.mit.edu/2.009/>>. Updated regularly, it provides detailed information about all assignments and class logistics. Lecture slides are posted, as are photographs and videos of all major team assignments, providing faculty, mentors, and anyone else who is interested the opportunity to see how teams are progressing and provide students with online feedback. Peer reviews, team performance survey tools, and design notebooks, all web-based, provide additional ways for team members to communicate.

The class is structured around the product development process, and students give presentations for five key milestones in the process. A project theme is revealed on the first day of class, such

as products for helping the elderly live independently, or products that use cleaner energy or consume less energy. Students brainstorm, discuss, and investigate possible project ideas for the first two weeks, eventually converging on six ideas per team, which are presented in a brief poster presentation: each team has six minutes to present six distinct project ideas that meet the class theme. After this initial ideation, the next phase involves fleshing out design ideas into design concepts and creating sketch models. Teams create preliminary, physical representations of four product concepts. During the subsequent stage, students focus on technical models and mockups intended to resolve key risks for two product alternatives. Early prototypes are built that demonstrate the feasibility of key challenges for each of the competing ideas. For the remainder of the class, teams work to develop a full alpha prototype that looks and functions like a real consumer product. At the technical review, students are expected to demonstrate a working alpha prototype, although there are often key functional and aesthetic limitations that faculty identify. For the subsequent final presentations, students present a refined product prototype and preliminary business plan to an audience of roughly 300 people including faculty, product designers, entrepreneurs, and potential clients.

At each stage throughout the development process and as the number of product concept alternatives decrease, students present more and more detailed technical, market, and customer needs data. While the process generally entails a winnowing of ideas, it is not uncommon for a new idea to emerge midway through the class, as students learn more about customer needs and the technical feasibility of their projects, or for students to merge multiple ideas, combining the best features of different alternatives.

Students receive faculty, industry mentor, and potential customer feedback soon after each milestone in the process, helping them to choose which concepts to pursue and to identify project strengths and weaknesses quickly. Students also give structured feedback to their teammates at four intervals during the term, helping each other (and faculty) to identify personality conflicts and communication challenges. Initially, the six student teams are divided into two sections of approximately equal size, permitting more ideas to be explored. Early on, each section chooses members to serve in the following roles: financial officers who maintain the budget of \$6500 per team, tool officers who maintain the workspace; information officers who manage information needs and gathering; safety officers who ensure product and team safety; and system integrators, who handle coordination and integration tasks. After the mockups are presented, the sections merge, and one project is pursued.

Figure 28 provides a graphical overview of the course organization. The concepts column demonstrates how teams progress from having many ideas to converging on one final product, using the light bulb icon to demonstrate how one idea may survive until the end of the class. The other shapes in that column represent the breadth of ideas considered at each stage. The final column contains pictures and descriptions of each stage of the process for the development of a manioc grater developed in the 2005 class. The device is intended for use in developing countries where the manual grating of that root vegetable is a time-consuming process.

4.3 Development of a Service Component in 2.009

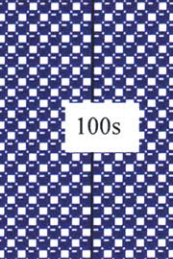
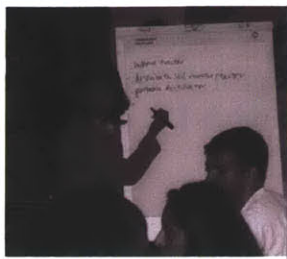
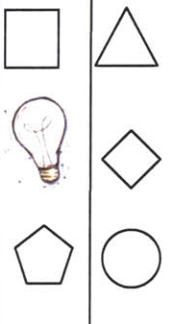

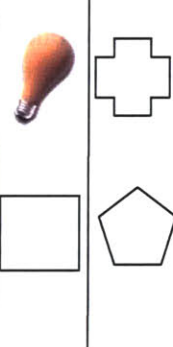

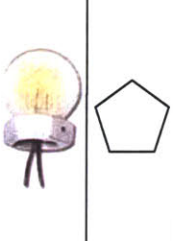
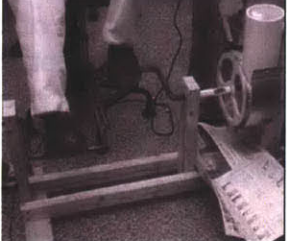


Soon after a service learning initiative was started at MIT in 2001, the service learning coordinator and 2.009 course instructor met to discuss the possibility of formally introducing


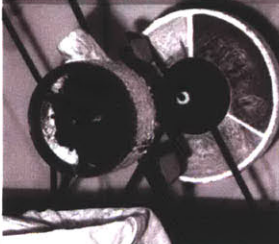
service-oriented projects into the class. A number of projects in prior 2.009 semesters had addressed certain community needs; however, these types of projects had never been encouraged intentionally. The pedagogy of service learning seemed like an excellent fit for the class, given the documented benefits of the practice. Service learning can help students with teamwork, communication skills, motivation for learning, and understanding of the ethical responsibilities of engineers [4-6]. Because the pedagogy requires regular, in-depth student interaction with real community partners, students can also gain the critical experience of product development constrained by real, challenging client needs [1]. Preliminary research at MIT supports these outcomes [69].

In order to introduce service projects into the class, in the first year, Fall 2002, the project theme was, simply, service. To help students identify service projects and community partners, the service learning staff worked with 2.009 staff to create an “idea fair” at which community clients presented a variety of ideas for projects that 2.009 students could address. From a student learning and engagement standpoint, this foray into service learning by 2.009 was successful; however, a number of lessons learned were identified, as discussed in section 4.5, that helped with course revisions for the next year. In Fall 2003, the course instructor chose the theme of personal home construction and improvement tools, and students collaborated with Habitat for Humanity to learn about what challenges “do-it-yourself-ers” face, as well as to identify and try to address the needs of that organization. Instead of an idea fair, students visited Habitat for Humanity worksites.

In the third and fourth year of this effort, the project themes were alternative energy and agriculture, respectively. The idea fair concept was reinstated, but students were no longer required to choose a service-oriented project, although one of the concepts developed for the 3-ideas presentation was required to have come from the fair.

Throughout the four years of this effort, the 2.009 course instructor has worked closely with MIT’s service learning coordinator and other service learning staff to identify community partners and projects appropriate to the theme of the class. It is the responsibility of the service learning staff, working in collaboration with 2.009 staff, to run the idea fair and to support and develop relationships with the community partners who attend the fair. Having the service learning coordinator as the primary community contact offers a significant benefit. Since the 2.009 process naturally involves a winnowing of concepts, many projects proposed by community partners do not come to fruition, but the service learning coordinator can often identify other classes and other service programs at MIT that might be able to work on the projects that are not addressed by 2.009 students.

Stage	Concepts	Time line (Week)	Example: Manioc Grater	
Brainstorming <i>Team divided into two sections, consider hundreds of ideas</i>		1-2		After learning that the theme for the class is Agriculture, students brainstorm projects that might fit, individually and in sections during lab. Each student is expected to document at least 20 ideas, and discuss his or her top three in lab (shown at left). Students attend an idea fair that provides additional concepts for them to consider.
3-Ideas <i>Team remains divided; each section develops three ideas from the brainstorming step</i>		3		From the many ideas proposed during the brainstorming period, each team section uses a decision-making process, supported by research into the projects' feasibility and marketability, to choose and present their top three ideas to the entire class. In six minutes, the team presented the Manioc Miracle Mincer, a manioc grater (shown at left); the Sun Bubbler, a solar-powered water purifier; Drink Dew, a dew collector for drinking water; the MegaPress, a human-powered oil press; and the Solar Composter, an improved composter.
Sketch Model <i>Team remain divided, each section develops two ideas further</i>		4-5		At this point, the faculty refined the team's focus to projects on processing agricultural products. For the sketch model stage, team sections proved key aspects of the device that seemed most challenging. The group working on the manioc grater demonstrated, as shown at left, that a grater made by punching holes into a can, attached to a drill at a low setting, would successfully and easily grate manioc. The team determined what angular speed and hole configuration led to the most effective shredding. Another sketch model investigated mechanisms for a peanut oil press.
Mockup <i>Team remain divided, each section refines one idea</i>		6-7		At the mockup stage, each section of each team works on just one project idea. This team demonstrated a working prototype that exceeded their goals for speed and met their quality requirements. They also presented marketing information, along with an exploration of different grating surfaces and materials.
Technical Review <i>Team join into one section, focus on one final idea</i>		8-11		The prototype shown at the technical review was much more refined, using appropriate materials and giving more consideration to usability and aesthetics. The students also added a flywheel, for improved energy transfer. The team created a product contract that defined the intended customers of the product, the market, and detailed how the product met each defined customer need.

<p>Final Presentation</p> <p><i>Team remains joined, developing the final idea</i></p>		<p>12-14</p>		<p>At the technical presentation, students further refined the prototype from an ergonomic and aesthetic standpoint. The feeding chute was improved, and a local Haitian artist was hired to decorate the device. In front of a packed lecture hall, students demonstrated their product and explained the need for the product, the customer specifications, the product's features, and a business plan.</p>
--	---	--------------	---	--

Key: shapes in the second column indicate project ideas; light bulb represents the chosen idea as it is refined over the semester.

Figure 28: Graphical Overview of 2.009 Organizational Structure

4.4 Research Approach

In order to understand the impact of the service learning method on the 2.009 class, a research program was established, focused particularly on the student experience, but taking into account feedback from course faculty, service learning staff, and community partners.

4.4.1 Methodology

During all four years of this effort, the quality of the service learning experience in the class was investigated. First, the logistical and administrative aspects of integrating service learning were documented and analyzed in terms of their perceived effectiveness. Second, the level and type of interaction between student teams and community partners was assessed, including the value of service products created; student intention and interest in the service aspect of the project, as reported by students and faculty; and community partner experience and feedback. Third, 2.009 students were assessed using qualitative and quantitative methods about the learning and social aspects of the service learning experience. This third aspect of service learning research is a critical area to pursue, given the importance of documenting students' academic and social gains in relation to new classroom pedagogies. Our data on the learning and social effects of service learning across the four years has resulted in promising initial findings.

4.4.2 Survey Methods

During the first two years of the study, 2002 and 2003, a paper survey was given to students on the last day of class. Students were asked to report on how the service component of the class affected them, in terms of effects on their motivation and interest in the class, learning styles, and relationships with students and faculty. Attitudes toward service and the service learning approach were also ascertained. Questions on a continuous 1-9 scale and open-ended questions were included.

In 2004 and 2005, a more detailed, methodical study was performed. Students took Internet-based surveys at the start of the class and at its conclusion, making more objective assessment of learning and social gains possible. A wider range of questions was used, investigating topics covered in the initial surveys as well as career interests and motivations and students' perceptions of their abilities for skills related to the 2.009 course objectives. The pre- and post-surveys had identical questions targeting areas of possible change over the course of the semester, with an additional set of questions targeting overall class experience on the post survey.

Given the pedagogical goals of the class, it was not possible to apply random assignment or control groups to this study. Further, while we are very interested in assessing differences between student teams who developed a service-oriented product versus those who did not, doing so is complicated by the class structure. In 2004 and 2005, all groups were required to consider service projects (by having at least one of the products per team section presented at the 3-ideas stage come from the idea fair) so true differentiation of groups that experienced service learning from groups that did not is difficult. For general analysis purposes, groups with a high level of service intent (as self-reported and identified by course instructors) and who had close community partner relations were considered to be service-oriented groups.

4.4.3 Survey Participation

Table 12 displays the survey participation rate and respondent demographics for all four years of the assessment. Because survey questions differed each year, some information is missing from Table 12, as denoted by a hyphen; for example, demographic information was not collected in 2002 and only post-surveys were administered in 2002 and 2003. Additionally, since service was a very limited aspect of the 2003 class, the indication that 100% of students focused on a service learning project is deceptive, when comparing that year to the other years.

4.5 Research Outcomes

As the study methods and service learning methods varied from year to year, it is difficult to perform a direct, analytical comparison of the classes. Given the similarities between the first two years and the last two years, those classes are compared directly, and key outcomes from each of the four years are, for the most part, presented independently. When appropriate, one-tailed t-tests and analysis of variance tests were performed.

Table 12: Survey Participation and Demographics of Survey Respondents

		2002	2003	2004	2005
Students in the class	<i>N</i>	81	81	97	78
Students who completed a pre-survey	<i>N</i>	-	-	86	71
	%	-	-	89	91
Students who completed a post-survey	<i>N</i>	62	50	73	55
	%	77	62	77	71
Students who completed both	<i>N</i>	-	-	65	44
	%	-	-	67	56
Gender of respondents, by percentage	Male	-	62	72	60
	Female	-	38	28	40
Ethnicity of respondents, by percentage	White	-	36	54	42
	Asian	-	26	22	26
	Hispanic	-	22	16	18
	Black	-	-	7	7
Students who focused on a service learning project, by percentage	Service learning	100	100*	66	51
	Not service learning	0	0*	34	49

Key:

- *information not collected*

* *all students were aware of the Habitat for Humanity connection; however, no projects were oriented toward service specifically*

4.5.1 Year One, 2002

This initial attempt to use service learning in 2.009 was reasonably successful, in terms of the logistical and administrative aspects of using service learning: most teams worked closely with their community partners and developed impressive, service-oriented prototypes and presentations by the end of the class. A notable success was the Kool Pool team, who developed an alternative billiards game that helped developmentally disabled students at a local school increase their social interactions and improve their hand-eye coordination. We believe that one of the reasons that this team was so successful was because of their close interaction with the school: they were able to test early prototypes and receive feedback on a regular basis. The final prototype, which was given to the school at the end of the semester, is shown in Figure 29.

A second service project, this one focused internationally, was the Kinkaju projector, shown in Figure 30 <<http://www.designthatmatters.org/k2/>>. This low-power, microfilm-based LED projector was intended to be used in rural regions of countries like Mali, where adults take night classes, but lack sufficient numbers of textbooks or fuel for lighting the classroom. This team also had close connections to their community partners, working via email and with people who lived near MIT but who had experience living and working in Mali. There are currently nearly 500 next-generation versions of this concept now in use in Mali.

All of the remaining teams worked on international projects and, while some had similarly good connections to community partners, others had more limited interactions and knowledge transfer. This limitation made it much more difficult for teams to develop projects that were appropriate for the regions and clients they were considering, a key aspect of all design projects and particularly international ones. Additionally, faculty often had less expertise on client requirements in developing countries than for more traditional consumer products, a frustration for both students and faculty themselves. The overly broad project theme, service, compounded this issue. Previous themes were narrower in scope, permitting faculty to research and lecture on overarching subjects within that theme, a step not possible with a generalized service theme.

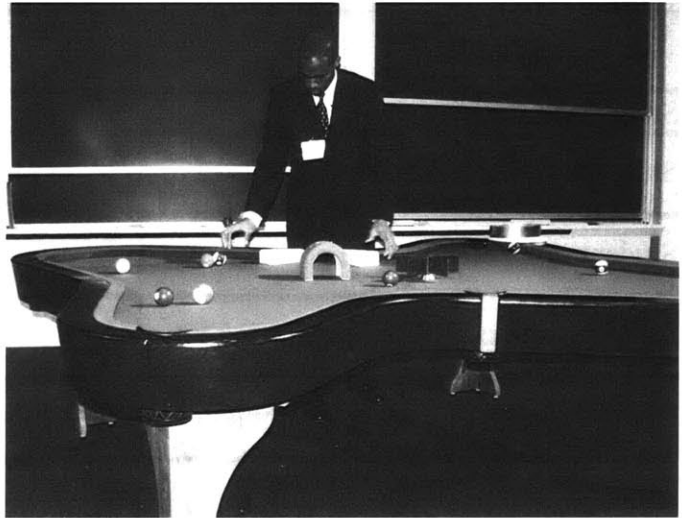


Figure 29: Kool Pool Billiards Table and Accessories Created in 2002

Another challenge that arose in this class was that a few vocal students were very displeased with the project theme, believing that service-oriented projects could not provide a sufficiently technical challenge, or that they wouldn't be profitable. While the projects that were developed were academically rigorous, and some have led to viable products, the students' frustrations were a concern. A final issue for this first attempt at using service learning in 2.009 is that a key part of teams' final presentations is a preliminary business model. Students were confused about how

to structure a business plan for a product with primarily humanitarian goals: some wanted to pattern their plan after a typical, mass-produced consumer product while others ignored the requirement, assuming it was unnecessary for a service-oriented project.

Despite these issues, overall, in the first year, students reported positive experiences with service learning on the end-of-term survey. Students responded most positively to the questions, “How did the service learning component of the class affect your motivation to work hard in this class?” and “How did the service learning component of the class affect your understanding of community needs and how you can help?” For both questions, the mean response was

approximately seven on a nine point scale, with one being strong negative effect and nine being strong positive effect. Students also responded at this very positive level, of approximately seven out of nine, to the question, “The service learning part of this class was worthwhile,” with the scale ranging from strongly disagree to strongly agree. The Kool Pool team, mentioned above, which had a particularly good service experience, had responses that verified this experience: respondents were more positive than the other teams on eight of the twelve scaled questions.

4.5.2 Year Two, 2003

Given the problems during the first year, as identified in the previous section, effort was put into redressing these issues. By focusing the class on home improvement projects and on working with Habitat for Humanity, it was expected that the problems that arose from working with international clients and having such a broad focus (service) would be eliminated. However, the new approach seemed to be an over-correction. The connection with Habitat for Humanity did provide students with great insights into home

improvement challenges, since most Habitat volunteers have little or no home construction experience. However, in the

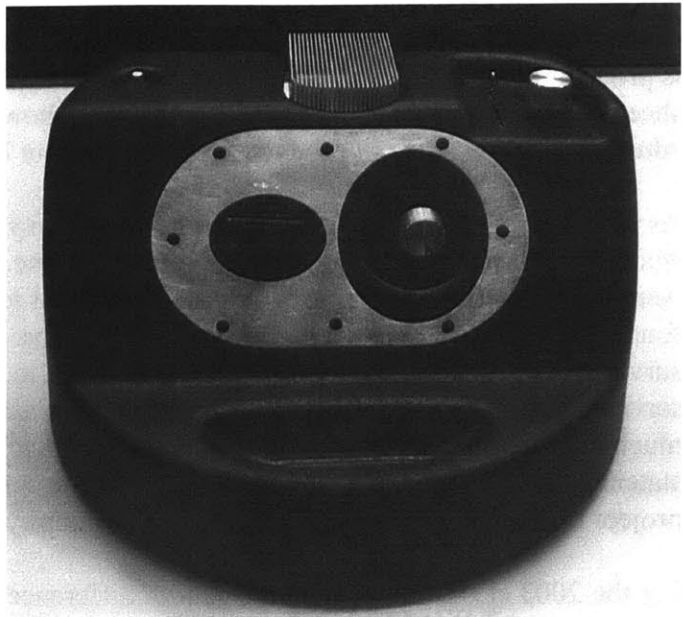


Figure 30: Kinkaju Projector Created in 2002



Figure 31: Mechanized Scaffolding Developed in 2.009 in 2003

process of working with Habitat, it became clear that 2.009 student projects were not likely to be of real benefit to the organization. The assistance Habitat needs most in the greater Boston area is procedural and financial, rather than mechanical. The products that were developed, such as a sheetrock lifter and the mechanized scaffolding shown in Figure 31, offered students a positive educational experience in product development, but lacked a true service component.

As the service experience was extremely limited in year two, it is not all that surprising that student responses were more muted than in year one. In 2002, all average responses to questions were more positive than neutral; in 2003, averaged responses were below the neutral point for four of the fourteen questions, and were, for the five questions that were identical to the 2002 survey, lower. The most negative responses were to the questions, “How much do you think service learning influenced your ability to apply class concepts to different problems,” “How much do you think service learning was a good match to the way you learn best,” and to the statements, “Service learning helped me learn the course material” and “The service learning project I worked on in this class helped a community in need.”

For the 2003 class, however, some gender differences we had started to witness across all service learning classes at MIT [69] started to emerge within the 2.009 data. While men had higher means on the two questions about the effect of service learning on relationships with other students and the instructor, for all other questions, women gave higher mean ratings and were significantly higher than men in feeling that service learning helped them learn the course material [$t(48) = -2.28, p=0.027$] and that service learning influenced their confidence in applying theoretical concepts to real world issues [$t(48) = -2.08, p=0.04$]. Despite the challenges experienced in the service learning implementation for this year, the service flavor and applied project methodology may have mitigated some of the traditional barriers that women experience in highly technical fields [70, 71].

When combining data from both 2002 and 2003, women had higher means for all questions, except for the influence service learning had on their relationship with the instructor. Women were especially more likely than men to rate service learning as worthwhile [$t(108) = -1.93, p=0.056$] and to recommend this class to their friends [$t(108) = -2.49, p=0.01$].

4.5.3 Year Three, 2004

The energy theme chosen for the third year was highly successful, in that it provided a wide number of service-oriented product possibilities but did not limit students to service projects solely. Finding community partners for the re-established idea fair also became simpler: the theme was not as overwhelmingly broad as “service,” but was not as narrow as simply Habitat for Humanity: such a narrow focus can lead to the student dissatisfaction experienced in the second year, and can also unduly burden the community partner.



Figure 32: The Vac-Pac Vaccine Transporter, Developed in 2004

Many student projects still focused on the needs of international under-served communities. Hence, to improve communication and customer feedback, students were provided with the opportunity to apply for grants from the service learning initiative, beyond their team budget, to travel to the community they were focused on and test their prototypes. One of the projects from 2004 that students have continued to work on was the Vac-Pac, a low-energy Sterling engine-powered vaccine refrigerator that is worn as a backpack for transporting vaccines to regions difficult to reach by truck. Following the class, students on the team founded a company to bring this device, shown in Figure 32, to market. Another highly successful project was the Kinkajuice, a human-powered generator intended to charge the Kinkaju projector developed previously in 2.009. The team working on this project secured funding to send one team member to Mali around the time of the technical review; the feedback that they received allowed them to make critical, highly beneficial improvements to their final prototype, as shown in Figure 33.

One of the most interesting findings from the surveys administered for this year was discussed in section 3.5 and shown in Figure 23: that students changed their career orientations over the course of the semester, showing much more interest in engineering-focused careers at the end of the class. Within subject analysis of variance (ANOVAs) indicated that management consulting [$F(1,51) = 54.12, p < 0.01$] and medicine [$F(1,51) = 130.61, p < 0.01$] significantly decreased in appeal and working in product development firms [$F(1,51) = 28.56, p < 0.01$] and attending graduate school [$F(1,52) = 77.58, p < 0.01$] significantly increased in appeal.

4.5.4 Year Four, 2005

Fall 2005 was one of the most successful 2.009 classes, based on faculty reviews of the technical quality of the prototypes produced and student evaluations of the class. The instructors believe that the success may stem from the fact that students in their junior year were very aware of the projects the senior students worked on in the previous year (2004), saw that the service-oriented projects were highly valued, and were very excited to pursue these types of projects. In previous years, students seemed to have had to warm up to the project theme before getting excited. Apart from a new theme, agriculture, and the normal, incremental changes that

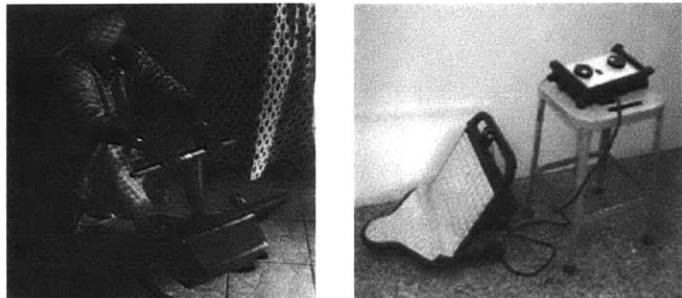


Figure 33 (from left): The Kinkajuice Human-Powered Generator, developed in 2.009 in 2004, being field tested in Mali; The Final Prototype of the Kinkajuice, connected to a production-version of the Kinkaju

occur each year, there was only one notable difference between 2004 and 2005 from a service perspective. In order to expand interactions between teams and community partners as the term progressed, community partners were individually invited during each stage of the class to submit feedback on milestone materials presented online using web-based response mechanisms. While this feature had been initiated in 2004, the increase in its use in 2005 was marked thanks to the additional effort made by the service learning and 2.009 staff to promote awareness of the tool.

In 2005, three of the six projects developed were service-oriented: an irrigation device for farmers in developing countries shown in Figure 34, a device for moving and planting trees needed by a local organization that does tree planting with inner-city youth shown in Figure 35, and the manioc grater used as an example in Figure 28 on page 71. Although two of these projects were focused internationally, once again, students effectively developed and maintained community partnerships that allowed them to meet their clients' needs.

The 2005 career survey results, shown in Figure 36, differed from the 2004 career question outcomes: students' career focus was almost identical at the start and end of the semester, and quite similar to the engineering choices at the end of the semester in 2004, as shown in Figure 23: students entered into and emerged from the class engaged and excited by engineering fields. Data on what field students chose upon graduation is not yet available because that class has not yet graduated; the data is normalized in the same way as in Figure 8. When considering why the career interests at the start of the semester were so dissimilar to those of the students in 2004, based on students' attitudes and questions at the start of the term, it seems likely that the positive experiences that students had in 2004 influenced the career interests of the students who took 2.009 in 2005. The course instructor noticed a marked increase in students' interest in 2.009 projects (before enrolling in the class) since the conclusion of the 2004 class. An additional consideration for this difference is that the vast majority of the 2005 2.009 students took a thermo-fluids engineering class in their junior year that had a significant service learning design and analysis component, an experience unique to this set of students. This experience likely heightened expectations for the projects that would follow in 2.009. It is conceivable that this junior-year experience affected their career interests and choices. Unfortunately, data were not collected on career choices prior to the 2.009 experience, so it is difficult to come to any firm conclusions.

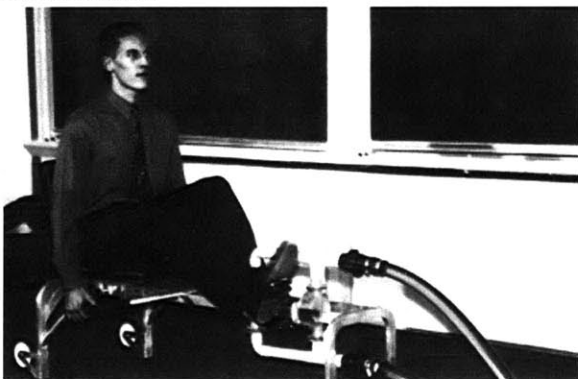


Figure 34: Irrigation Device for Farmers in Resource-Limited Areas, Developed in 2005

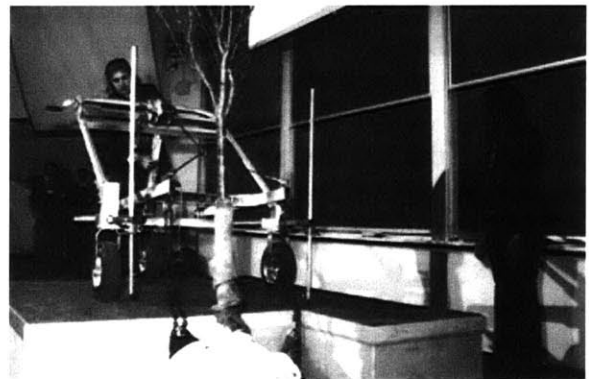


Figure 35: Tree Planting Device Developed for a Local Community Organization in 2005

One interesting outcome for the 2004 class discussed in the previous section was that, at the start of the class, women rated themselves more negatively on their product design skills than men [2004: $F(1,58)=14.1$, $p < 0.01$]. At the conclusion of the class, women’s perceptions of their product design skills increased significantly more than did men’s, though both groups increased [2004: $F(1,42)=7.61$, $p < 0.01$]. In 2005, again, women rated themselves below men and both groups increased, but men actually increased slightly more than women. In 2005, however, certain women seemed to be more engaged in the class than in previous years: five of the six de facto team leaders (identified as such by faculty at the conclusion of the class) were female, even though only approximately 30% of the class was female in 2005, a much higher rate than in previous years.

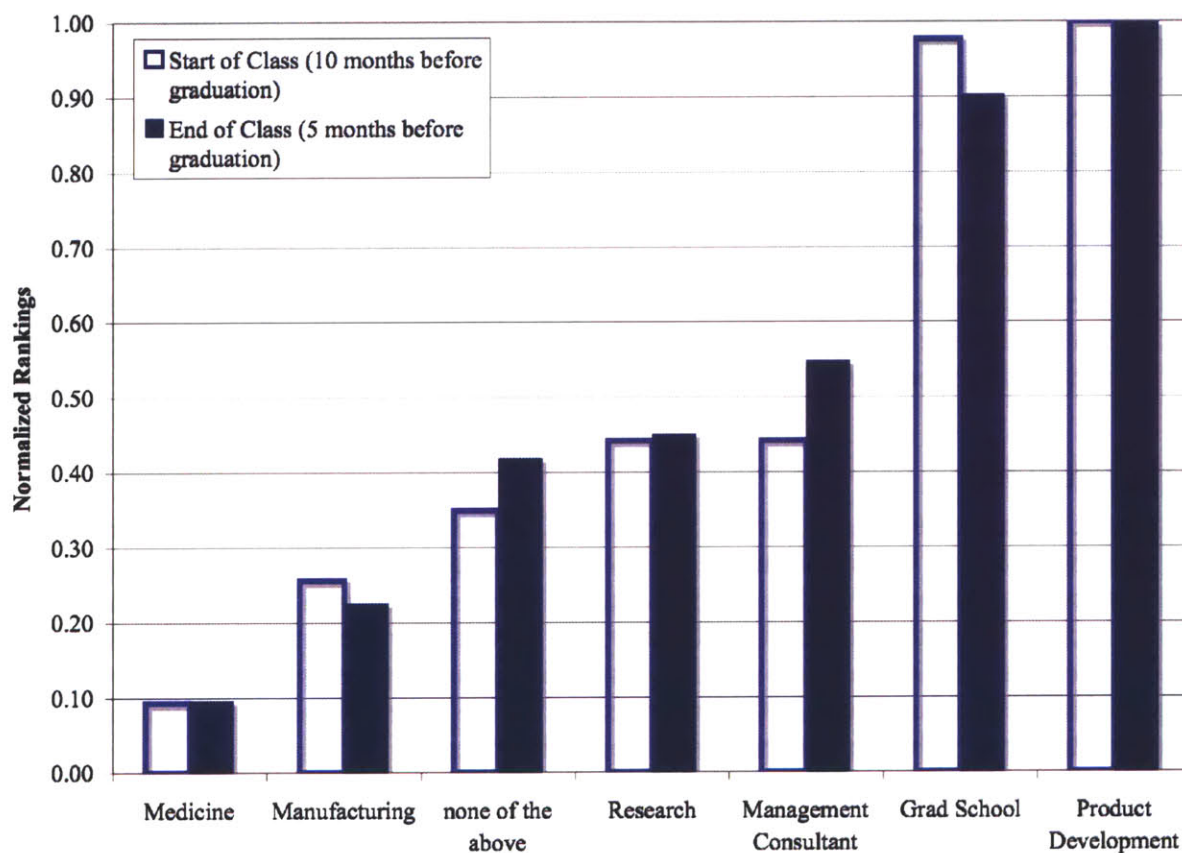


Figure 36: 2005 Career Choice Rankings

A common outcome for both classes is that students who participated more fully in the service learning experience (based upon their self-reported attitudes toward the projects and faculty views on which projects were highly service-oriented), reported much more strongly than their “non-service learning” peers that “2.009 helped me better understand community needs and how I could help as an engineer” [2004: $F(1,69)=5.91$, $p < 0.02$; 2005: $F(1,53)=5.542$, $p=.022$]. Although this outcome is not overly remarkable given the focus of engineering service projects

in the class, it is encouraging to find that students' perceptions of the role engineering can play in finding innovative solutions to difficult societal problems can be influenced, an important step in helping to increase students' awareness of the broad role engineering skills and professions can play.

It is interesting that few other differences between service learning-focused teams and non-service learning-focused teams emerged. There are a few plausible reasons for this finding. First, all students in 2.009 work very closely together, and students on different teams are fully aware of what their peers are working on, thanks to friendships, competitiveness, interactions in the shared laboratory space, and the regular presentations that they give. Hence, the students who did not participate in service learning projects directly likely received incidental benefits through this contact. Second, since all students were exposed to service learning projects at the idea fair and had to consider at least one for the 3-idea presentation, the line between the different project experiences is even less distinct. Third, all teams maintained regular contact with potential users, so that even the students who were not focused on service projects likely perceived that they were working for others. Although these realities are challenging from a research perspective, it is encouraging from an educational perspective to see that students may be benefiting from this pedagogy.

Additionally, a testament to how motivating students find the service-oriented projects is that many continue to work on the projects after the class is over for their senior theses. While 2.009 has always been a source of projects for students' senior theses, that trend has increased since the introduction of a service component to the class; students tend to be particularly excited about these projects, perhaps because of the connection they feel to the community partners.

4.6 Conclusions

Given the strong success of using service learning in 2.009 in the past two years, this practice is being institutionalized. While adopting a service learning approach for Product Engineering Processes posed a number of challenges that required a few semesters to resolve, the approach has been successful for the class and has been widely accepted by students taking the class. Further, given the complexities that arise when addressing real problems for under-served clients with particularly significant needs, it is unsurprising that this new pedagogy required some time to evolve into a reasonably smooth and well-accepted method.

The research that has been performed on the class thus far offers some interesting outcomes. Students report finding benefit from the service learning experience, and there were differential outcomes for men and women. In 2004, students also significantly changed their career aspirations toward an engineering orientation.

Many more questions remain to be answered. Quantifying a multitude of positive outcomes is extremely difficult, given the limitations of the research design that are necessary so that academic rigor is not compromised. However, more experimental data would be highly beneficial, as it would offer stronger arguments to expand the use of service learning in engineering design classes.

In addition, it is hoped that this overview of 2.009 and how the service learning pedagogy was incorporated into the class might serve as a preliminary model for other instructors with similar classes. Product design education may be well-served by this pedagogy, given the positive outcomes for students, and the ways that service learning can help under-served communities.

5. Overall Conclusions and Future Steps

Given the initial success of service learning in these classes, service learning will continue to be encouraged in these classes, and in other core and elective classes in the department, at a modest rate that allows for a high level of quality in terms of the education and the service. In the 2005-2006 academic year, service learning has been used again in 2.009 (with the theme of agriculture) and in 2.006 (with a project on low-energy refrigerators for health clinics in developing countries), and has been tried for the first time in 2.72 Elements of Mechanical Design (for which students are working on a range of projects, including a bicycle-powered washing machine for use in Guatemala). Eventually, it is hoped to expand the use of service learning into other engineering departments at MIT, but resources require that the focus remain on one department for the time being.

Research into the use of service learning in engineering at MIT continues, and every year the assessment methods used are expanded and refined. Collaboration has also begun with the University of Massachusetts, Lowell to perform interuniversity studies of service learning in the engineering core [72], and there is interest to expand the depth of this research, and work with other universities to expand its breadth.

References

1. Oakes, W.C., *Service-Learning in Engineering: A Resource Guidebook*. 2004, Campus Compact. Available from: http://www.compact.org/publication/SL_Engineering.html.
2. Coyle, E.J., L.H. Jamieson, and L.S. Sommers, *EPICS: A Model for Integrating Service-Learning into the Engineering Curriculum*. Michigan Journal of Community Service Learning, 1997. **4**: p. 81-89.
3. Martin, P.T., *Service-Learning and Civil and Environmental Engineering: A department shows how it can be done*, in *Projects that Matter: Concepts and Models for Service Learning in Engineering*, E. Tsang, Editor. 2000, American Association for Higher Education: Washington, DC. p. 135-147.
4. Eyler, J.S., *What Do We Most Need to Know About the Impact of Service-Learning on Student Learning?* Michigan Journal of Community Service Learning, 2000(Special Issue): p. 11-17.
5. Steinke, P. and S. Buresh, *Cognitive Outcomes of Service Learning: Reviewing the Past and Glimpsing the Future*. Michigan Journal of Community Service Learning, 2002. **8**(2): p. 5-14.
6. Tsang, E., ed. *Projects that Matter: Concepts and Models for Service Learning in Engineering*. 2000, American Association for Higher Education: Washington, DC.
7. Demirbas, A., *Biomass to Charcoal, Liquid, and Gaseous Products Via Carbonization Process*. Energy Sources, 2001. **23**(6): p. 579-587. Available from: <http://dx.doi.org/10.1080/00908310152125229>
8. McCauley, R.F., N.C. Burbank, and R.H.F. Young. *The Production of Charcoal from Bagasse*. in *25th Industrial Waste Conference*. 1970. Purdue University.
9. Tatom, J.W., et al., *Interim Report: Pyrolysis of Rice Husks in Indonesia*, T.D.T.C.I.o.T. Bandung, Editor. 1980, Government of Indonesia and U.S. Agency for International Development.
10. Warwick, H. and A. Doig, *Smoke - The Killer in the Kitchen: Indoor Air Pollution in Developing Countries*. 2004, Practical Action: London. Available from: http://www.itdg.org/?id=smoke_index.
11. Wood, T.S. and B. S., *Fuelwood and Charcoal Use in Developing Countries*. Annual Review of Energy and the Environment, 1985. **10**: p. 407-429. Available from: <http://links.jstor.org/sici?sici=0004-5608%28198506%2975%3A2%3C163%3ATCODID%3E2.0.CO%3B2-H>.
12. Heltberg, R., *Household Fuel and Energy Use in Developing Countries: A Multicountry Study. Draft*. 2003, Oil and Gas Policy Division of the World Bank. Available from: [http://lnweb18.worldbank.org/ESSD/sdvext.nsf/81ByDocName/HouseholdFuelandEnergyUseinDevelopingCountries-AMulticountryStudy/\\$FILE/FuelUseMulticountryStudy_05.pdf](http://lnweb18.worldbank.org/ESSD/sdvext.nsf/81ByDocName/HouseholdFuelandEnergyUseinDevelopingCountries-AMulticountryStudy/$FILE/FuelUseMulticountryStudy_05.pdf).
13. *World Development Indicators*. 2002, The World Bank: Washington, DC.
14. Barnes, D. and W. Floor, *Rural Energy in Developing Countries: A Challenge for Economic Development*. Annual Review of Energy and the Environment, 1996. **21**: p. 497-530.
15. *Consumer Expenditure Survey*, B.o.L. Statistics, Editor. 2006, U.S. Department of Labor. Available from: <http://www.bls.gov/cex/>.

16. Emrich, W., *Handbook of Charcoal Making : The Traditional and Industrial Methods*. 1985, Dordrecht ; Boston: D. Reidel for the Commission of the European Communities; Sold and distributed in the U.S.A. and Canada by Kluwer Academic Publishers. xvi, 278 p.
17. Antal, M.J., et al., *High-Yield Biomass Charcoal*. *Energy Fuels*, 1996. **10**(3): p. 652-658. Available from: <http://pubs.acs.org/cgi-bin/article.cgi/enfuem/1996/10/i03/html/ef9501859.html>.
18. Wines, M., *Malawi is Burning, and Deforestation Erodes Economy*, in *New York Times Online*. 2005.
19. Habitat, *Application of Biomass-Energy Technologies*. 1993, United Nations Centre for Human Settlements (Habitat): Nairobi.
20. *CharDust Ltd*. Available from: <http://www.chardust.com>.
21. *Charcoal Fuel from Bagasse - Chardust Ltd. in Kenya*, in *Village Power Newsletter*. 2002. Available from: <http://www.repp.org/discussiongroups/resources/stoves/Karstad/canecoal/vpnchemelil.html>.
22. Owen, M., *Status of CaneCoal Email*, A. Banzaert, Editor. 2006: Nairobi, Kenya. p. Email about the status of the CaneCoal project by Chardust, Ltd.
23. Katyal, S., K. Thambimuthu, and M. Valix, *Carbonisation of Bagasse in a Fixed Bed Reactor: Influence of process variables on char yield and characteristics*. *Renewable Energy*, 2003. **28**(5): p. 713-725. Available from: <http://www.sciencedirect.com/science/article/B6V4S-475JBFN-3/2/b37b5d74d4284d4dda587af758dc27ad>
24. Zandersons, J., et al., *Studies of the Brazilian Sugarcane Bagasse Carbonisation Process and Products Properties*. *Biomass and Bioenergy*, 1999. **17**(3): p. 209-219. Available from: <http://www.sciencedirect.com/science/article/B6V22-3X4W4MR-3/2/2e8139990fe0d27b443455c483517354>
25. Koser, H.J.K., W. Siemers, and U. Stuvén, *Technical and Economic Assessment of Charcoal and Densified Fuel from Water Hyacinths and Cotton Stalks*. *Fuel Processing Technology*, 1983. **7**: p. 23-42.
26. Demirbas, A., *Properties of Charcoal Derived from Hazelnut Shell and the Production of Briquettes Using Pyrolytic Oil*. *Energy*, 1999. **24**: p. 141-150.
27. Demirbas, A., et al., *Kinetics for Fast Pyrolysis of Hazel Nut Shell*. *Fuel Science and Technology International*, 1996. **14**(3): p. 405-415.
28. Culcuoglu, E. and F. Karaosmanoglu, *Rapeseed Charcoal: Production and Characterization*. *Energy Sources*, 2000. **22**(7): p. 625-630. Available from: <http://dx.doi.org/10.1080/00908310050045573>
29. Karaosmanoglu, F. and E. Tetik, *Charcoal from the Pyrolysis of Rapeseed Plant Straw-Stalk*. *Energy Sources*, 1999. **21**(6): p. 503-510. Available from: <http://dx.doi.org/10.1080/00908319950014632>
30. Grover, P.D. and S.K. Mishra. *Biomass Briquetting: Technology and Practices*. in *Regional Wood Energy Development Programme in Asia*. 1996. Bangkok: Food and Agriculture Organization of the United Nations. Available from: <http://rwedp.org/acrobat/fd46.pdf>.
31. Beker, U.G., *Briquetting of Afsin-Elbistan Lignite of Turkey Using Different Waste Materials*. *Fuel Processing Technology*, 1997. **51**: p. 137-144.

32. Beker, U.G., *Briquetability of Lignite and Woody Wastes Composite Fuel*. Energy Sources, 2000. **22**: p. 99-107.
33. Richards, S.R., *Briquetting Peat and Peat-Coal Mixtures*. Fuel Processing Technology, 1990. **25**: p. 175-190.
34. Rahman, A.N.E., et al., *Influence of size and shape on the strength of briquettes*. Fuel Processing Technology, 1989. **23**: p. 185-195.
35. Smith, A., *Fuel from the Fields: A Guide to Converting Agricultural Waste into Charcoal Briquettes*. 2003. Available from: web.mit.edu/d-lab/portfolio/charcoal/Sugarcane%20Charcoal%20Manual%20Draft%20October%202004.doc.
36. Vechakul, J., *Design of a Bagasse Charcoal Briquette-Making Device for Use in Haiti in Mechanical Engineering*. 2005, Massachusetts Institute of Technology: Cambridge.
37. Fan, V.Y., *Design of a Crushing and Agglomeration Process for Manufacturing Bagasse Charcoal*. 2006, Massachusetts Institute of Technology: Cambridge.
38. Ang, D.W. and Massachusetts Institute of Technology. Dept. of Mechanical Engineering., *Designing the Sugar Cane Charcoal Extruder*. 2005. p. 32 leaves.
39. Ramírez, A. and Massachusetts Institute of Technology. Dept. of Mechanical Engineering., *A Comparative Analysis of Emissions from Bagasse Charcoal and Wood Charcoal*. 2005. p. 27 leaves.
40. Kamimoto, L.K. and Massachusetts Institute of Technology. Dept. of Mechanical Engineering., *Economic feasibility of bagasse charcoal in Haiti*. 2005. p. 16 leaves.
41. EPA, *Air Quality Criteria for Particulate Matter*, O.o.R.a.D. National Center for Environmental Assessment-RTP Office, Editor. 2004, U.S. Environmental Protection Agency. Available from: <http://www.epa.gov/pmresearch/>.
42. Ezzati, M., *Indoor Air Pollution and Health in Developing Countries*. The Lancet, 2005. **366**(9480): p. 104-106. Available from: <http://proquest.umi.com/pqdweb?did=868111351&sid=2&Fmt=2&clientId=5482&RQT=309&VName=PQD>.
43. EPA. *National Ambient Air Quality Standards (NAAQS)*. 2006 [cited; Available from: <http://epa.gov/air/criteria.html>].
44. Bruce, N., R. Perez-Padilla, and R. Albalak, *Indoor air pollution in developing countries: a major environmental and public health challenge*. Bulletin of the World Health Organization, 2000. **78**(9): p. 1078-1092. Available from: http://www.scielo.org/scielo.php?pid=S0042-9686200000900004&script=sci_pdf&tlng=.
45. *ASM Handbook*. 2003, ASM International: Materials Park, OH.
46. Jacoby, B., *Service Learning in Today's Higher Education*, in *Service-Learning in Higher Education: Concepts and Practices*, B.a.A. Jacoby, Editor. 1996, Jossey-Bass: San Francisco. p. 3-25.
47. Eyler, J.S. and D.E.J. Giles, *Where's the Learning in Service-Learning?* 1999, San Francisco: Jossey-Bass, Inc.
48. Mabry, J.B., *Pedagogical Variations in Service-Learning and Student Outcomes: How Time, Contact and Reflection Matter*. Michigan Journal of Community Service Learning, 1998. **5**: p. 32-47.
49. Oakes, W.C., et al. *Service Learning in Engineering*. in *ASEE/IEEE Frontiers in Education Conference*. 2002. Boston, MA: IEEE.

50. Dahir, M., August/September). Educating engineers for the real world. *Technology Review*, 14-16., *Educating engineering for the real world.*, in *Technology Review*. 1993. p. 14-16.
51. Kolb, D., *Experiential Learning: Experience as the Source of Learning and Development*. 1984, Upper Saddle River, NJ: Prentice Hall.
52. *Publication Manual of the American Psychological Association, 5th Ed*. 2001, Washington, DC: American Psychological Association.
53. Banzaert, A., et al. *Faculty Views of Service Learning in Mechanical Engineering at MIT in ASEE Annual Conference*. 2005. Portland, OR: ASEE.
54. Driscoll, A., *Studying Faculty and Service-Learning: Directions for Inquiry and Development*. Michigan Journal of Community Service Learning, 2000(Special Issue): p. 35-41.
55. Hammond, C., *Integrating Service and Academic Study: Faculty Motivation and Satisfaction in Michigan Higher Education*. Michigan Journal of Community Service Learning, 1994. **1**(1): p. 21-28.
56. Hesser, G., *Faculty Assessment of Student Learning: Outcomes Attributed to Service-Learning and Evidence of Changes in Faculty Attitudes about Experiential Education*. Michigan Journal of Community Service Learning, 1995: p. 33-42.
57. McKay, V. and P. Rozee, *Characteristics of Faculty Who Adopt Community Service Learning Pedagogy*. Michigan Journal of Community Service Learning, 2004: p. 21-33.
58. Abes, E., G. Jackson, and S. Jones, *Factors that Motivate and Deter Faculty Use of Service-Learning*. Michigan Journal of Community Service Learning, 2002: p. 5-17.
59. Adams, S. and F. Pereira. *Measuring Faculty Preparation to Lead Teams in the Engineering Classroom: A Pilot Study*. in *ASEE Annual Conference*. 2002. Montreal, Quebec: ASEE.
60. Zwyno, M. *Engineering Faculty Teaching Styles and Attitudes toward Student-Centered and Technology-Enabled Teaching Strategies*. in *ASEE Annual Conference*. 2003. Nashville, TN: ASEE.
61. Mitchell, J. *Time Professors Spend Improving their Teaching*. in *34th ASEE/IEEE Frontiers in Education Conference*. 2004. Savannah, GA: IEEE.
62. Duffy, J., E. Tsany, and S. Lord. *Service-Learning in Engineering: What, Why, and How*. in *ASEE Annual Conference*. 2002. St. Louis, MS: ASEE.
63. Pinnell, M., C. Daprano, and G. Williamson. *A Multi-Disciplinary Community Based Service-Learning Project: the Girl Scout Wall Project*. in *ASEE Annual Conference*. 2003. Nashville, TN: ASEE.
64. Tsang, E. *Integrating Service-Learning in a Sophomore-Level Materials, Manufacturing, & Design Lab*. in *32nd ASEE/IEEE Frontiers in Education Conference*. 2002. Boston, MA: IEEE.
65. Orne, M.T., *On the Social Psychology of the Psychological Experiment: With Particular Reference to Demand Characteristics and their Implications*. *American Psychologist*, 1962. **17**: p. 776-783.
66. Department of Mechanical Engineering, M., *Program Self-Study Report for Mechanical Engineering*. 2001.
67. Goodman, I.F., et al., *Final Report of the Women's Experiences in College Engineering (WECE) Project*. 2002, Goodman Research Group: Cambridge, MA. Available from: <http://www.grginc.com/reportsandpubsframe.html>.

68. Banzaert, A., S.G. Ariely, and D.R. Wallace. *Incorporating Open-Ended, Service-Oriented Projects into a Senior Product Design Class: Methodology and Outcomes*. in *ASME 2006 International Design Engineering Technical Conferences & Computers and Information in Engineering Conference*. 2006. Philadelphia, PA: ASME.
69. Ariely, S.G., A. Banzaert, and A. Smith, *MIT's Public Service Design Seminars and Service Learning in Mechanical Engineering at MIT - Poster Session*, in *Annual K-H International Conference on Service-Learning Research*. 2004: Greenville, SC.
70. Busch-Vishniac, I. and J.P. Jarosz, *Can Diversity in the Undergraduate Engineering Population be Enhanced through Curricular Change?* *Journal of Women and Minorities in Science and Engineering*, 2004. **10**: p. 255-281.
71. Seymore, E. and N. Hewitt, *Talking about Leaving: Why Undergraduates Leave the Sciences*. 1997, Boulder, CO: Westview.
72. Banzaert, A., J. Duffy, and D.R. Wallace. *Strategies for Integrating Service-Learning into the Engineering Core at the University of Massachusetts Lowell and the Massachusetts Institute of Technology*. in *ASEE Annual Conference*. 2006. Chicago, IL: ASEE.