

Exploring Design Based Wilderness Education: A pedagogy to develop design thinking, an engineering science worldview, and leadership capacity.

by

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## ABSTRACT

This study explores the experience of students during the implementation of a design-based wilderness education curricula. I introduce the concept of a curriculum that combines the pedagogies of design-based learning and wilderness education to encourage the development of design thinking, an engineering science worldview, and leadership ability. This project bridges the gap between the wilderness education and engineering education literature as this is a novel approach to engineering education. In bridging the two literatures, we find that the outcomes of wilderness education align well with the contemporary demands of engineering education.

The initial implementation of the design-based wilderness education curriculum took place in the Summer of 2014. Thirty students from the Singapore University of Technology and Design and six students from MIT participated in the program. A mixed-methods study was performed, relying on surveys, exit interviews, and instructor observations.

The findings from the research illustrate that design-based wilderness education holds the potential to serve as an exciting novel avenue to encourage design thinking, the development of an engineering science worldview, and leadership ability. While further research is necessary, this initial exploration finds that wilderness education is a promising vector for supporting effective design thinking practices and the development of an engineering science worldview, alongside leadership ability.

Thesis Supervisor: John G. Brisson  
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I couldn't have led the expeditions without Tory, Jesse, Kate and Jacob who volunteered their time as assistant instructors during the wilderness expeditions.

The past two years in Cambridge would not have been the same without my friends in the TPP '15 cohort. Alex, Justin, and Jacob<sup>1</sup> - while our increasingly elaborate weekday breakfasts didn't always help my productivity, they certainly resulted in enjoyable mornings.

Sally Miller provided the artwork for the background material within the curriculum. She was also willing to abandon me at Intervale, so I could write this thesis while she went climbing.

Finally, I need to thank my family. While they might not have always understood the path I've followed to get to where I am, they've been supportive along the entire journey.

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<sup>1</sup> and later John.

# Table of Contents

<b>1</b>	<b>Introduction .....</b>	<b>8</b>
1.1	Educating the Engineer of Today .....	9
1.2	Design Thinking, Engineering Science, and Leadership .....	11
1.2.1	Design Thinking .....	12
1.2.2	Engineering Science Worldview.....	13
1.2.3	Leadership .....	13
1.3	Research Question.....	14
1.4	Study Context.....	14
1.4.1	The Learners .....	15
<b>2</b>	<b>Conceptual Framework .....</b>	<b>18</b>
2.1	Project- and Design-Based Learning .....	19
2.2	Engineering Leadership .....	20
2.3	Wilderness Education .....	20
2.3.1	Conceptual Change .....	21
2.3.2	The Role of Culture .....	22
2.3.3	Development of Design Thinking .....	24
<b>3</b>	<b>The Curriculum.....</b>	<b>25</b>
3.1	Generative Question .....	25
3.2	Rationale.....	27
3.3	Understanding Goals.....	27
3.4	Curriculum Overview .....	28
3.5	Assessment Plan .....	31
3.6	The Role of Transfer .....	31
3.7	Reflection and Critique .....	32
<b>4</b>	<b>Methods.....</b>	<b>34</b>
4.1	Sample .....	35
4.2	Data Collection .....	35
4.3	Grounded Theory Analysis .....	37
4.4	Validity Threats.....	38
<b>5</b>	<b>Analysis .....</b>	<b>39</b>
5.1	Design Thinking Analysis .....	40
5.1.1	Flexibility .....	41
5.1.2	High-Fidelity Testing .....	43
5.1.3	Simplicity .....	43

5.1.4	Importance of Trying .....	44
5.1.5	Survival .....	44
5.1.6	Empathy.....	45
5.1.7	Trusting the Process .....	46
5.1.8	Identifying Team Strengths.....	46
5.2	Engineering Science Worldview Analysis .....	46
5.2.1	Knowing Why .....	47
5.2.2	Theory vs. Practice .....	49
5.2.3	Experimentation.....	51
5.3	Leadership and Teamwork Analysis .....	53
5.3.1	Personal Leadership .....	54
5.3.2	Group Leadership.....	57
5.3.3	Quantitative Analysis of Survey Results.....	60
5.4	Students Emotional Reaction.....	61
5.4.1	Enjoying / Having Fun .....	62
5.4.2	Challenge.....	62
5.4.3	Comfort & Discomfort.....	63
5.4.4	Accomplishment .....	63
5.5	Motivation .....	64
5.5.1	Practical and Relevant to Life .....	64
5.5.2	Learning by Doing.....	65
5.5.3	Survival .....	65
5.5.4	Freedom .....	66
5.5.5	Not Challenging Self.....	67
5.6	The Role of the Wilderness Environment .....	67
5.6.1	Appreciating Nature.....	67
5.6.2	Using Environment .....	68
5.6.3	Human Impact .....	68
5.7	The Role of Gender .....	69
5.8	Program Improvements.....	69
5.8.1	More Content / Activities.....	69
5.8.2	Individual Learning Opportunities .....	70
5.8.3	Longer Expedition .....	70
5.8.4	Shorter Class to Trip Gap.....	70
<b>6</b>	<b>Implications .....</b>	<b>71</b>
6.1	Discussion of Learning Objectives.....	71
6.1.1	Design Thinking .....	71
6.1.2	Engineering Science Worldview.....	73
6.1.3	Leadership .....	74
6.2	Emergent Themes .....	75

6.3	Program Improvements.....	76
6.4	Future Work .....	77
6.5	Conclusion.....	78
<b>7</b>	<b>References .....</b>	<b>80</b>

## **Appendices**

<b>Appendix A</b>	<b>Curriculum.....</b>	<b>85</b>
<b>Appendix B</b>	<b>Interview Guide .....</b>	<b>123</b>
<b>Appendix C</b>	<b>Leadership Survey Questions .....</b>	<b>124</b>

## **Chapter 1**

### **Introduction**

As a teenager I watched a middle-aged gentleman with strands of grey in his hair place a bag of charcoal on top of a barbecue grate, cut away the bottom and top of the bag, then carefully mist the outside with a spray bottle. After pouring lighter fluid into the bag, he threw in a match as he continued to deliberately mist the outside of the bag. Not understanding the reason for this peculiar barbequing ritual, I asked what he was doing. I remember the moment of blinding clarity when I understood that he was creating a chimney to promote airflow over the bricks, helping them fully ignite much more efficiently than if they were simply strewn about the bottom of a barbecue. This clever yet simply engineered solution to an everyday problem awakened a passion that continues to this day for applying an engineering science worldview to understand, examine, and modify the world around me.<sup>2</sup>

Everyone should have the opportunity to develop the special combination of basic scientific knowledge, curiosity in how the world works, and confidence that they can make the world around them better through design inherent in the profession of engineering. This thesis explores a new approach to engineering education that attempts to holistically develop student capacity for design thinking, applying an engineering science worldview, and leadership capacity. This is accomplished by combining elements of adventure-,

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<sup>2</sup> The man in this story is Ed Jernigan, an MIT alumnus ('69, SM '71, PhD '75) who at the time was the Chair of the Department of Systems Design Engineering at Waterloo University.

wilderness-, and design-based education. Taking advantage of the unique characteristics of these pedagogies, design-based wilderness education may provide a fertile environment to develop engineering science and design thinking competencies while at the same time developing competency in the leadership, communication and teamwork skills that engineers need in todays world. The design-based wilderness education curriculum begins with classroom and lab activities that are implemented on the MIT campus, followed by a wilderness education experience, a 3-day backpacking expedition in the White Mountain National Forest of New Hampshire.

Before establishing the conceptual framework to help us situate this novel approach to engineering education, we will first explore the undercurrents in engineering education that have been driving the exploration of new approaches. Next we will examine and attempt to define the three domains this curriculum addresses: the development of design thinking, an engineering science worldview, and leadership skills. Finally, to help understand the context within which this study took place the end of this chapter will focus on introducing the MIT-SUTD Collaboration and its role within the development and evaluation of this curriculum.

Chapter 2 will present a framework for understanding how design-based wilderness education is positioned between a diverse array of academic fields. We will also take time to explore how these diverse fields interact with each other. Particular attention is paid to exploring how the outcomes of wilderness education programs map to those desired in engineering education.

Chapter 3 introduces the curriculum as it was developed, taking into account the theoretical grounding established in Chapter 2 and the context of the learners described in Chapter 1. Chapter 5 describes the methods used to investigate the effect of the curriculum on student design thinking, leadership ability, and ability to apply an engineering science worldview. Chapter 6 includes a discussion of the findings, conclusions, and directions for future research.

## 1.1 Educating the Engineer of Today

*What attributes will the engineer of 2020 have? He or she will aspire to have the ingenuity of Lillian Gilbreth, the problem-solving capabilities of Gordon Moore, the scientific insight of Albert Einstein, the creativity of Pablo Picasso, the determination of the Wright*

*brothers, the leadership abilities of Bill Gates, the conscience of Eleanor Roosevelt, the vision of Martin Luther King, and the curiosity and wonder of our grandchildren.*

(National Research Council 2004, p. 57)

The above statement was penned over a decade ago by the National Academy of Engineering in a report entitled *The Engineer of 2020: Visions of Engineering in the New Century*. While strong analytical skills remained foundational, this report foresaw a complex world filled with social, environmental, political and economic considerations that would increasingly become a part of daily life for those in the profession of engineering.

Since the 1950's, engineering education has been primarily focused on developing strong competencies in engineering science, the application of scientific principles to solving technical problems (de Neufville, 2001). While engineering science has remained core to engineering education, by the late 1980's engineering programs began to recognize the need for graduates to develop broader professional competencies (Prados, Peterson, & Lattuca, 2005). There are currently substantial efforts underway to reform engineering education and encourage global collaboration. In the United States, the introduction of the Engineering Criteria 2000 (EC2000) by the Accreditation Board for Engineering and Technology (ABET) required students in engineering programs to "learn to function on multidisciplinary teams", "communicate effectively", and "understand the impact of engineering solutions in a global, economic, environmental and social context" (Prados et al., 2005). This trend towards outcome and competency based criteria targeting professional competencies is not limited to the United States. The 23 signatories of the Washington Accord, representing accreditation bodies from an array of countries in North America, Europe, Asia and Oceania, recognize the substantial equivalency of their individually accredited programs. Under this accord, a statement of graduate attributes and professional competency profiles requires engineering graduates be able to "assess societal, health, safety, legal and cultural issues", act "as a member or leader in diverse teams and in multi-disciplinary settings", and "communicate effectively on complex engineering activities with the engineering community and with society at large" (International Engineering Alliance, 2013).

Continuing to build on this theme while calling for a new kind of engineer in the United States, the National Academy of Engineering released a report entitled *The Engineer of 2020: Visions of Engineering in the New Century*, arguing that a broad range of skills should be inculcated into engineering graduates, including ingenuity, problem-solving capability, scientific insight, creativity, determination, leadership, conscience, vision, curiosity and wonder (National Academy Of Engineering, 2005). While strong analytical skills remained foundational, this report highlighted a complex world filled with social, environmental, political and economic considerations that would increasingly become a part of daily life for engineers. To help encourage success in this new context, engineering educators were challenged to engender creativity, communication, leadership, boldness, courage, dynamism, agility, resilience and flexibility in their students, attributes that would help engineering students meet the challenges of the modern world (National Academy Of Engineering, 2005).

Despite efforts to implement curricula addressing the development of new skills and competencies, and the work of international collaborations, some indicators point to these efforts as being largely unsuccessful. Cech (2013) found in a longitudinal survey of students at four US colleges (MIT, the Franklin Olin College of Engineering, Smith College, and the University of Massachusetts-Amherst), that engineering education may foster a culture of disengagement, resulting in graduating students “less concerned with the importance of professional and ethical responsibilities, understanding the consequences of technology, understanding how people use machines, and social consciousness” than when they started their programs.

How can we hope to reach the aspirational goals of the Engineer of 2020 when our current engineering education practices are seemingly not working? This thesis explores a potential new approach to engineering education that may help address some of the shortcomings of more traditional classroom environments.

## **1.2 Design Thinking, Engineering Science, and Leadership**

This thesis explores a new approach to engineering education that attempts to holistically develop student capacity for design thinking, applying an engineering science worldview, and leadership capacity. These three themes

were chosen as they exemplify the past, present, and future of engineering practice.

As we will examine, the process of design thinking can be argued to fundamentally define engineering as a profession. Looking to the past, engineering education focused on developing strong engineering science competencies and looking to the future, while those competencies are still foundational engineers play an increasingly important leadership role. The following sections explore each of these ideas in greater detail.

### 1.2.1 Design Thinking

As described by Dym, Agogino, Eris, Frey, & Leifer (2005) design thinking “reflects the complex processes of inquiry and learning that designers perform in a systems context, making decisions as they proceed, often working collaboratively on teams in a social process”. The application of design thinking to generate physical artifacts is one of the fundamental distinctions of engineering as a profession. Over time the literature has explored design thinking through two main paradigms: design as a rational problem solving process, and design as a process of reflection-in-action. (Dorst & Dijkhuis, 1995).

The historically dominant view of design is that of a technical and rational problem solving process. This viewpoint was most famously described by Simon in his book *Sciences of the Artificial* (1996). Design as a rational problem solving process has positivist underpinnings, and continues to serve as the foundation of most of the design processes that are taught in classrooms today. As a rational problem solving process, once the problem has been defined there is a series of steps that can be followed to narrow the search space and ultimately come to a solution.

The dominant competing paradigm to design as a rational process is Schön’s (1983) notion of design as a process of reflection-in-action. The notion of design as a reflective activity is well suited to integration with wilderness education as the same paradigm of learning through experience underlies both. Rather than requiring that designers follow a prescribed rational problem solving process, in this paradigm design is instead regarded as a reflective conversation with individual situations, guided by the lessons learned from past experiences. During reflection-in-action is it surprising results and unexpected

outcomes that drive a practitioner to step back from simply following a problem solving process and instead engage in a process of reflection-in-action.

When discussing design thinking in this thesis we are referring to the notion of reflection-in-action. It is hoped that through designing in and for a wilderness environment students will be provided with the opportunity to experience the “surprises, pleasing and promising or unwanted” that will encourage students to respond as reflective practitioners (Schön, 1983, p. 56).

### **1.2.2 Engineering Science Worldview**

As mentioned previously, engineering education has been primarily focused on developing strong competencies in engineering science since the 1950’s. This focus has specifically been targeted to the application of scientific principles to solving technical problems (de Neufville, 2001).

The notion we are invoking when discussing an engineering science worldview is the paradigm, or viewpoint, through which engineers strive to examine and understand the world. In the previous section we discussed design thinking, the approach employed by engineers to solve problems. Before design thinking can be successfully deployed, engineers must be able to examine the world and break it down into constituent underlying scientific principles. This underlying requirement in part justifies the historically strong emphasis on developing strong technical competencies in engineering programs.

This curriculum is developed with the intention of helping students transition their engineering science worldview from the classroom environment to every-day real-world situations. Students should practice developing this engineering science worldview such that they instinctually apply the same scientific rigor and principled approach to problems in their everyday life as they would in the classroom environment.

### **1.2.3 Leadership**

As the profession of engineering has transitioned into the 21<sup>st</sup> century communication and leadership has increasingly been emphasized for engineering students. As we examined earlier, the introduction of the EC2000 by ABET required students to learn how to lead teams, communicate, and understand the social impacts of engineering. Looking to the future, the

National Academy of Engineering has continued to call for a renewed and increased focus of the social and team based aspects of engineering.

Our curriculum will seek to emphasize aspects of leadership associated with engineering such as teamwork, communication, and understanding the social impact of engineering.

### **1.3 Research Question**

Within the context of the previous discussion, this thesis explores a novel approach to engineering education combining wilderness education with design-based learning. Wilderness education was chosen as a pedagogical framework as it may be well suited as a learning environment to foster effective design thinking practices and the application of an engineering science worldview.

As we can not find other examples of this approach in the literature, this is an exploratory study. We ultimately consider the role that design-based wilderness education could play in the development of design thinking, the application of an engineering science worldview, and development of leadership ability.

The findings from this exploration will be used to guide further curriculum development and identify interesting research questions for instances of design-based education situated in a wilderness environment.

### **1.4 Study Context**

The design-based wilderness education curriculum was developed and implemented within the context of an international academic exchange program organized by the MIT-SUTD Collaboration Office. This program, entitled the Global Leadership Program (GLP) brings together students from the Singapore University of Technology and Design (SUTD) and the Massachusetts Institute of Technology (MIT) for ten weeks during the summer semester and provides SUTD students with the opportunity to interact with the MIT community and experience MIT's academic culture. During GLP, students participate in a program that assists in the development of engineering science and engineering design competencies alongside leadership skills. This program exists broadly in the context of a series of activities designed to encourage academic cultural transference between MIT and SUTD.

More broadly, MIT has been helping to develop curriculum and educational programs for SUTD students since 2010. This collaboration aims “to accomplish the development of a new engineering-oriented university that will reach the Engineer of 2020 vision, while in parallel addressing the timely formation of an institutional identity and culture that borrows from those of MIT” (Bagiati, de Neufville, & Sarma, 2013). Through this collaboration, MIT is involved in faculty training, the development and deployment of curricula, and supporting student life related initiatives such as the development of co-curricular and leadership activities (Bagiati et al., 2013; Bagiati, Fisher, & Sarma, 2012; Fisher, Bagiati, & Sarma, 2012; Sakhrani, Bagiati, Sarma, & de Neufville, 2012).

The curriculum examined in this thesis was designed with the multifaceted nature of the MIT-SUTD collaboration in mind, and was first implemented in June to August of 2014. The inclusion of a wilderness education component was expected to be a somewhat novel learning environment for both the SUTD and MIT students alike. This novel learning environment was seen as a way to help level the playing field between the MIT and SUTD students, placing them in a learning environment with which they were all initially unfamiliar. By encouraging many students to step slightly outside of their comfort zone, students would have to learn to rely on each other and practice effective teamwork. This approach also resulted in a unique element of the curriculum that was able to cut across the three learning objectives of GLP.

#### **1.4.1 The Learners**

The 2014 iteration of GLP had 30 participants from SUTD, and 6 participants from MIT. Of the 30 SUTD participants 10 are female, and of the 6 MIT participants 4 are female. The 30 SUTD students attending GLP have already completed an intensive Introduction to Design course during their first year at SUTD. The MIT students were at various places in their studies, having at least completed their first year of classes. All of the students participating in GLP participated in the design-based wilderness education curriculum. As the curriculum was developed it was expected that:

- The SUTD students attending GLP have already completed an intensive Introduction to Design course during their first year at SUTD. They should therefore be capable of transferring a design process to a new environment.

- MIT's motto "Mens et Manus", Latin for "Mind and Hand", captures the hands-on academic culture that is found at MIT. While MIT students are expected to be familiar with a culture that values hands-on do-it-yourself approaches to problem solving, this cultural attitude is not the norm in Singapore. SUTD is working to cultivate a hands on academic experience, and continuing to expose SUTD students to this culture is one of the primary goals of GLP.
- The North American environment is unfamiliar to the SUTD students. The flora, fauna, climate, terrain and remoteness of the expedition area all present new and unexpected challenges for the students. Singapore is a relatively flat island with very little area that could be considered wilderness, with consistently warm and humid weather. Conversely, New Hampshire has vast expanses of remote wilderness and a more temperate climate prone to large variations in temperature between day and night.
- All male Singaporean citizens are conscripted for two years of National Service prior to entering university. Many of the students will therefore demonstrate strong pre-existing leadership and teamwork capability in physically and emotionally challenging environments.

While many of these assumptions proved to be correct, there were some surprises along the way that should be taken account for in future programs. While it was expected that the participants from MIT would be more familiar with the North American environment, it seemed that this advantage was not as apparent when it came to the particulars of being in a backcountry environment. Some environmental factors did come as a surprise to the SUTD students, such as the temperature variation between day and night. More than one student would fall asleep outside of their sleeping bag, waking up freezing cold at some point during the night.

Developmentally these students are at the beginning of their college career, transitioning between the characteristics of late adolescence and those of an adult learner. Students in this age group tend to be more concerned with structured education that can help prepare them for an often unclear future than older adult learners, who prefer self-directed learning that is relevant to their present experiences and situation (RIT Teaching and Learning Services, n.d.). Choosing design-based learning will allow us to respect the students

desire for structure by providing appropriate scaffolding while simultaneously encouraging students to participate as adult learners in a self-directed learning process.

Students at this developmental stage may still respond positively to being asked to step outside of their comfort zone, finding risk taking attractive (Sullivan, 2012). This is of particular relevance to wilderness education programming as “challenge, difficulty and especially risk do not need to be contrived when engaged in wilderness education” (Gookin, 2006). Adult learners tend to not find risk taking attractive, and would tend to appreciate more scaffolding and personal support when asked to step outside of their comfort zones and engage in risk taking behaviors (Grotzer, 2013a).

## **Chapter 2**

### **Conceptual Framework**

The design-based wilderness education curriculum draws from many fields of literature and is entirely captured by none. While we have been unable to find any literature discussing similar forays into engineering education, Figure 1 presents a diagram of a conceptual framework highlighting the major components of this project and associated literature. The solid box encircles the topics typically regarded as professional engineering competencies, competencies that are increasingly important to develop in engineering students: leadership, teamwork and communication. (International Engineering Alliance, 2013; National Academy Of Engineering, 2005; Prados et al., 2005). The dotted box envelops the bodies of literature that provide much of the conceptual framing for the structure of our curriculum. Project-based learning is an educational approach that seeks to have students emulate how experts solve real-world problems (Krajcik & Blumenfeld, 2006). Within the context of project-based learning, design-based learning adds the additional constraint that students are following a design process. The design process followed is guided by the literature on engineering design. One of the important considerations that we will return to is that the specific structure provided by the design process during design-based learning may have important effects on the learning outcomes and experience of the student. The literature associated with wilderness education provides insight into how to approach the development of leadership skill, and appropriate challenges to include in the design-based learning environment.

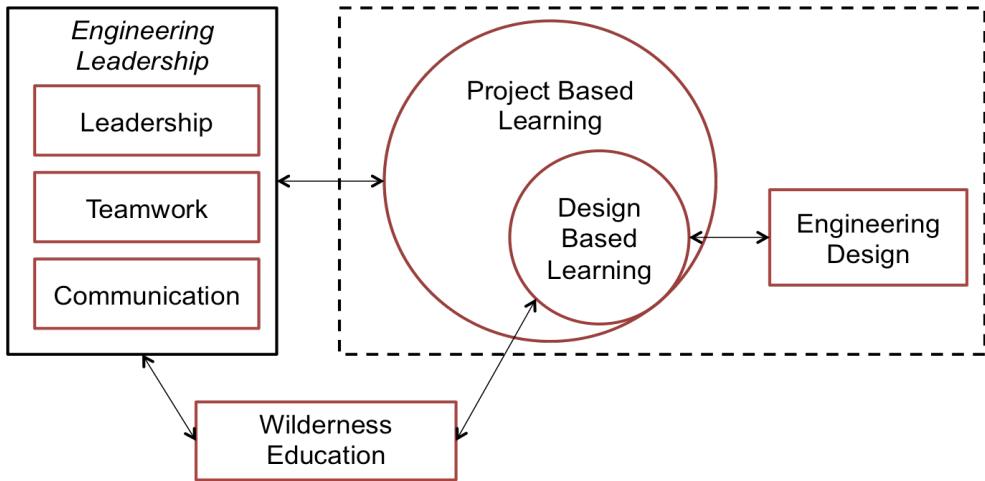


Figure 1 Conceptual Framework

## 2.1 Project- and Design-Based Learning

A project-based learning framework (Grant, 2002) is used throughout the course for mini-projects that consume a single classroom session or few hours while on expedition. These projects give the students the scaffolding necessary to explore concepts important to the progression in the program, simultaneously engaging students by situating the knowledge in (somewhat) ‘real-world’ applications. The concept of project-based learning and building artifacts will be very familiar to the engineering students.

The application of design-thinking to generate physical artifacts is one of the fundamental distinctions of engineering as a profession. As described by Dym, Agogino, Eris, Frey, & Leifer (2005), emulating real-world engineering projects in the classroom “has recently turned out to be a major innovation in design pedagogy.” These Project-Based Learning (PBL) experiences, often drawn from industry partners, “appear to improve retention, student satisfaction, diversity, and student learning” (Dym et al., 2005). Projects drawn from industry partners help to contextualize the social and professional aspects of engineering, such as teamwork and communication (Mills & Treagust, 2003). Design-based wilderness education draws inspiration from the success of project-based learning experience, and instead of drawing on the needs of industry partners we will rely on the personal needs of students in a wilderness environment.

Returning to consider the role of the design process on learning, while there are many different design processes, North American engineering students are most commonly introduced to a nested iterative process that typically progresses through stages of identifying a need, defining a problem, prototyping a solution, refining the prototype, and final evaluation. (Ward, Liker, Cristiano, & Sobek II, 1995). Following this process, students cycle through a series of stages, returning to previous stages as deemed necessary. This design process typically results in a single solution to a problem that is then refined successively over consecutive iterations. While this standard approach to engineering design may be appropriate for the creation of a successful final product, it is not necessarily the most effective process to be used when encouraging students to learn new and unfamiliar scientific concepts. It may be beneficial to encourage students to spend more time exploring alternative solutions as they are developing an understanding of new scientific concepts. Future work should explore the role of the design process as a pedagogy.

## **2.2 Engineering Leadership**

The development of engineering leadership competencies in traditional engineering programs is typically addressed through hybrid problem-based and project-based learning approaches, most often in the form of cornerstone (i.e. freshman year) and capstone (i.e. senior year) design projects, structured to allow students to work with industry partners on real world problems; this industry connection helps to contextualize the social and professional aspects of engineering, such as teamwork and communication (Mills & Treagust, 2003). Instead of relying on this traditional structure, we have chosen wilderness education as an alternative approach to augment the development of this skillset.

## **2.3 Wilderness Education**

Wilderness (and adventure) education programs aim to create a supportive environment in which students learn through the experience of challenge and adventure, relying on “the lessons available from the direct experience of nature and extended wilderness expeditioning” (Gookin, 2006). Participants undertaking wilderness education experiences typically express long-term increased competency in skills such as leadership, teamwork, self-confidence,

and communication skills (Sibthorp, Furman, Paisley, & Gookin, 2008). Wilderness education is a promising vector for mixed pedagogical approaches as alongside these previously mentioned and seemingly universal benefits, specific outcomes influenced by outdoor orientation programs have been found to depend partially on the focus of the curriculum (Bell, Gass, Nafziger, & Starbuck, 2014).

Many of the traditional learning outcomes associated with wilderness education, such as leadership, teamwork, communication and self-development (Gass, Garvey, & Sugerman, 2003; Hattie, Marsh, Neill, & Richards, 1997; Sibthorp et al., 2008) are regarded as professional competencies for engineers (ABET Engineering Accreditation Commission, 2013). Experiential approaches to education are a common approach to addressing these competencies in engineering programs. As an example, Technology and Policy students within the Engineering Systems Division at MIT participate on an Outward Bound program as a component of an introductory leadership course (de Neufville, 2001). These programs are typically targeted solely at developing leadership, teamwork and communication skills, ignoring the technical side of engineering.

An appropriately designed wilderness education curriculum may hold the potential to effectively develop both engineering science competencies and leadership ability. This approach may be preferred to other curricular designs that approach the learning objectives separately. Explicitly combining the development of professional competencies with the development of an engineering science mindset in the context of wilderness education will perhaps help students more effectively transfer lessons beyond the confines of the course experience.

Despite the fact that some of the skills and attributes developed through wilderness education map well to the skills and attributes desired in engineering education, design-based learning taking advantage of a wilderness environment appears to be a novel approach to engineering education. I have been unable to find other authors discussing the use of wilderness education to teach engineering competencies in the literature.

### **2.3.1 Conceptual Change**

Wilderness and Adventure Education is a particularly effective learning environment through which to invite conceptual change. Wilderness Education

programs have the potential to provide substantial and lasting outcomes regarding a student's perception of self, and changes in life perspective. In a study interviewing participants 17-years after a 5-day wilderness orientation program, participants consistently reported that the experience had helped them challenge assumptions of self and others. The participants indicated that the program had provided "direction in their careers, direction in their personal lives, development of personal values and skills, and development of life-long friendships" (Gass et al., 2003).

Increased self confidence and changes in life perspective are often reported in studies on wilderness education, and this effect is noticed even when not purposefully targeted by a curriculum (Sibthorp et al., 2008). As concluded by Sibthorp et al. (2008), "Wilderness education provides a unique social environment that allows participants to explore beliefs and assumptions that they hold, seemingly allowing for lasting changes in life perspective." A meta-analysis of 96 studies found that adventure programs have a greater effect on students' self-concept than traditional classroom-based interventions. Most strikingly, unlike other interventions "the effects of adventure programs continue to increase over time, and are maintained over considerable time" (Hattie et al., 1997). The program proposed in this paper invites conceptual change in how students regard interests and values aligning with the profession, and what characteristics they recognize as being valuable for engineers.

This curriculum intends to situate students in an environment in which they are able to experience conceptual changes in their understanding of the engineering profession and its role within an increasingly global society, while developing the skills and characteristics required to succeed in a increasingly modern interconnected world.

### **2.3.2 The Role of Culture**

Culture plays two important roles within the context of this curriculum. The instructors are instructing students from different cultural perspectives and backgrounds, while simultaneously attempting to inspire and encourage the SUTD students to transfer elements of MIT's academic culture back to SUTD. While the students have different cultural perspectives, wilderness education introduces an academic culture with which the students are likely to be unfamiliar.

Learning and teaching can be regarded as inherently cultural processes (Nasir, Rosebery, Warren, & Lee, 2006) and the academic culture of wilderness education will be novel to both the MIT and SUTD students. In the context of cross-cultural learning, successful out-of-school learning environments typically have scaffolding that consists of

- (1) organizing participation in activities in ways that address basic human needs for a sense of safety as well as belonging;
- (2) making the structure of the domain visible and socializing participants for dispositions and habits of mind necessary for expert-like practice;
- (3) helping novices understand possible trajectories for competence as well as the relevance of the domain to the learners; and
- (4) providing timely and flexible feedback (Nasir et al., 2006).

Wilderness educators recognize that wilderness experiences are a cross-cultural experience for most learners, no matter their cultural background. Mapping common wilderness education practices to this scaffolding:

- (1) conceptual models, such as Maslow's hierarchy of needs (Maslow, 1943), are often used as a model to discuss physiological needs and security needs from the perspective of risk-management and creating an effective learning environment;
- (2) demonstrations, modeling, and coaching are all used to illustrate and encourage expert-like practice;
- (3) students are motivated by learning skills that are directly relevant to basic needs in their current living situation;
- (4) the natural environment is able to give direct and regular feedback to students, as there is no "need to contrive challenge, difficulty or especially risk" when students are engaged with the natural world (Gookin, 2006).

One of the primary purposes of GLP is to expose and transition participants from SUTD to the MIT academic culture. Wilderness Education is commonly used in North America in the context of introducing freshmen to the academic culture of college. There are indications that outdoor orientation programs are more effective at helping students transition into new academic cultures than more traditional orientation programs.

Almost 200 colleges in the United States and Canada use outdoor orientation programs to help students “develop a sense of belonging and status in transition”, often resulting in long term measureable increases in factors such as retention rate and GPA (Bell et al., 2014). These positive benefits, like others observed for wilderness education, have been attributed to a positive learning environment consisting of small and supportive peer groups. While there are some seemingly universal benefits, specific outcomes influenced by outdoor orientation programs depend partially on the focus of the curriculum (Bell et al., 2014). This success of outdoor orientation programs to transition students into new academic cultures provides some indication that wilderness education may be a useful tool for achieving academic cultural transference as desired by the GLP.

### **2.3.3 Development of Design Thinking**

The previous sections considered benefits traditionally associated with wilderness education that map directly to desired engineering education outcomes. Alongside these expected benefits, the design-based wilderness education environment has been specifically envisaged to help students develop their engineering science worldview and design thinking.

The unique environment of the North American wilderness provides an opportunity for students to explore a problem-space with which they may be initially unfamiliar. This unfamiliarity is used to our advantage, with early lessons focusing on how basic scientific principles can be used to understand this seemingly new problem domain. Throughout the course students are encouraged to explain the world around them using basic scientific principles by relying on prior knowledge and through the exploration of new scientific concepts.

Design as a component of wilderness education results in a different set of incentives than traditional classroom experiences. As students are immediate users of their own design projects, often for the fulfillment of basic survival needs, students may be more intrinsically motivated to complete projects successfully. This is in contrast to a traditional design project in which students are designing for an external user. In many cases students may not expect their design to progress beyond an initial prototype or be used in any practical application other than for the awarding of a course grade.

## **Chapter 3**

### **The Curriculum**

The curriculum was originally developed using the Teaching for Understanding Framework which focuses on the development of generative topics, understanding goals, performances of understanding, and on-going feedback (Wiske, 1997). The wilderness education components of the curriculum are based on best practices from both Outward Bound (Crane et al., 2008) and the National Outdoor Leadership School (Gookin, 2006). With a curriculum that combines elements of design-based learning and wilderness education, students are situated in an environment in which they are able to experience conceptual changes in their understanding of the engineering profession and its role within an increasingly global society, while developing the skills and characteristics required to succeed in an increasingly modern interconnected world. The curriculum is specifically aimed at developing students design thinking competency, the ability to apply an engineering science mindset, and leadership skills. The complete curriculum is described in Appendix A. The following sections discuss the generative question, rationale for the curriculum, the understanding goals for the course, and provide an overview of the curriculum activities. We also introduce the role of transfer, and provide a brief reflection and critique of the curriculum.

#### **3.1 Generative Question**

*What role can engineers play in how individuals relate to the natural environment, each other, and society as a whole?*

Central to most definitions of engineering is the concept of applying scientific understanding to build artifacts that change our environment for the betterment of individuals within a society. This ongoing iterative process of engineering science has resulted in highly developed urban centers that are vast expanses of ‘artificial’ space filled with man-made artifacts. These spaces are largely devoid of the natural environment, except for the animals and plants that have successfully adapted to living in our new concrete jungles.<sup>3</sup>

*A wilderness, in contrast with those areas where man and his own works dominate the landscape, is hereby recognized as an area where the earth and its community of life are untrammeled by man, where man himself is a visitor who does not remain.*

*The United States Congress in passing The Wilderness Act of '64*

Through this course students will prepare for, and travel through, a true wilderness environment. By stripping away much of the infrastructure and technology that has insidiously built up over time, students will be able to better examine their personal relationship with technology and engineering. Students will also be given the opportunity to examine how engineers change the way that individuals and society interact with the natural world and each other.

Through imagining, building and using artifacts of their own design to survive and thrive in the wilderness, students will practice applying an engineering science worldview while demonstrating design thinking and directly experiencing the individual and social impact that engineering artifacts produce. Students will be encouraged to transfer this learning experience to their ongoing conceptualization of the engineering profession and its role within society.

The activities within the course are focused around a classic wilderness education objective, a hiking expedition. The following question will serve to provide the overarching framework for the activities throughout the duration of the program:

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<sup>3</sup> Much has been written on the subject of the decline of natural spaces, most popularly summarized as Richard Louv's metaphor of nature-deficit disorder.

*You will be embarking on a 3-day backcountry-hiking expedition in the White Mountains of New Hampshire. What knowledge, skills, and equipment do you need to thrive in the wilderness?*

### **3.2 Rationale**

This topic will allow students to engage with concepts in a novel and deliberate manner, genuinely inviting conceptual change while helping students develop the ability to apply an engineering science worldview and design thinking to ‘everyday’ situations to gain previously hidden insight and understanding. Through course activities, students will fully and directly experience the social nature and individual impact inherent in the practice of engineering as a profession. Students will be encouraged to transfer this learning experience to their ongoing conceptualization of the engineering profession.

### **3.3 Understanding Goals**

*What role can engineers play in how individuals relate to the natural environment, each other, and society as a whole?*

This curriculum aims to explore the generative question posed above within the context of a wilderness experience. While pursuing this question, students will use their growing understanding of the wilderness to contextualize a conceptual change in their perception of the impact, skills and characteristics required in engineering as a profession. At the same time, students will practice applying the lens of an engineering scientist to real world situations to develop previously hidden insights.

- Students will understand the social and environmental impact of technological artifacts produced by engineers.
  - Students will understand how much technology is still used to comfortably survive, even when visiting a wilderness area.
  - On a very basic level, students will consider the evolution of engineering and technology that allowed society to progress to its current state. This consideration will inform the understanding that society today is represented by a complex world filled with social,

environmental, political and economic systems all affected by engineering and technology.

- Students will understand that characteristics such as creativity, communication, leadership, boldness, courage, dynamism, agility, resilience and flexibility are valuable as professional engineers.
  - Students will understand what forms leadership can take, through different contexts throughout the course including risk management, group problem solving and effective group process.
  - Students will understand the necessity to be creative, agile, and flexible when planning and participating in design activities in the natural world.
  - Through the physical and emotional challenge of a wilderness expedition students will understand that displaying boldness, courage, resilience and perseverance can allow students to complete tasks they thought were not within their ability or current skillset.
- Students will understand the insight and clarity that can be obtained by examining everyday situations and experiences through an engineering science worldview.
  - Students will understand how to constrain a situation to define a system, recognize the underlying scientific basis of phenomena, and construct a mental model of the system interactions.
  - Using the mental model that students have constructed, they will understand how to apply the design thinking to effectively solve associated problems.

### 3.4 Curriculum Overview

As a subcomponent of GLP, the prototypical design-based wilderness education program is focused around a classic wilderness education objective, a hiking expedition. A series of progressions take concepts from more traditional classroom settings to wilderness environments. These progressions are meant to

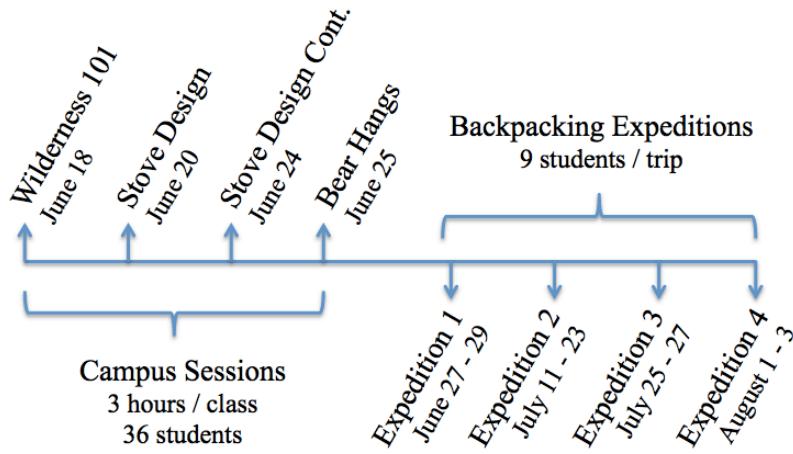


Figure 2 Curriculum Timeline

enable students to practice design thinking and applying an engineering science worldview, while simultaneously developing leadership skills.

As outlined in Figure 2, the design-based wilderness education curriculum as implemented consisted of four 3-hour long sessions on campus over two weeks, followed by groups of 9 students and 2 instructors embarking on 3-day backpacking expeditions over 4 weekends.

The novel environment of the American wilderness provides an opportunity for students to explore a problem-space with which they may be initially unfamiliar. To help students understand that this new and unfamiliar problem domain can be understood by applying basic engineering science principles, students were encouraged to consider clothing layering systems as a heat transfer problem. Considering heat loss and/or gain associated with convection, conduction, radiation and evaporative cooling alongside the properties of various fabrics commonly used in clothing, students are able to gain an understanding of appropriate clothing layering choices for the backcountry, a seemingly new understanding, from only the application of basic scientific principles. Students were encouraged to continue to apply this inquisitive and exploratory mindset through the rest of the course activities.

A series of progressions that begin with on-campus activities and progress to the wilderness environment provide students with the opportunity to engage in design-projects both individually and on teams. In the first progression,

beginning in a classroom environment, students are provoked to consider what it means to design *for* a natural environment, developing a set of general design principles (such as durability, transportability, and reparability). Still on campus, students are challenged to design and build a prototype of a single burner alcohol stove. This design activity requires consideration of the physics of combustion, properties of the selected fuel, and the limitations of available materials. This design project follows students into the wilderness expedition as they are expected to use the stoves that they have designed and built to cook while camping. This use of their own design project, in the context of fulfilling a survival need, provided a very visceral context in which to consider the individual impact that engineering technology has on members of society.

Another progression challenges students to consider what it means to design *in* a natural environment. To begin to develop the skills necessary to use rope as a tool, students engaged in an activity on campus challenging them to build bear hangs (systems designed to elevate food above the ground in a forest such that bears and rodents cannot reach it). To do this students will have to understand and construct hauling systems using mechanical advantage, taking into account factors such as system extension under load, force on anchors, frictional force, and material breaking strength. Students then used this system while on the wilderness expedition, examining how the build process and design considerations changed when implementation is performed in an unknown natural wilderness environment. Further extending this concept, while on the backpacking expedition, students were challenged to design and construct a method to assist a person with a broken leg to cross a stream. To successfully construct the rope bridge students had to apply the skills learned during previous activities in novel ways.

Additionally, students slept under tarp shelters of their own design and construction while on the backpacking expedition. Using only plastic sheeting and string, students independently designed and constructed a shelter that they slept in for two nights. During initial construction students were encouraged to consider various design tradeoffs that may be apparent. After the first night students could choose to adjust their shelters based on their new experiences.

### **3.5 Assessment Plan**

Given the context of this specific implementation of the course (a not-for-credit summer enrichment program) the assessments are focused around ensuring that individual students are deriving the maximum possible benefit.

As most lessons involve a tangible performance of understanding, such as the design and construction of an artifact or development of understanding through experimentation, students will receive direct feedback from their own self-reflection and peer-interactions. This form of assessment and feedback will be most directly applicable to the understanding goals involving the application of engineering science.

Time for reflection and discussion promoting meta-cognition throughout the course (focused towards the end) will encourage students to use their growing understanding of the wilderness to contextualize a conceptual change in their perception of the impact, skills and characteristics required in engineering as a profession. In small supportive peer groups students will be challenged to evaluate their current understanding in the context of the learning experience that they have been undergoing. Metacognitive processing is particularly valuable for the learning goals associated with this curriculum as research indicates that it is effective for both assisting in transfer and facilitating conceptual change (Grotzer, 2013b). The wilderness education framing of sitting in a circle and using a talking piece during discussion will be an effective and helpful framing for this activity. These discussions will serve as a form of self-assessment and peer-assessment for learners.

### **3.6 The Role of Transfer**

In this course, as in wilderness education in general, transfer is a challenging yet incredibly important component of the learning process. Using Perkins and Solomon (1988) model of teaching near and far transfer with hugging and bridging respectively, transfer will be an important component of every lesson.

Far transfer is the transfer of concepts between contexts that seem very different. To encourage far transfer students are being asked to engage in backwards-reaching transfer, by bringing an engineering science mindset to novel problems such as layering clothing and building bear hangs. This backwards-reaching transfer is engaged in the spirit of parallel problem solving,

with the intention that students will transfer this experience forward, and continue to apply the engineering mindset to gain understanding in situations they would not have considered appropriate before. The other bridging tools (anticipating applications, generalizing concepts, using analogies, and metacognitive reflection) will be used throughout the lessons when appropriate to aid in developing the encouraged far transfer. While on the wilderness expedition, transfer will be explicitly discussed and students will be engaged in a meta-cognitive process regarding transfer, considering what lessons they want to carry forward beyond the wilderness experience.

Near transfer is the transfer of concepts between contexts that seem very similar. Many of the initial lessons rely on tools considered effective for near transfer to comfortably introduce students to the topics that they will continue to apply in various contexts throughout the course. Design-based learning allows students to solve problems (by building artifacts) that will share structural similarities with projects experienced later in the course.

### **3.7 Reflection and Critique**

This curriculum has evolved through multiple forms during the course of development and implementation. It was originally conceived as an unstructured problem-based learning curriculum where students would have the complete freedom to construct the knowledge necessary for backpacking, and build whatever artifacts they thought would be helpful for that purpose.

The current curriculum is far more structured for a few reasons:

- A completely constructivist approach to learning is challenging to implement well.
- With limited time, more structure allows for a deeper dive into the concepts that have been determined are important.
- Having a variety of mini-projects allows students to experience multiple iterations and versions of similar concepts – hopefully increasing generalizability and transfer.
- Wilderness Education will be really unfamiliar to the learners involved in this iteration of the course

The structure of the course is also challenging, as it is somewhat externally constrained. Ideally a weeklong intensive experience, or something similar taking place completely in a wilderness environment, would be ideal for a true

wilderness education pedagogy to be implemented. Research points to course length being highly correlated with gains from wilderness education (Sibthorp, Paisley, & Gookin, 2007). This concern regarding course length will re-emerge in the analysis of student interviews.

## **Chapter 4**

### **Methods**

This study is a preliminary exploration of the outcomes associated with a design-based wilderness education curriculum. As this was a preliminary study, an epistemologically pragmatic viewpoint towards data collection and analysis was used, ultimately resulting in a mixed-methods approach. As this project has focused on the development and evaluation of a novel approach to engineering education, we are naturally drawn towards answering emergent questions that rely on understanding the experience of the students and instructor. This preliminary exploration into the effects of design-based wilderness education will serve to guide further research inquiry.

We are oftentimes unable to triangulate our findings across multiple sources of data, as our quantitative investigation focuses on the leadership outcomes of the program while our qualitative investigation focused on the design thinking and engineering science outcomes of the program. While some observational data was collected in the form of video-recordings, these recordings did not yield much in the way of useful data to assist in answering these research inquiries.

Along with authoring this study, I was also responsible for the development of the curriculum and instruction of the design-based wilderness education class. While analyzing the results of this study, it is necessary and important to take into consideration the sometimes complementary and sometimes competing value of these three roles. We will return to this issue when we later consider threats to the validity inherent in this study.

## 4.1 Sample

During the initial implementation of the curriculum, all 36 students, 30 from SUTD and six from MIT, enrolled in a research study examining the effects of participating in design-based wilderness education on leadership ability, design thinking, and the application of engineering science. Of the 36 participants in the study, 14 were female. As discussed in Section 1.4.1 (The Learners), the 30 SUTD students attending GLP have already completed an intensive Introduction to Design course during their first year at SUTD. All male Singaporean citizens are conscripted for two years of National Service prior to entering university. Many of the students therefore demonstrated strong pre-existing leadership and teamwork capability in physically and emotionally challenging environments. The six MIT students had various levels of pre-existing design experience and very little in the way of pre-existing wilderness experience.

## 4.2 Data Collection

As described by Table 1, the data collection plan included video, instructor observations, reflective journals, a leadership survey and exit interviews.

The video observational protocol was originally constructed to allow observation of the students design practices. It was hoped that the video observations would provide insight into how students applied the design process while engaging in the design components of our program. As students had previously participated in design-intensive curriculum, we were interested

Table 1 Data Collection Summary

Type of Data	Students (N=36)	Instructor
Video of in-class design and synthesis	-	1 hour of recordings from 4 class sessions
Video of outdoor design and synthesis	-	9 hours of recordings from 4 expedition trips
Reflective journals	2	-
Field notes and photos	-	Handwritten notes and approximately 100 photos from class sessions and expedition trips
Leadership survey	20	-
Exit interviews	34	-

in how students translated this knowledge to a new environment. The observations that we recorded did not effectively serve this purpose. The video from the classroom sessions was of synthesis activities, and was a series of short (2-5 minute) interviews where students were asked to describe what they were working on. Continuity through the design process was not assured and students were not purposely sampled by the videographer. The videos from the outdoor design problem suffered from issues including low audio quality, and an inability to capture details of what had taken place. As the design challenge was to build a rope-bridge across a stream, groups would often be working on both sides of the stream concurrently, providing a obvious barrier to effective video observation. For these reasons we do not further analyze the video data.

While students were encouraged to maintain reflective journals serving a secondary purpose as design logs, only two were turned in at the conclusion of the course. This appeared to be for a variety of reasons:

- students did not feel the need to maintain a notebook for this experience based class;
- class activities never mandated the use of the design logbook;
- the classroom environment encouraged building and experimenting over planning.

Due to the lack of journals they are not further analyzed.

Interviews were chosen to help investigate student perception of learning while engaged in a design process in a novel environment. These interviews also provide the opportunity for students to articulate and explain new skills or concepts they may have acquired. The interview questions were open-ended and were asked within four days of the individual student completing the backpacking trip (the final element of the curriculum). The exit interview was completed by 34 of the 36 students, each interview lasted approximately 15 minutes. During their semi-structured exit interview students were asked to reflect upon their learning experience while participating in the curriculum and to compare the class to previous design experiences. The complete question guide can be found in Appendix B. As we analyze the interviews, instructors observations and anecdotes will be used to add context and supporting information. The extremely high rate of participation provides the opportunity for data-triangulation; we will observe that most of the themes identified are

present across multiple interviews, in many cases more than half of subjects will discuss the same theme (Shenton, 2004).

Supporting the findings of our qualitative work this study included a survey on engineering leadership taken by the students after completing the curriculum. The administered survey was an inventory developed by Ahn et al. (2014). Specifically, the leadership survey assessed four separate factors of engineering leadership: *Individual Leadership Skill*, *Group Leadership Skill*, *Society and Economy*, and *Development of an Adaptor to Change* (Ahn et al., 2014). The *Individual Leadership Skill* (21 items) and *Group Leadership Skill* (8 items) factors are of particular interest as we expect that the traditional benefits of wilderness education would align closely with these factors. The third factor assessed consideration of the role of *Society and Economy* (12 items) on engineering as a profession. The remaining factor concerned with the *Development of an Adaptor to Change* contains four items and was not found to be as reliable as the other three factors contained within the instrument (Ahn et al., 2014). Thus, while the items in the *Development of an Adaptor to Change* factor were included on the survey for the sake of completeness, we do not analyze the results further. The 45-item survey was administered online as a retrospective post-then-pre test to minimize response-shift bias and to effectively measure students perception of change in their leadership abilities after the completion of the curriculum (Sibthorp, Paisley, Gookin, & Ward, 2007).

All students were emailed a link to the survey four days after the last group had finished the backpacking expedition. Students were sent a reminder a week later. Twenty students (56% response rate) voluntarily rated each item on a four-point Likert scale (1-Rarely, 2-Sometimes, 3-Frequently, and 4-Almost Always). The complete survey can be found in Appendix C.

### 4.3 Grounded Theory Analysis

The interview analysis was performed using a constructivist grounded theory approach. This approach is appropriate as it expressly considers the role of the researcher in the research enterprise. As Charmaz (2014, p. 14) writes “I chose the term ‘constructivist’ to acknowledge subjectivity and the researcher’s involvement in the construction and interpretation of data”. The reflexive capacity of a grounded theory approach is necessary to yield meaningful results and address the unique threats to validity inherent within this study.

Grounded theory allows codes to emerge from the transcripts, and should better capture the content of the discussions than an etic coding arrangement. Grounded theory also provides a framework in which the bias of the researcher has less of an effect on the codes chosen, as they are formed through a two-step process. In the first stage, each thought or idea within a transcript was gerund coded, that is given a code ending in -ing describing what the thought is expressing. The gerunds were then used to identify emergent themes and a thematic coding scheme consisting of codes organized in groups associated with a primary theme was generated and subsequently applied to each of the transcripts in a second round of coding.

After the emic coding was complete, we found that some of the emergent themes aligned with best practices found within engineering design and wilderness education literature. Design literature provides a framework through which the outcomes of design-based wilderness education can be evaluated. In the discussion of our analysis, we will see that some of the suggested outcomes of design-based wilderness education align with best-practices supported by the current literature.

#### **4.4 Validity Threats**

As raised by Maxwell (2010), two of the major threats to validity for qualitative research are researcher bias and reactivity, two threats abundantly present in this study. As the same person developed the curriculum, instructed the course, and was the primary investigator for the associated pilot study. It has been necessary to carefully balance these sometimes competing and sometimes complementary roles. An important consideration is that, as the instructor of the program performed the interviews, student responses may have been influenced by a social desirability bias.

It is important to be explicit that the population participating in this study is extremely specialized and may not be representative of other academic populations. The students participating in this study have been selected from the undergraduate population of SUTD for excellence in both academic and leadership-pursuits. The MIT undergraduates are just that – undergraduates at an elite American university. This study is also vulnerable to instructor effects, as only one instructor has been implementing the intervention. Future work should include more diverse students, and multiple instructors.

## **Chapter 5**

### **Analysis**

The two stage grounded theory analysis of the exit interview transcripts resulted in 8 primary codes and 34 sub-codes. Many excerpts had multiple codes applied. When a sub-code was applied the parent code was also applied. Table 2 summarizes the 8 primary codes, the number of unique interviews containing at least one application of the code, and the total number of excerpts to which the code was applied. As you can see almost all of the primary themes identified were discussed across more than three quarters of the 34 interviews.

The single exception is the role of gender in the program. While the role of gender was mentioned by a smaller subset of students, it still emerged as an important consideration and has an important role to consider in future program implementation.

Table 2 Primary Theme Code Applications

<b>Primary Theme</b>	<b># of Interviews Code is Present</b>	<b>Total # of Excerpts</b>
Design Thinking	31	93
Engineering Science	29	80
Personal and Group Leadership	28	70
Emotional Response (Feelings)	34	150
Motivation	33	149
Program Improvements	28	68
The Wilderness Environment	24	44
Role of Gender	8	14

The emergent primary themes generated during the coding include design thinking, engineering science, and leadership, the three thematic elements that the curriculum was designed to address. We will first analyze these three areas in turn. The analysis will then return to examining the remaining 5 primary themes that emerged: emotional response, motivation, the wilderness environment, the role of gender and suggestions for program improvement.

### **5.1 Design Thinking Analysis**

The analysis of design thinking that follows differs in an important way from the sections that will follow. The following sections will base the discussion of primary themes on the emergent subcodes associated with them; the codes associated with design thinking and their application counts are found in Table 3. In the case of design thinking, we are able to perform an alternate analysis that provides a slightly more nuanced understanding of how students associated their experience in the program with their design thinking process.

To understand how students had integrated their experience with design-based wilderness education into their design thinking practice, towards the end of each interview students were asked, “What lessons are you taking away from this experience and do you think it will change how you approach design in the future?” Student responses ranged from specific skills they planned on transferring beyond their wilderness experience to “I’m not sure”. Table 4 summarizes the responses of the 30 students who responded to this question into eight primary themes. Three students responded that they were unsure or did not know, and one student was unintentionally not asked this question. These responses are not reflected in the 8 themes.

Table 3 Design Thinking Code Applications

Code	# of Interviews Code is Present	Total # of Excerpts
<b>Design Thinking</b>	<b>31</b>	<b>93</b>
Creativity / Flexibility / Improvisation	22	34
Constrained Resources	15	17
Design Practices	14	16
Refining / Iterating	10	16
Simplicity	6	9

Table 4 Themes of Responses to Lesson Learned Question

Theme	# Students
Flexibility	6
High Fidelity Testing	6
Simplicity	5
Importance of Trying	5
Survival	4
Empathy	2
Trusting the Process	1
Identifying Team Strengths	1

These 8 themes provide a more nuanced understanding of how students constructed their understanding of design through participation in the design-based wilderness education curriculum. Some responses to the questions, such as flexibility and simplicity also emerged as codes during the overall interview analysis. As we proceed, we will see that constrained resources and iteration play an import role in the responses of students as well. Most interestingly, some students associated surprising themes with what they considered to be their future design thinking practices such as the importance of trying, developing empathy for others, and identifying team strengths.

The vast majority of the analysis of design thinking that follows has been published as a conference paper entitled *Changes in Design Thinking through Participation in Design Based Wilderness Education* (Saulnier, Bagiati, Ahn, & Brisson, 2015). The complete analysis is included as it is essential for a complete understanding of program impact.

The eight themes present in Table 4 provide a natural starting point through which to examine various ways students discussed their design thinking in relation to their participation in the design-based wilderness education curriculum. To provide narrative structure the student responses have been classified into a singular theme that best reflects the overall idea expressed by the response of each student.

### 5.1.1 Flexibility

While participating in design-based wilderness education, students felt themselves pushed to be flexible, creative and improvise. Students

contextualized flexibility in three different ways that we will examine in turn: being open to the ideas of others, thinking on their feet, and having to improvise due to a lack of skill or knowledge.

Many students felt that the wilderness environment encouraged them to be more open to the ideas of others, equating it in some contexts with teamwork and cooperation. Being less rigidly attached to their particular way of doing things, students saw that listening to others provided opportunity to learn different ways of solving the same problem. This willingness to listen to others in their group may have been connected to the small supportive group environment that was deliberately encouraged. Expeditions were limited to nine students and two instructors, and students were in smaller cook groups of 2 or 3.

The wilderness environment often required students to be flexible and improvise, as circumstances did not always match plans. Students felt they had to “think on their feet” and creatively solve problems as they encountered them. This was most apparent during construction of the bear hangs outside, as students did not realize in advance how difficult it would be to get a rope over a branch 20 feet off of the ground. While going through the curriculum, students often felt that they were constrained by the resources that were available. Having limited resources required students to innovate with available materials, oftentimes taking advantage of the natural resources that were available in the wilderness setting such as sticks and rocks.

The third factor driving students to feel the need to be flexible during the course was not an intentional curricular element. In some cases students felt that they were forced to innovate due to a lack of skill or knowledge. This was most common when building artifacts that required knots such as the bear hang, rope bridge, or shelters. Even though many students did not remember the knots they were taught, they were still able to improvise successful solutions. This did provide an opportunity for peer-learning, as some students had a strong grasp of knots. Peer-learning was an effective strategy for some students to master new knowledge. As one student put it, “during class I didn’t pay that much attention to the knots and the stuff you taught us but during the trip I actually put that into practice and I had other people teach me. And that’s when the knot tying and stuff really solidified.”

As we will return to when discussing the theme of survival, some students expressed that the wilderness environment provided pressure that prevented flexibility, innovation and creativity.

### **5.1.2 High-Fidelity Testing**

Prototyping is an important stage of any design process, and through their experiences in design-based wilderness education students became advocates for the importance of high-fidelity testing, placing prototypes in situations that closely matched their final use. When responding to how participation had affected their design thinking, one student said, “whatever we design has to be tried out like in real life against... real life circumstances before going through a second round of prototyping and not just imagining it or thinking a similar situation but in the actual situation itself.” The importance of high-fidelity testing was apparent as students were often forced to deal with unexpected consequences of their actions. In our analysis of outcomes related to engineering science we will return to consider the role that high-fidelity testing played in illustrating the contrast between theory and practice.

### **5.1.3 Simplicity**

The wilderness environment uncovered the value of simplicity through two mechanisms. Having constrained resources encouraged some students to explore simple and often surprisingly elegant and effective designs. For others, the motivation of survival resulted in valuing simple yet functional designs for their likelihood to be, and remain, functional and have a minimum chance of failure. We will later more fully consider the role that survival played as a motivation in the program.

While discussing the role limited resources played, one student said, “it was a great way to be creative about it, and there’s different combinations so you aren’t just limited by your materials, you’re just limited by the way you think.” The student continued by referencing the benefits of working in a team, “So, like, definitely getting different viewpoints from different people is really helpful.” Having simple and limited resources encouraged creativity and out of the box thinking by students.

In response to the pressure of using their own design in survival situations, some students were able to recognize the value in “thinking of the simplest way

to do something instead of being very complicated and elaborate. The easiest thing that will do the job is usually also what will have the least room for error.” This was a practice that the student could see herself continuing to apply in the future.

#### **5.1.4 Importance of Trying**

While at times tasks in the wilderness environment, or simply the expedition itself, may have seemed overwhelming, upon reflection students recognized the importance of “just trying”. There were two distinct reasons students suggested that just getting started was a valuable lesson and future practice. It wasn’t just starting that students found important, starting was discussed in close connection with being adaptable to change, and expecting that change would be necessary. Others felt that excessive planning was unnecessary and often occurred in their groups.

While discussing building a shelter to sleep under, one student prone to analysis paralysis said, “You just give it a shot and then you realize that oh, shucks, it’s off to the right. So tomorrow just change it, I mean, you can still change it. But if you don’t start somewhere you won’t get there, right?” To succeed at a task, he argued that, “The biggest thing is just to start, right, and be more adaptable to changes”. This point of view seems related to the difference between theory and practice noted by students that we will return to more fully consider. Despite their best efforts at planning, oftentimes the result of attempts would not align with expectations so learning through experience, and sometimes experimentation, was the most efficient path.

Some students saw excessive planning as detrimental to the efficient implementation of the design process. One student complained that his group spent a lot of time talking and indicated that after a short planning session the team should “just choose a direction and get on with it. And then, if it doesn’t work, just go back and choose another idea and move on with it”. Once again, through this experience we see that students are flexible and counting on having to change their design plans.

#### **5.1.5 Survival**

The theme of survival permeated the course, with students being told that they would be expected to thrive, not just survive, in the wilderness during the

first classroom session. While some of the design activities associated with the course, such as cooking food and building shelter, support basic survival needs, student safety is not in jeopardy at any time during the program; at the most some discomfort may arise through failing to successfully complete design tasks. Despite this, students emphasized the ‘survival’ aspect of the program.

Survival was discussed by students in three distinct contexts: as a motivation to be successful, as a way to connect design to everyday experience and, as some students identified as their primary lesson, a path through which to develop empathy for others.

The survival aspect of the expedition resulted in a very different set of incentives for students participating in the curriculum than more traditional design-based classes. We will later fully consider the role that survival played as a motivation for students.

Using their own artifacts for the purpose of survival helped students connect design to their everyday life experience. “I guess it would make me realize that design is part of your ability to survive. It’s not just like a far off concept like designing the next big technological thing but it’s in every aspect of my life, so it will probably make me think more about my daily decisions realizing there are better ways of doing things like cooking, eating, and sleeping.”

#### **5.1.6 Empathy**

While two students identified a lesson regarding empathy as their primary take-away, that theme is best considered as a continuation of our discussion on the underlying effect that survival has as motivation. Having experienced their artifacts as users, some students reflected on how the experience made them more likely to empathize with the users of products they would design in the future. Students felt that they would be able to make better choices, and come up with better designs, by being more willing to “put on the shoes of someone who’s actually using your design”.

More immediately, empathy for their classmates served as another source of motivation during the course as students recognized that their decisions and designs would “not just affect you but also your teammates, and you don’t want them to get wet or starve.”

### **5.1.7 Trusting the Process**

The response of one student somewhat defies classification yet also exposes the underlying goal of design thinking education. The student responded to the original prompt by saying, “Have more faith and follow the taught methodology very carefully and more often than not I’ll end up fine. That’s the one thing that I took away because I tend to skip steps and get into trouble, so that’s one thing I learned a lot. And, this definitely is something that I will take away from this. I think I can apply it to everywhere in my life.”

A design-process gives structure to a complex, difficult to achieve task. In the context of design-based wilderness education the design process and design thinking is being applied to a task that also threatens student survival instincts. If design thinking helps student success in that context, it is no great surprise that some students choose to apply the design process to other tasks.

### **5.1.8 Identifying Team Strengths**

When asked to identify changes in their design thinking, one student was unsure but followed with, “I guess to identify the strengths in the group is very important... to get to know the people.” While not directly related to design thinking, this student highlights a theme that ran deeply through the interviews and students regarded as an important component of the learning environment in which the design-projects took place. While students identified and leveraged the strength of their teammates by readily accepting and offering help to each other, what was more notable was the extent to which students supported each other’s learning. Later sections explore the role of the learning environment and teamwork.

## **5.2 Engineering Science Worldview Analysis**

The second learning objective associated with the design-based wilderness education curriculum is the development of an engineering science worldview. The curriculum was designed to encourage students to examine problems from a scientific frame of reference while applying scientific principles to the identification and solution of problems. Table 5 summarizes the codes associated with the development of an engineering science worldview. As we will explore, there are some indications that the curriculum encouraged

Table 5 Engineering Science Code Applications

Code	# of Interviews Code is Present	Total # of Excerpts
<b>Engineering Science</b>	<b>29</b>	<b>80</b>
Knowing Why	20	36
Theory vs. Practice	16	27
Experimenting	14	24

students to develop and demonstrate an engineering science worldview. This finding is tempered by the awareness that while the curriculum shows promise, future curricula will require more effective scaffolding to help fully achieve this learning objective.

### 5.2.1 Knowing Why

To help us understand the role of students knowing why, we will consider the first classroom session. The first session focused on introducing clothing layering and sleeping systems as a heat transfer problem. Students were introduced to the equations governing conduction, convection, radiation, and evaporative cooling. These equations were used to approximate the heat loss that would be experienced by a hiker in the North American environment. Once students understood the various components of heat loss, the properties of modern materials (i.e. GORE-TEX, down insulation, and wool) were briefly introduced. Students were then given prompts to report back on, such as “How can you stay comfortable in the winter?” and “How can you stay comfortable in the rain?”

The ability of students to quickly synthesize knowledge in this new context was initially impressive. In one instance a group of Singaporean students was confidently discussing how you should properly layer in the Winter to stay warm when hiking (an environment they had never experienced before). The posters that were generated by the students contained information that guided common layering systems, with only a few misunderstandings.

The most conceptually interesting poster was from a group that was given 3 sleeping pads and asked to compare them and explain their differing design features. This poster is displayed in Figure 3. While all of their explanations for design decisions were not necessarily correct, they were plausible and interesting. These students were the only group to include scientific language in their poster and were concerned with possible scientific explanations of design decisions such as ridges existing to lower the surface area in contact with the ground and person. This group was also the only group to have physical artifacts to consider while synthesizing their knowledge.

It appears that having access to a variety of commercially realized design possibilities effectively encouraged students to apply a more scientific language and framework to their exploration. This should be explored further in future programs, giving people physical artifacts could be more effective in prompting thinking. For example, If students had been given jackets of various materials to put on and run around in, they could have made better comparisons between the properties of GORE-TEX, soft-shell and down jackets. They would also develop a better appreciation of just how breathable waterproof/breathable fabrics really are.

During the exit interviews many students discussed how the inclusion of a lesson on layering was beneficial and allowed them to see the connection

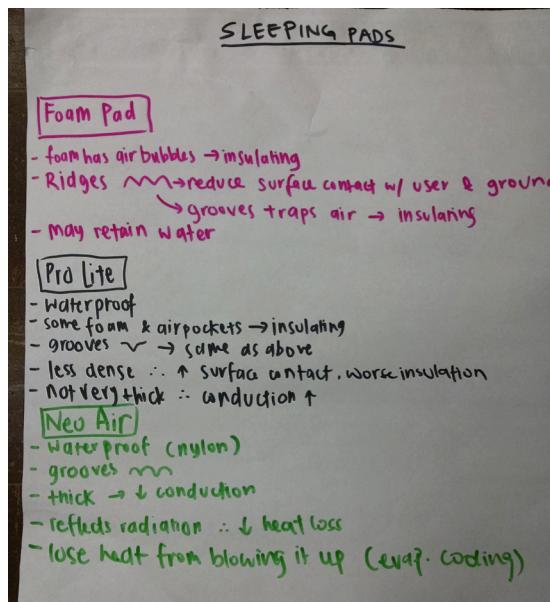


Figure 3 Student Poser Comparing Design Features of Three Sleeping Pads

between a scientific concept and their everyday lives.

*We saw certain physics that we never really thought would be ever used to teach these kind of situations, like heat loss through radiation, convection, conduction. Those are the kinds of things that you already know, and you know that you know because you've been tested on them before but you've never actually seen it being used in this way before, and, you realize that the things you learn are actually very applicable to real life.*

The lesson examining layering systems as a heat transfer problem was the most deliberately formulated curriculum piece to help students develop an engineering science mindset. Students were also able to apply this mindset during other elements of the curriculum.

While on the wilderness expeditions, students were able to apply scientific concepts and language to solve problems that they encountered. In the case of the student who woke up cold outside of their sleeping bag, understanding how heat transfer related to their issue, the student knew that “with the sleeping bag I know that I can get a layer of air inside and it’s going to keep me warm so I just stuck myself in the sleeping bag and got warm”.

### 5.2.2 Theory vs. Practice

The contrast between theory and practice became increasingly obvious as students became users of their own designs. While theoretical knowledge helped students understand the world around them and make predictions, practice would often produce unexpected results. When considering students design thinking practice we saw this reinforce the value of high-fidelity testing and just getting started. The wilderness environment was particularly effective was a source of many unexpected results. In one case students underestimated the friction that would result from trying to pull a weighted rope over a tree branch:

*I was part of the second group that did the bear hang and the thing is even though we had the first group there to give pointers on how to, let's say, throw the rope over the branch and how to set up the system that could actually haul up the bag, we realized that we ran into a lot more issues than we expected. For example, using the branch as a pulley, that did not work out as well as we thought. That was, yeah, so hard. We tried so many solutions, you know, like, we were having*

*problems pulling it so we tried to create a more mechanically efficient system. So we tried to, like, do like a 3:1 system and it didn't really work out, and then we realized it is a simple problem of friction and we just solved it by throwing over a carabineer and using it as a pulley instead [of the branch].*

In this example we see students attempting to solve a design challenge that they have encountered as a result of their backpacking expedition. Students encountered an unexpected problem when the friction from a running a rope over a branch was much higher than expected. Students tried to solve this problem by using mechanical advantage, but the gain within a 3:1 system did not translate to a  $2/3^{\text{rds}}$  reduction of force in practice. To solve this problem students then replaced running the rope over a branch with running the rope through a carabineer that was attached to the branch. In this relatively simple example we see two times when students expectations were not met in practice.

Using their stove for the first time outside, another group of students discovered that the ground is not as flat as a workbench. While sticks may be an attractive material to create a level platform for a stove, sticks also turn out to be quite flammable. After the sticks were doused with water the students switched to rocks for their building material. As was discussed when considering the role of high-fidelity prototyping in students design-thinking, the wilderness environment was able to highlight the importance of fully testing predictions:

*I suppose that because of the lesson I learned you can't just say, you can't just take something and put it on the table, look at it in theory and say, "oh, this will work because it looks good, or this will work because the math checks out." But, if you don't do it in real life you will not actually...a theory is just that, it's fine it may look good on paper, but it might not necessarily apply to your life and that is an important thing you have to do because what you need to do has to apply to whatever you are doing in real life. And the most important lesson will be to prototype, prototype, prototype, and do it again and again and do it in real life. Don't just stare at it and say, "okay, this should work."*

### 5.2.3 Experimentation

When students did not know why, they often relied on experimentation to try and figure things out. The single burner alcohol stove design and building activity was most commonly discussed in the context of experimentation, but students often stopped short of being able to offer an explanation of why a particular phenomena emerged from their experimentation.

*In our cooking group we had three people so we had three different stoves and different designs and we found out that [Student B]'s stove was good at boiling the water really fast, but it didn't last very long. And then, my stove and [Students A]'s stove lasted longer. Yeah, so, I guess making it with the different designs and how it behaves differently was interesting but I guess we didn't really analyze why it behaved differently.*

This was not the case for all students though, some students displayed a more thoughtful consideration of the underlying scientific concepts.

*In chemistry we learned about vapor pressure, that kind of thing, vapor pressure, expansion, contraction, as in less of...a little bit further away from the atoms and molecules side. But, we didn't actually realize, or at least I didn't actually realize it applied to this case until you explained the way the pilot flame would be able to result in the rest of the stove acting up through the vapor pressure of evaporating alcohol.*

While some students were able to articulate how the stoves functioned, during the classroom design and testing sessions many students displayed conceptual misunderstandings of combustion mechanics. During the first classroom session the idea of wicking spread rapidly throughout the classroom, with students experimenting by adding wicks to their designs to attempt to bring the flame front from the large opening of the stove used for priming to closer to the level of the fuel within the can.

These experiments were not successful as students were not changing the gas mixture within the cans which would serve as the limiting factor for the location of the flame front. Building the stoves was originally planned for one three hour lab session, and a second session had to be added. The second session began with a review of basic combustion mechanics, and examination of why the attempts to wick the flame failed.

While initially students were encouraged to create pressurized stoves, during the second classroom session students abandoned pressurized designs in favor of building pot stands that resulted in a much more conceptually simple open flame design. Their desire to simply have something that worked (as 9 of the students were leaving for an expedition 3 days after the second session) overrode a desire for further scientific experimentation. As discussed in previous sections, the role of survival as motivation likely played a factor in this.

Students may have also been pushed in this direction through incorrect explanations of the issues that they were facing when designing and building the stoves. One student attributed their stove not moving past the priming stage to their pressurized holes being too small, “I think ‘cause it’s too small so when I put something over it then there’s no fire, right? It extinguished it; there’s not enough oxygen.” The most likely alternative explanation for the issue was that the vapor pressure was not high enough in the stove, resulting in fuel was not being forced out of the smaller holes in a significant quantity to mix properly and produce a consistent flame front. Simply allowing the priming flame to burn for longer may have “fixed” the problem by allowing sufficient vapor pressure to be reached. This inability to quickly and efficiently troubleshoot problems likely led to frustration and ultimately conceptual simplicity in the final solution.

Even the students who were able to successfully construct a pressurized stove did not always articulate their accomplishment in a scientific fashion. This scientifically naïve articulation makes it seem that the students have not thought through why a pressurized flame would be more efficient. While learning through experience and experimentation is acknowledged, the students do not attempt to explain why what they are observing is happening.

*At first we thought big holes are better but after a while we realized that once the stove got covered and the flames were through the small holes it seemed to burn better. Like our pots were heating up faster rather than from the big fire. So you don't really...like you don't...for me I don't really know why...*

The knowledge was not lacking in the entire class group. One astute student approached me during the second session and was quite confused as to what his classmates were doing. They were still building pressurized stove designs with a large priming hole and smaller holes that would only be effective

for a pressurized mode of operation. They were also enclosing these stoves within pot stands that would ensure that the stove would only be able to operate in the priming mode, preventing the closure of the priming hole.

The stove activity clearly presents the opportunity to correct conceptual misunderstandings students hold regarding combustion mechanics, and encourage the development of an engineering science worldview. Future curricula should focus on extending and refining these opportunities. More active instruction, and better scaffolding would quickly address many of the issues raised by this section. It can be argued that some students were exhibiting behaviors more consistent with trial and error, than a formal engineering design process.

### **5.3 Leadership and Teamwork Analysis**

The third learning objective of the curriculum was the development of leadership skills. To assess this outcome an instrument developed by Ahn et al. (2014) was used to explore the development of student individual leadership skill, group leadership skill, and understanding of the role of society and the economy. The result of this analysis is published in a paper entitled *Leadership Development through Design Based Wilderness Education* (Saulnier, Ahn, Bagiati, & Brisson, 2015). The following analysis will draw on the survey results to better contextualize the results of the exit interview analysis as described by Table 6. The tables and explanation of the quantitative results that follow are excerpted from Saulnier, Ahn, et al. (2015).

Table 6 Leadership Code Applications

Code	# of Interviews Code is Present	Total # of Excerpts
<b>Personal and Group Leadership</b>	<b>28</b>	<b>70</b>
Relying on Peers	11	13
Physical or Emotional Support	10	10
Teamwork Lessons	10	17
Supporting Learning Opportunities	9	9
Learning from Peers	8	9
Listening to Others Ideas	7	9
Stepping Back	6	8
Stepping Forward	5	6
Teaching Skills	2	2

### **5.3.1 Personal Leadership**

Table 7 shows the pre- and post- survey results for each item belonging to the Individual Leadership Skill factor contained in the survey. The table presents items in descending order of difference, with the largest difference between pre- and post- score items listed first. The magnitude of the pre- and post- score differences ranged from 0.55 to 0.10 on a four-point scale. Larger differences indicate students reporting larger changes in behavior after completing the curriculum. As all the items in Table 7 show net increase in the difference, the course had a positive impact related to the skills associated with the Individual Leadership Skill factor.

A review of the items contained in Table 7 shows that many of the items with the largest changes correlate with the exit interview themes of students discussing stepping forward and stepping back. Students stepped forward into leadership roles by taking on responsibilities that are not assigned (Item 1), sharing knowledge with others (Item 3), motivating peers to accomplish goals (Item 4), and seeking leadership opportunities (Item 6). Students could be seen to be stepping back from leadership opportunities by effectively delegating projects and authority (Item 5).

The prominence of interview themes does not always align with the reported increase of skill on the survey. The survey results indicate that students expressed increased confidence in taking on leadership roles after participating in the class, however during interviews students paradoxically focused on how they often relied on their peers to have the technical skill to perform tasks while on the expedition; relatively few students discussed stepping forward and taking on group leadership roles. While relying on peers to perform tasks during the expedition could be framed as effective delegation, students often felt if they did not possess the skill themselves it was a form of stepping back from a challenge and a missed opportunity for learning. This difference is likely in-part due to the format and focus of the semi-structured interview questions. The survey was administered primarily to evaluate the leadership outcomes of the program; the interviews were focused towards understanding the effect of the curriculum on students design thinking and engineering science worldview, discussion of leadership was often framed through these experiences.

Table 7 Item Scores for Personal Leadership Skill

#	Individual Leadership Skill Questions (Factor 1)	Pre	Post	Diff.
1	If I see the need, I take on responsibilities that are not assigned to me.	2.40	2.95	0.55
2	I clearly visualize a project even when I am given limited information.	2.25	2.70	0.45
3	I look for opportunities to share my knowledge with my peers.	2.40	2.85	0.45
4	I motivate my team members to accomplish predefined goals.	2.50	2.90	0.40
5	I effectively delegate projects and authority to other people.	2.30	2.65	0.35
6	I actively seek leadership opportunities in and out of the classroom.	2.40	2.75	0.35
7	I am able to solve problems in nontraditional ways.	2.25	2.55	0.30
8	Change is a smooth and easy process for me.	2.30	2.60	0.30
9	I establish goals for a project and explain the best way to accomplish these goals to my team members.	2.45	2.75	0.30
10	I am not afraid to take risks when making project-related decisions.	2.50	2.80	0.30
11	I clearly explain technical matters to people who are not familiar with my area of study.	2.25	2.50	0.25
12	I manage and organize my time efficiently.	2.35	2.60	0.25
13	I can organize and structure a group to accomplish a common goal.	2.60	2.85	0.25
14	I take ownership of a project in which I am involved.	2.90	3.15	0.25
15	I independently initiate new individual or team projects.	2.30	2.50	0.20
16	I perceive myself to be technically competent.	2.20	2.40	0.20
17	I identify conflicts in a team project and solve them before they harm the project and the people involved.	2.35	2.55	0.20
18	I actively encourage my peers to solve problems.	2.40	2.60	0.20
19	I easily explain and discuss the fundamental elements of a project with other team members.	2.35	2.50	0.15
20	I am a confident person.	2.50	2.65	0.15
21	I facilitate developmental opportunities for my team members during a project.	2.30	2.40	0.10

Another paradox that exists between the survey results and interview analysis is in how students considered their role in creating a supportive learning environment. During the exit interviews students discussed how their groups established supportive learning environments for students to learn new skills, instead of simply relying on the students in the group who already possessed those skills. However, the survey item evaluating if students facilitated developmental opportunities for their team members during a project (Item 21) had the lowest reported change in this category.

The most prominent example of students establishing a supportive learning environment was during the navigation exercise on the second day of the expedition. Students were given a brief navigation lesson, handed a map and some compasses, and chose an objective to reach. While many of the students had participated in national service and received previous training in navigation, these students most commonly did not take the lead. This surprised some, as one student said, “I would have expected those with experience to lead the way but instead it seemed like there was another system which was to let those without experience to try it.”

On three of the four expeditions students without experience navigating led the group during the navigation exercise. Students from the only group that did not select an inexperienced leader later made the suggestion that inexperienced members of the group should have been the ones who navigated:

*I think it would be good as a learning experience to actually let those who know how to navigate step aside and perhaps just give advice. Maybe then the people who don't have nearly as much experience kind of do most of the work themselves, and then if they need help, you know, they can ask you, they can ask any of the ones with experience.*

These students are supporting learning opportunities rather than adopting a performance-oriented mind set. The group that selected experienced navigators was the first group to go on expedition, and the unknowns associated with being the first group on expedition may have encouraged more performance-oriented behavior than later expeditions. The survey question specifically asked about creating learning opportunities during projects; it is probable that students did not regard this navigation exercise as a project. While this example makes it clear that students are skilled at supporting each others learning, it appears that students may regard tasks they associate as

“projects” as requiring performance-oriented execution, and not necessarily as an appropriate venue for encouraging skill-development.

There are a number of items in Table 7 that had low pre-scores (i.e. equal to or below 2.30 on a four point scale) but had high post-scores. For example, clearly visualizing a project with limited information (Item 2) and solving problems in nontraditional ways (Item 7) were initially rated equal to or below 2.30; however, after the course, they had some of the largest gains (a net gain of equal to 0.30 or above). The increase in this skill may be a result of the nature of the wilderness setting of the program; students had little information regarding the terrain they were travelling in and the problems they were being asked to solve. Additionally, the wilderness environment encouraged creativity and this result supports the finding that the wilderness environment supports creative approaches to problem solving.

Interestingly, even though students expressed increased positive leadership behaviors, students reported little change when asked on the survey if they considered themselves confident people (Item 20). This finding may be partially explained by students having a relatively high pre-score for this item, but it is worth noting that students may not have associated increased positive leadership behaviors, or wilderness skills, with increased confidence.

### 5.3.2 Group Leadership

The same item analysis used for Individual Leadership Skill was also conducted for the items associated with Group Leadership Skill. Table 8 presents the 20 students’ averaged pre- and post-survey scores and their differences. The magnitudes of the differences ranged from 0.43 to 0.21.

When considering students group leadership skill, we see that students listened to the ideas of others and integrated these ideas into their decision making process (Item 3 and Item 4). Students valued learning from each other through discussion:

*In the process of discussing we get to learn from each other, and it's definitely, from my experience, it's definitely better than your own idea. Even if you have a pretty good idea, because of other people's additional prompts and the exchange of ideas it will actually be better.*

Table 8 Item Scores for Group Leadership Skill

#	Group Leadership Skill Questions (Factor 2)	Pre	Post	Diff.
1	I can acknowledge when I am wrong and learn from my mistakes.	2.68	3.11	0.43
2	I work well with people who have backgrounds that are different than my own.	2.58	3.00	0.42
3	When making decisions, I take into account opinions of all the people involved in the project.	2.63	3.00	0.37
4	I gather as much input as I can before making decisions.	2.63	3.00	0.37
5	I do my best to make my team members feel important and get involved in a project.	2.63	3.00	0.37
6	I treat my peers with respect and dignity.	3.26	3.53	0.27
7	I create an environment of trust among my team members.	2.79	3.05	0.26
8	I listen to my peers' concerns and opinions even if they are different from my own.	3.05	3.26	0.21

The item with the largest reported increase, the ability of students to acknowledge when they are wrong and learn from their mistakes (Item 1) may also be related to this appreciation of the value of sharing ideas with peers.

Students supported each other by directly teaching certain required skills. While direct teaching and learning was taking place, students emphasized the importance of learning through observation. By seeing what other students had done, or how they solved problems, students expressed that they were able to change their perspective and consider alternative solutions to problems. This learning by observation was more commonly discussed than directly teaching or learning a skill from others.

The three factors with the smallest difference all had the highest pre- and post- scores in this category. Students were skilled at treating each other with respect (Item 6), creating an environment of trust (Item 7) and listening to concerns and opinions (Item 8). These three skills are all related to the physical and emotional support that students provided to each other during the expedition and discussed during the exit interviews. Students emphasized the physical and emotional support that was provided directly and indirectly

by their peers. As one student expressed, “when you’re in the wild it’s always better to have people around you. It’s not just a morale booster, but they can also help you do things that you may not be able to do on your own.”

Students also felt they learned to work well with people who have backgrounds that are different than their own (Item 2). This result could be simply attributed to the cross-cultural aspect of the participants; the 30 SUTD students and 6 MIT students likely regarded each other as having significantly different backgrounds.

The same analysis used for the first two factors was conducted for the items associated with Society and Economy. Table 9 summarizes the gains after the design-based wilderness education course. The net average difference

Table 9 Item Scores for Society and Economy

#	<b>Society and Economy Questions (Factor 3)</b>	Pre	Post	Diff.
1	I pay attention to environmental issues while designing new products.	2.26	2.68	0.42
2	I am primarily aware of cost and revenue when designing a product.	2.53	2.84	0.31
3	I anticipate having to learn new skills over the course of my career.	3.25	3.55	0.30
4	I consider my work as helping people to live better lives.	3.05	3.20	0.15
5	I am aware of the impact that engineers have on society.	3.10	3.25	0.15
6	I feel responsibility for the success and failure of a project.	3.21	3.32	0.11
7	I understand the business implication of product development.	2.80	2.90	0.10
8	I believe societal issues affect how engineers to their jobs.	2.95	3.05	0.10
9	I believe that engineering design is affected by issues related to social and business environments.	3.05	3.10	0.05
10	I am aware of competition among companies in my field.	2.70	2.75	0.05
11	I am passionate about achieving my goals.	3.21	3.21	0.00
12	I believe that changes in the economy will impact my job.	3.10	3.05	-0.05

in magnitudes ranged from a decrease of 0.05 to an increase of 0.42.

The item with the largest change (Item 1) addresses the students' intention to pay attention to environmental issues when designing new products. While this was not an expressly stated goal of the program, simply living in a wilderness environment seemed to encourage an increased appreciation for the environmental impact of human activity, as we will consider again later.

Interestingly, the second largest difference is for an item regarding cost and revenue awareness. On its face, this item is unrelated to the curriculum. One possible explanation is that students connected cost and revenue to their experience designing in and for a heavily resource-constrained environment. This item warrants further investigation.

Many of the remaining items focus on social issues: the role of engineering to help people live better lives (Item 4) and to have an impact on society (Item 5) and the belief that societal issues affect how engineers do their jobs (Item 8). Even though these items were not a focus of the curriculum as implemented, a modest increase between pre- and post- scores is present.

### **5.3.3 Quantitative Analysis of Survey Results**

Saulnier, Ahn, et al. (2015) performed a descriptive statistic and paired sample t-test analysis on the three leadership factors. This following analysis has been excerpted and included to provide context for the previous qualitative analysis.

Descriptive statistic analysis was performed to obtain the factor scores, which are the sums of raw item scores loading on each factor. For example, for the Individual Leadership Skill factor with 21 items rated using a four-point scale, before the design-based wilderness education course, students' factor scores ranged from 32 to 64 with a mean of 49.26. The results of the descriptive statistic analysis are presented in Table 10.

The paired sample *t*-test analysis was conducted to determine whether there was a significant increase between the mean of the 20 students' factor scores before and after the design-based wilderness education course. Table 11 summarizes the *t*-test results. For the Individual Leadership Skill factor, the result was significant,  $t(18)= 6.55$ ,  $p < .05$ ,  $d = 1.50$ , indicating that there was a statistically significant increase in factor scores from before the course ( $M=49.26$ ,  $SD=9.42$ ) to after the course ( $M= 55.47$ ,  $SD= 8.38$ ). Similarly the

Table 10 Descriptive Statistics for Individual Leadership and Group Leadership Skills, and Society and Economy Factors

Factor (# of items)	Sums Scores	Min.	Max.	Mean (SD)	Median	Range
Individual (21)	Before	32	64	49.26 (9.42)	51	32
	After	43	70	55.47 (8.38)	54	27
Group (8)	Before	18	30	22.26 (2.98)	22	12
	After	20	32	24.95 (3.44)	25	12
Society and Economy (12)	Before	27	45	35.05 (5.33)	35	18
	After	29	47	36.68 (5.06)	35	18

Table 11 Paired Sample t-test Results for Individual and Group Leadership Skills, and Society and Economy Factors

Factor (# of items)	Avg. mean difference (SD)	95% Confidence		t	df	Sig. (2-tailed)	Cohen's d
		Lower	Upper				
Individual (21)	6.21 (4.13)	4.22	8.20	6.55	18	0.00	1.50
Group (8)	2.68 (2.71)	1.38	3.99	4.32	18	0.00	0.99
Society and Economy (12)	1.63 (1.57)	0.87	2.39	4.53	18	0.00	1.04

results for the Group Leadership Skill and Society and Economy factors were  $t(18)= 4.32$ ,  $p < .05$ ,  $d = 0.99$  and  $t(18)= 4.53$ ,  $p < .05$ ,  $d = 1.04$ , respectively, indicating a significant increase in mean factor scores from before to after the course. In addition, the effect sizes for all three factors were large based on Cohen's convention. These results indicate that the curriculum was effective in elevating students' individual and group leadership skills as well as their consideration of society and the economy as it relates to the profession of engineering.

#### 5.4 Students Emotional Reaction

During the exit interviews students spoke at length regarding their emotional reactions to participating in the program as summarized by Table 12. Overall, the consensus was that the program was enjoyable, and while looking back students were able to say the experience was fun. At various times students felt challenged, comfortable, discomfort, and a sense of accomplishment.

Table 12 Emotional Reaction Code Applications

Code	# of Interviews Code is Present	Total # of Excerpts
<b>Feeling</b>	<b>34</b>	<b>150</b>
Enjoying / Having Fun	28	57
Challenge	25	51
Comfort	12	17
Discomfort	12	20
Accomplishment	9	17

#### 5.4.1 Enjoying / Having Fun

Students enjoyed participating in the design-based wilderness education curriculum. Students often exclaimed during interviews that the experience was, “really fun”. Students most commonly mentioned that building and cooking on the stoves was enjoyable, along with just being able to spend time in a wilderness environment. The novelty of the experience contributed to students enjoyment. Through this experience students were also able to feel more connected to unique aspects of North American culture; a highlight of each trip was when the students from MIT would instruct the SUTD students on how to roast marshmallows and make s’mores, a uniquely North American pastime.

When asked, 33 of the 34 students indicated that they would recommend the experience to their peers. The 34<sup>th</sup> student indicated that he would recommend it if more content was added. Students expressed that the experience was overall an enjoyable one, along with being a valuable learning experience.

#### 5.4.2 Challenge

Students most often spoke of dealing with physical challenges associated with being in a wilderness environment. Students carried heavy packs, dealt with mosquitoes, and had to navigate through the wilderness environment. Some students felt challenged by the design projects, whereas other students wanted more challenges to be introduced to the program.

### **5.4.3 Comfort & Discomfort**

Students felt prepared for the wilderness environment by the classroom sessions, and students with experience and those without experience were all able to feel comfortable at times. For some students aspects of the wilderness environment were initially uncomfortable, but through experience moved into their comfort zones. For one student who was afraid of the dark:

*Getting used to the darkness, it's not something I thought I would be able to do because I'm very afraid of the dark, I don't like darkness, I don't like being alone especially when we are in the wilderness, yeah. And somehow when I went through this process I realized that it's fine, it's okay.*

The most common complaint of discomfort involved the mosquitoes, a physical and mental challenge that students quickly learned to deal with. While many students were taken outside of their comfort zone, in retrospect they regarded the experience as fun, or felt that their comfort zone had expanded.

### **5.4.4 Accomplishment**

Students felt a sense of personal accomplishment from having participated in the expedition. For many students simply sleeping on the ground or drinking water from a stream was a surprisingly pleasant achievement. The expedition also provided the opportunity to take leadership roles. One student expressed pride in how he successfully lead the team to a specified point during the navigation exercise; discussing the experience he said he would remember the experience, and that accomplishment, for his whole life.

Other students felt increased confidence and an increased willingness to try their ideas. As one student said:

*I think a lot of times, me included, people are just afraid to carry out their ideas. Like, I'm just one person, I can't make something new. And they are afraid to reach out to people who might help them, but we made a friggin stove...I don't know, I thought that was pretty cool. Just, like, why not, right? I think it made everyone more willing to go for it. I think that's something I've generally taken away. Just a little bit more confident, I think, is the main take away. Just...the worst thing you can do is fail, and you improve and you learn something.*

Table 13 Motivation Code Applications

Code	# of Interviews Code is Present	Total # of Excerpts
<b>Motivation</b>	<b>33</b>	<b>149</b>
Practical & Relevant to Life	25	53
Learning by Doing	24	53
Survival	20	36
Freedom	10	15
Not Challenging Self	8	10

## 5.5 Motivation

As we will see, one of the more unique aspects of the design-based wilderness education curriculum is just how students are incentivized to participate fully in the curriculum. As we saw when exploring how student design thinking was affected by the curriculum, perceived survival needs could serve as a motivation for succeeding in the course. Survival was not the only motivation students discussed, or even the most common, as can be seen in Table 13. Many students benefited from immediate application of ideas and learning by doing. Others benefited from seeing how the projects they were working on were practical and relevant to their lives. Many students were motivated by the freedom provided by the instructional style of wilderness education. While the vast majority of students were highly motivated to participate fully in the curriculum, some students spoke of times they chose not to challenge themselves.

### 5.5.1 Practical and Relevant to Life

Students felt increased motivation in the wilderness environment due to the immediate applicability and usefulness of what they were doing, “I really learned how to do the ropes in the wilderness itself. Like while it was on the campus I learned it but I like forgot quite fast ((I: Um-hum.)) ‘cause it wasn’t like a motivation or incentive to do it well.” Students enjoyed making things and using them in the wilderness, building stoves, and then seeing the design work in the natural environment was some students favorite part. Students enjoyed how the projects were all immediately relevant to their lives, and were not contrived assignments for a class. Students had to learn how to tie a clove-hitch knot to effectively build their tarp shelters. Since she needed to survive,

one student caught on immediately and during the exit interview didn't think she could ever forget how to tie one.

The immediate application and learning by doing was appreciated by the vast majority of students. As we will return to when considering the learning environment, students appreciated learning

### **5.5.2 Learning by Doing**

Students appreciated the combination of having time to learn theory during classroom sessions, and then testing out that knowledge in the real world. Through experiencing their designs students were able to realize what gaps existed in their understanding, and they were able to go back and figure out what they missed.

This freedom to experiment allowed students to learn experientially. The course was especially appreciated by those students who enjoyed learning visually and experientially. One student who considered themselves not good in physics before the course left with more interest in physics.

*I felt it was a good process throwing yourself into the situation, forcing yourself to think on your feet, and better yourself as you go. So, I felt that is the best way I learn, so I wouldn't change it at all, actually.*

### **5.5.3 Survival**

One student compared her experiences by saying, "It's a bit different because you feel a bit more vulnerable when you are outdoors and so you put a little bit more effort into the little details. Compared to school where you just get a grade, it's not like a live or die kind of decision." Some students felt this motivation helped them master certain skills. One student reported, "I need to do the ropes in order to survive so when someone taught me, I caught on immediately, and, well, I don't think I can ever forget how to do the clove hitch [knot]."

Relying on survival for motivation was not without its drawbacks. As mentioned previously, some students felt that the pressure of perceiving they were in a survival situation made them not want to take risks or spend time innovating while designing. As explained by one student, "when you're in the wilderness you really struggle between trying to stay alive and comfortable and then the other side, which is doing innovation. So, when you're out there and

dealing with that you don't want to focus too much on the innovation part rather you tend to just lean towards the struggle to survive part." This concern was for the most part moderated by the division of the curriculum between on-campus and expedition activities. This was especially true for the stove, which was designed and built in the classroom and then used in the wilderness environment.

#### 5.5.4 Freedom

Students were surprised by the amount of freedom that was granted during both the classroom sessions and expedition. Students appreciated that they were not being spoon-fed information, and that they were given the flexibility to explore within the tasks that they were assigned. As one student said while discussing the expedition, "You were just physically present but you weren't helping us. And, in a way, that really pushed us to do well". Despite the noticeable lack of close guidance, students still felt supported. Another student discussing the expeditions noted, "Obviously if we do something really stupid you'll let us know, but it was giving us a chance to learn and make our own decisions and then own up to them. I liked that a lot."

Providing this freedom through stepping back from a leadership role is a common wilderness education technique in which students are coached in the skills necessary to take over complete responsibility for the expedition by the end of the program. In NOLS, this is expressed through students travelling and camping separately from the course instructors during the final portion of the program (Gookin, 2006).

While designing and building the stoves on campus, students were encouraged to take charge of the design process in a different way:

*The fact that you didn't show us how to do it. You were just like, "This is the idea. Here's some [stoves] my friends made, some of them might not work." I liked that. Don't try to just copy, actually think about what you are doing, think about your set up, everything, nicely without telling us how to do it and then we had a lot of freedom to choose our materials, decide everything. Just, like, here's some fuel and some pots to try it out and then just throwing us there and letting us go.*

Table 14 Wilderness Environment Code Applications

Code	# of Interviews Code is Present	Total # of Excerpts
<b>Wilderness Environment</b>	<b>24</b>	<b>44</b>
Appreciating Nature	18	25
Using Environment	11	12
Human Impact	6	7

While this freedom did serve as motivation for some students, as we saw while examining the engineering science outcomes from this curriculum, more formal scaffolding could have the potential to encourage stronger learning outcomes. This speaks to the need to achieve a careful balance between this constructionist approach and a more structured step-by-step design process.

### 5.5.5 Not Challenging Self

Some students discussed not challenging themselves during portions of the curriculum. As discussed previously, students who considered survival as their motivation were more likely to not pursue creative or innovative solutions to challenges. As mentioned previously, some students also chose not to challenge themselves when stepping back from leadership activities.

## 5.6 The Role of the Wilderness Environment

The most obvious contribution of the wilderness environment was in its previously discussed role as providing an environment in which students felt that they had to meet survival needs. The remote environment also allowed for constraints and a feeling of getting away from campus. As summarized by Table 14, students discussed the role of the wilderness environment in three distinct ways: evoking an awareness of human impact, as inspiration for design, and most commonly simply as a thing to be appreciated.

### 5.6.1 Appreciating Nature

For many students the natural environment was simply something to be enjoyed and a rare opportunity to escape modern convenience. Students were able to enjoy themselves and have fun without their phones and being constantly connected to the world, which was a new experience for many of them. As one student said, “it really opens your eyes to how people lived a few

years ago - and they thrived; they just didn't survive. So we definitely don't have to be so reliant on technology and comfort. Nature has a lot to offer for us. I want everyone to appreciate that."

### 5.6.2 Using Environment

The natural environment also served as a source of inspiration for design. In some cases this was as simple as students using rocks or logs as building materials, but others drew deeper inspiration. Students commented on the inherent beauty of the designs created by nature, and the ideas that could be copied. The campsite that 3 out of 4 of the groups used was located right beside a beaver dam, an incredible feat of engineering in its own right, yet as one student found surprising, "just a whole bed of branches and sticks and it blocks such a large amount of water".

### 5.6.3 Human Impact

Travelling through and living in a wilderness environment made visible the hidden human impact on the environment. Before leaving Cambridge, students had to consider the waste that they would be generating during the trip, as they had to carry it all back out with them. Meal selection included considerations of how easy leftovers would be to deal with and dispose of. These considerations caused students to change their decisions to have a smaller impact, and less waste to deal with. Students also considered the effect that their waste would have on the environment, and the broader impacts of human activity on nature.

*It makes me aware of a lot of other things such as caring for the environment ... I never thought of the consequences of how [rinsing and cleaning dishes] would affect animals. But in this case we camped near a beaver dam and saw the beavers at night. When we would wash our oily food and whatever is in our soap, it may harm them. So when you have to walk 20 meters up just up to dig a hole and clean up that was when I realized, okay, what we do has an impact on others we just don't notice it until you really go into the wilderness. Yeah, and that's one of the things that... that hit me quite strongly, and it stuck with me for a while.*

## **5.7 The Role of Gender**

A few students commented on the role that gender played during the program as shown in Table 15. Amplifying traditional gender roles, most of the male SUTD students are two years older than the female students as male Singaporean's perform two years of national service before entering college. A student who noticed herself being subordinate because of her age thought that, "if more opportunities could be given for the girls or other people to show their expertise and independence I think that would be great." One female participant who wanted to be independent during the day-hike was told regarding a pack she was sharing with others, "you don't have to carry it because you're a girl". On one trip with 2 female and 7 male participants one of the female participants suggested that a more even ratio would make for a less intimidating environment.

## **5.8 Program Improvements**

While discussing elements of the curriculum students offered suggestions to improve the course, and towards the end of the exit interviews students were also directly asked if they had any suggestions for improvements. The responses are summarized by Table 16.

### **5.8.1 More Content / Activities**

Students also advocated for increased challenge. There was a substantial amount of free time built into the expedition schedule to allow for students to cook and to account for the unexpected. Fortunately the weather was pleasant on all four expeditions, and no unexpected problems arose. Students suggested that there could be more challenges, or activities such as the design challenge could be made more complex.

Table 15 Gender Code Applications

Code	# of Interviews Code is Present	Total # of Excerpts
The Role of Gender	8	14

Table 16 Program Improvement Code Applications

Code	# of Interviews Code is Present	Total # of Excerpts
<b>Program Improvements</b>	<b>28</b>	<b>68</b>
More Content / Activities	13	19
Individual Learning	10	13
Longer Expedition	7	8
Shorter Class to Trip Gap	4	4

### 5.8.2 Individual Learning Opportunities

While the course was hands on and experiential, the most common feedback was that more individual hands on experience would have made for a better learning environment. This was especially true for skills such as knot tying, where students who were in a group working on a project often did not get to practice or contribute.

### 5.8.3 Longer Expedition

Many students suggested that the expedition should be made longer. This suggestion came both from students that were comfortable in the wilderness environment, and those for which it was more of a challenge. Having a longer expedition aligns with research on wilderness education programs, which tends to find that longer programs have larger effects (Sibthorp, Paisley, & Gookin, 2007). Students recognized that a longer program would be more impactful if they had more time to integrate into and become comfortable in the natural environment.

### 5.8.4 Shorter Class to Trip Gap

An unfortunate artifact of the structure of the program is that for some students there is a substantial lag between the final classroom session and their expedition. Students on the final expedition had the last classroom session five weeks prior to departing. This lag caused some of the students in the later expeditions to feel that they had forgotten many of the skills that they had initially learned before being able to apply them.

## **Chapter 6**

### **Implications**

This study is an exploratory investigation into the role that design-based wilderness education could play in the diverse field of engineering education. The results of this qualitative study highlight avenues for future research. Before discussing the remaining emergent themes identified from the grounded theory analysis of the interviews, we will first consider what we have learned from examining the three main learning objectives: design thinking, the development of an engineering science worldview, and leadership.

#### **6.1 Discussion of Learning Objectives**

The three main learning objectives provide direction for the continuing development of more impactful design-based wilderness education curricula. While in the analysis we have seen that some elements of each learning objective were successfully encouraged by the curriculum, we still need to turn a cautious eye towards our results.

##### **6.1.1 Design Thinking**

Through our analysis of the effect of the design-based wilderness education curriculum on student design thinking we found that students highlighted the importance of flexibility, high fidelity testing and simplicity. Turning to the literature on design, we find that many of the practices that students felt were emphasized by the design-based wilderness education curriculum align with recognized effective practices. These aligned themes provide inspiration for future curriculum development and research opportunities. It may be that

design-based wilderness education is particularly situated to encourage certain mechanisms of effective design thinking.

One of the more direct comparisons is that the wilderness environment motivates students to appreciate simplicity. A student who learns to appreciate simplicity may be more successful in future classwork. When investigating the role of design complexity in classroom outcomes Yang (2005) found that “prototypes with fewer parts correlate with better design outcome, as do prototypes that have fewer parts added to them over the course of development.” The wilderness environment is particularly well suited to encouraging students to consider simplicity in a positive light. Along with enjoying the simplicity of the design projects, students appreciated the simplicity of the environment. Some students noted that not having access to their cell phones or being surrounded by technology was a refreshing and enlightening experience.

The wilderness environment also required students to consider the notion of having constrained resources. In a comparison of the use of design language by freshmen, seniors, and experts Atman, Kilgore, & McKenna (2008) found that “identifying constraints grew in importance from the first year of an engineering education to the last, and most experts shared a perspective that this activity is important”. The constrained environment of the wilderness encouraged students to consider the role that constraints played during the design process, and also appreciate what was possible to achieve with limited resources.

We found that students emphasized the importance of high fidelity testing. This could indicate that students were open to failure and learning at late stages of the design process. A study by Adams, Turns, & Atman (2003) found that seniors with higher quality final projects were more open to re-defining the problem throughout the entire design process, and open to the idea of failure. This theme was also expressed by students discussion of the difference between theory and practice. In discussing this distinction students recognized that they would learn throughout the entire design process as their ideas were tested out with increasingly high levels of fidelity against reality.

For some students, the curriculum encouraged flexibility, creativity and innovation. While there is on-going research considering how to define, measure and teach creativity as part of design thinking, there is a clear

consensus that creativity plays an important role in the design process (Dorst & Cross, 2001; Dym et al., 2005; Howard, Culley, & Dekoninck, 2008). It may be that among other benefits, the wilderness environment provides effective scaffolding that encourages students to approach problems in a creative manner.

While the curriculum was structured to encourage design thinking, and students reported changes in their approach to design, students were not always engaged in a design thinking processes. Some aspects of the curriculum could be better thought of as ‘hacking’, or problem solving. Our definition of design requires students to practice reflection-in-action as defined by Schön, or more simply a “complex process of inquiry and learning” as defined by Dym et al. As we continue to develop situated instances of design-based learning, it is important to consider the scaffolding necessary to ensure that a design activity results in the reflective practice necessary to serve as an effective instance of design thinking.

When designing future curricula it will also be important to take into account the role of survival on students design thinking practice. While survival as a motivation illuminated the value of high-fidelity prototyping and developing empathy for others, it was negatively associated with students feeling the ability to creatively innovate.

Caution must also be exercised when giving students tasks for which they lack pre-requisite knowledge or skill. While this may encourage flexibility and creativity, it also may have the unintended consequence of encouraging students to engage in poorly planned improvisation and problem solving, rather than purposeful and reflective design.

### **6.1.2 Engineering Science Worldview**

The curriculum was able to somewhat help students develop an engineering science worldview, however more effective scaffolding is clearly required. With quantitative tools and physical artifacts to examine, students were encouraged to start “knowing why” and connecting scientific understanding to their everyday life experiences. The wilderness environment seemed to encourage increased appreciation for the difference between theory and practice, encouraging students to experiment and engage in high fidelity testing. When students were faced with novel design challenges they sometimes engaged in

experimentation to gain increased understanding, other times students simply followed the path of least resistance to a prototype that just worked. Future work requires a more careful consideration of how deliberate experimentation can be supported to increase understanding and subsequent reflective design thinking.

Effective design activities need to be developed to help encourage development of an engineering science worldview. The alcohol stoves, despite their conceptual simplicity, posed a challenge for students mental models of combustion mechanics. Effective scaffolding can help to illuminate breakdowns of students personal conceptual models, and encourage the development of more accurate understanding of various scientific phenomena.

Other activities proved to be less effective than the alcohol stove at supporting the development of an engineering science worldview. The rope bridge building task was able to be solved in a much more simplistic manner than originally envisaged, allowing students to engage in trial and error rather than purposeful design. Most groups constructed a bridge by simply tying knots around two tree trunks. In fact, the designs were more often based on a single trial, as the first attempt to solve the problem was often effective. While some groups did attempt more complex solutions taking advantage of mechanical advantage to tension ropes, the original intention of the task, most groups did not. Future design activities should be selected such that they provide more opportunity to explore scientific phenomena and continue to develop an engineering science worldview.

### **6.1.3 Leadership**

Students reported increased personal and team leadership competencies after participation in the curriculum. Students are skilled at supporting each others learning, but as we learned may distinguish between learning opportunities and projects that require a performance-orientated mindset. The wilderness expedition effectively supported students adopting a learning-orientated mindset. When participating in design projects students would often return to a performance-orientated mindset, focusing on tasks for which they already possessed competency.

There were many paradoxical results when comparing the results of the leadership survey to the exit interviews. While in the survey students

expressed confidence in taking on leadership roles, in the exit interviews students focused on how they often relied on their peers. Interestingly, students did not express increased confidence in the results of the leadership survey.

As expected students expressed beneficial outcomes to group leadership skills. Most of these results could likely be attributed to the supportive small group learning environment. A longer expedition would provide further opportunity to focus on the development of specific leadership traits. The limited time spent on expedition prevents the assignment of leadership roles to many members of the group, and further limits the ability to have students rely on themselves rather than the expedition instructors.

## 6.2 Emergent Themes

Now that we have examined the three domains targeted by the curriculum we will turn to examining the other ways students responded to the curriculum and what they found important. These themes provide insight into what components of the curriculum resonated with the students beyond the three targeted learning areas of design thinking, engineering science, and leadership. This insight will help to guide future curricula, and provide guidance as to how future curricula can be strengthened by capitalizing on the unique aspects of the design-based wilderness education curricula.

Novelty played an important factor in the initial success of this curricular approach. Students found the activities enjoyable, and the unique learning environment was perhaps better situated to capture students attention while encouraging them to consider the design process in a different context.

Students were motivated by creating artifacts that they used to meet their own survival needs. This motivation was coupled with a sense of accomplishment; the stoves that students constructed were immediately and obviously relevant to their lives.

Students enjoyed the fact that they were able to experiment and think on their feet. While experimentation is an important element of the engineering science process, if the experimentation is not reflective, it can cause an activity to cross the line from design to simply problem solving by trial and error. Finding ways to balance these two activities effectively is important to encourage effective design behaviors.

This brings us to a broader consideration of the role of a constructivist experiential approach to education versus the role of scaffolding within the program. Given the constraints on time, more effective scaffolding could provide for a more effective learning environment. As has been discussed the scaffolding could be framed in such a way as to ensure that the engineering science and design thinking content of the program is emphasized.

This course provides an opportunity for students to enjoy and appreciate nature and the natural world, an end unto itself. Through spending time in the natural environment students were able to gain an increased appreciation for the role that engineering plays in making the world more comfortable for humans, while also highlighting the importance of protecting and preserving natural spaces for future generations.

### **6.3 Program Improvements**

These results were used to guide development of the 2015 implementation of a design-based wilderness education program. While design-based wilderness education shows promise as an educational approach for engineering students, substantial improvement is possible.

It was challenging having 36 students in a single section of many of the classroom activities. Multiple sections of the on-campus classes would provide for a more effective learning environment. Having multiple sections would also allow for classes to be taught closer to the later expeditions as well, responding to the concern that students had with the sometimes substantial gap between classroom sessions and later expeditions.

As found in the wilderness education literature, longer expeditions would allow for students to derive greater benefit from the wilderness environment. This is unfortunately challenging from both a scheduling and financial perspective. Design-based wilderness education programs need to balance the requirement for an extended wilderness experience and the demands of that extended experience.

One of the more important aspects of the design-based wilderness education experience is the specific design challenges posed to students. While the alcohol stoves effectively introduced a new and somewhat challenging scientific phenomena to students in the form of a design challenge, other tasks were less successful. Future iterations of the design-based wilderness education curricula

need to incorporate additional successful activities integrating design thinking with the development of engineering science concepts.

#### 6.4 Future Work

While there are indications that design-based wilderness education is a promising novel approach to engineering education, future curricula will need to carefully consider potential benefits and trade-offs that have been identified in our analysis.

Beyond that, this exploratory study has illuminated the necessity of further research into the role of the situated learning environment. The core feature of design-based wilderness education is the transition of design activities and artifacts from the classroom environment to the wilderness environment. We can break down design activities into two unique contexts:

1. Design and fabrication activities take place in a traditional classroom environment. The students are the users of their final artifact. The final artifact is then used in the external environment for which it was designed, with students and their teammates depending on the artifacts proper functioning for an important personal need (e.g. building single burner alcohol-fuel stoves on campus and then using those stoves to cook while on a wilderness expedition).
2. Design and fabrication activities take place in the same environment in which the artifact is used. Students are users of their artifact, and may depend on the artifact for an important personal need (e.g. building a debris-shelter in the forest or figuring out how to desalinate water while on an island).

While it is clear that the wilderness environment itself plays a large role in the overall learning experience for students, understanding the precise role of the environment in design-based wilderness education requires further investigation. These two contexts enumerated above will allow us to explore situated design across the axis of the intensity of the role of the situated environment. Situated instances of design may result in a different set of incentives than more traditional classroom experiences. In our case, students

are the immediate users of their own design projects, and are often using their projects for the fulfillment of perceived survival needs. This is markedly different to more traditional experiences where the main motivation may be grades that are awarded. Exploring the differences between the two contexts enumerated above, we will be able to begin exploring the role of the wilderness environment in this uniquely situated design-based learning experience.

As we are interested in educating engineers, it is also important to clearly grasp the role of design thinking in this curriculum. Further investigation is required into the role of the design process in design-based learning experiences. The specific structure provided by the design process during design-based learning may have important effects on the learning outcomes and experience of the student. Future implementations of design-based wilderness education should more carefully consider the specific design-process being implemented by students.

We also briefly explored what effective design practices are seemingly encouraged by integrating wilderness education pedagogy with design-based learning. These comparisons provide some inspiration for future refinements to design-based wilderness education curricula, and begin to identify areas where design-based wilderness education may have unique strengths that could be effectively leveraged by engineering educators. A more comprehensive survey of the engineering design literature should be performed to categorize best practices in engineering design.

Further research is also needed to understand how the creative inspiration afforded by the wilderness environment can be integrated into different stages of the engineering design process. The persistence of the effects of design-based wilderness education experiences should also be investigated.

## 6.5 Conclusion

This exploratory study has documented the ways in which a design-based wilderness education curriculum encourages design thinking, the development of an engineering science worldview and leadership ability. We have found that design activities in and for a wilderness environment encourage an appreciation for simplicity, flexibility, high-fidelity testing, and understanding resource constraints. These design practices also appear to mirror those found to be effective in the engineering design literature. The wilderness environment

provides a unique context through which to encourage students to examine the world around them through a scientific lens. While on expedition students work together in small teams and self-reported growth in both personal and group leadership traits.

This thesis focuses on the engineering related learning objectives associated with this experience; we have not began to explore the benefits of simply having engineers spend time in the great outdoors. As the exploration into applications of design-based wilderness education continues researchers should take a broader view of the benefits of the wilderness environment.

Design-based wilderness education holds the potential to serve as an exciting novel avenue to encourage design thinking, the development of an engineering science worldview and leadership ability. While further research is necessary, this initial exploration finds that wilderness education is a promising vector for supporting effective design thinking practices and the development of an engineering science worldview.

## **Chapter 7**

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## **Appendix A Curriculum**

## **Appendix A Curriculum**

A.1	Introduction	
A.1.1	Vision .....	87
A.1.2	Program Structure.....	87
A.1.3	Generative Question.....	87
A.1.4	Understanding Goals .....	89
A.1.5	Wilderness Educator Instructor Moves .....	90
A.1.6	Pre-Course Contact.....	90
A.2	Lesson 1 - Wilderness 101	
A.2.1	Objective .....	91
A.2.2	Understanding Goals .....	91
A.2.3	Background Information.....	92
A.2.4	Assessment .....	97
A.2.5	Materials .....	97
A.2.6	Route Plan .....	97
A.3	Lesson 2 – Engineering for a Wilderness Environment	
A.3.1	Objective .....	101
A.3.2	Understanding Goals.....	101
A.3.3	Background Information.....	101
A.3.4	Assessment .....	104
A.3.5	Materials .....	105
A.3.6	Route Plan .....	105
A.4	Lesson 3 - Return of the Fire!	
A.5	Lesson 4 – Bear Hangs	
A.5.1	Objective .....	109
A.5.2	Understanding Goals.....	109
A.5.3	Background Information.....	109
A.5.4	Assessment .....	112
A.5.5	Materials .....	112
A.5.6	Route Plan .....	112
A.6	Expedition Activities	
A.6.1	Shelter Building.....	116

## A.1 Introduction

### A.1.1 Vision

This curriculum is a prototype exploring the thesis that wilderness and adventure education can serve as an effective pedagogical framework for developing the engineering science competencies of adults. This approach is not limited to the traditional learning outcomes associated with wilderness education: leadership, teamwork, communication and self-development. While these skills are receiving increased emphasis in engineering classrooms, our approach to wilderness education reaches past these low hanging fruit. This curriculum aims to create an environment in which students can explore and develop technical engineering science competencies, applying an engineering science lens to the real world to develop competency in unstructured problem solving and the iterative design process.

### A.1.2 Program Structure

There were four 3-hour classroom sessions spread over two weeks. Following the classroom sessions, students were broken into smaller groups (9) and embarked on 3-day backpacking expeditions over subsequent weekends.

The following generative question and understanding goals section were written for an early iteration of the program. As the curriculum was delivered, the focus was much more centered on developing engineering science competency and discussing the technical aspects of the wilderness experience. Some students still created strong connections between their role as engineers and their experiences in the natural environment. Future versions of the program could put more emphasis on these elements.

### A.1.3 Generative Question

*What role can engineers play in how individuals relate to the natural environment, each other, and society as a whole?*

Central to most definitions of engineering is the concept of applying scientific understanding to build artifacts that change our environment for the betterment of individuals within a society. This ongoing iterative process of

engineering science has resulted in highly developed urban centers that are vast expanses of ‘artificial’ space filled with man-made artifacts. These spaces are largely devoid of the natural environment, except for the animals and plants that have successfully adapted to living in our new concrete jungles.<sup>4</sup>

*A wilderness, in contrast with those areas where man and his own works dominate the landscape, is hereby recognized as an area where the earth and its community of life are untrammeled by man, where man himself is a visitor who does not remain.*

*The United States Congress in passing The Wilderness Act of 1964*

Students will prepare for, and travel through, a true wilderness environment. By stripping away much of the infrastructure and technology that has insidiously built up over time, students will be able to better examine their personal relationship with technology and engineering. Students will also be given the opportunity to examine how engineers change the way that individuals and society interact with the natural world and each other.

Through imagining, building and using artifacts of their own design to survive and thrive in the wilderness, students will develop their engineering science competencies, while directly experiencing the individual and social impact that engineering artifacts produce. Students will be encouraged to transfer this learning experience to their ongoing conceptualization of the engineering profession and its role within society.

The activities within the course will be focused around a classic wilderness education objective, a hiking expedition. The following question will serve to provide the overarching framework for the activities throughout the duration of the program.

*You will be embarking on a 3-day backcountry-hiking expedition in the White Mountains of New Hampshire. What knowledge, skills, and equipment do you need to thrive in the wilderness?*

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<sup>4</sup> Much has been written on the subject of the decline of natural spaces, most popularly summarized as Richard Louv’s metaphor of nature-deficit disorder.

#### A.1.4 Understanding Goals

*What role can engineers play in how individuals relate to the natural environment, each other, and society as a whole?*

This curriculum aims to explore the generative question posed above within the context of a wilderness experience. While pursuing this question, students will use their growing understanding of the wilderness to contextualize a conceptual change in their perception of the impact, skills and characteristics required in engineering as a profession. At the same time, students will practice applying the lens of an engineering scientist to real world situations to develop previously hidden insights.

- Students will understand the social and environmental impact of technological artifacts produced by engineers.
  - Students will understand how much technology is still used to comfortably survive, even when visiting a wilderness area.
  - On a very basic level, students will consider the evolution of engineering and technology that allowed society to progress to its current state. This consideration will inform the understanding that society today is represented by a complex world filled with social, environmental, political and economic systems all affected by engineering and technology.
- Students will understand that characteristics such as creativity, communication, leadership, boldness, courage, dynamism, agility, resilience and flexibility are valuable as professional engineers.
  - Students will understand what forms leadership can take, through different contexts throughout the course including risk management, group problem solving and effective group process.
  - Students will understand the necessity to be creative, agile, and flexible when planning and participating in design activities in the natural world.
  - Through the physical and emotional challenge of a wilderness expedition students will understand that displaying boldness, courage, resilience and perseverance can allow students to complete tasks they thought were not within their ability or current skillset.

- Students will understand the insight and clarity that can be obtained by examining everyday situations and experiences through the lens of engineering science.
  - Students will understand how to constrain a situation to define a system, recognize the underlying scientific basis of phenomena, and construct a mental model of the system interactions.

Using the mental model that students have constructed, they will understand how to apply the engineering design process to effectively solve associated problems.

#### A.1.5 Wilderness Educator Instructor Moves

It is assumed that a skilled wilderness educator is delivering this curriculum. Wilderness education relies on effective framing, facilitation and debriefing of activities. While there are many common frameworks and practices, those suggested by NOLS and Outward Bound tend to be regarded as industry standards.

Transference is an important component of any wilderness education expedition. Many readings are publically available, such as “*Briefing for Entry to a Harsher Environment*” by Morgan Hite. Effective models for teaching transfer have been developed and described by David Perkins. These models should be kept in mind, and leveraged, while delivering the course components.

#### A.1.6 Pre-Course Contact

Wilderness Education is a logically challenging activity, with large demands on time and logistics. Many of the lessons described within this lesson plan are fairly resource intensive, and proper preparation is essential.

## A.2 Lesson 1 - Wilderness 101

### A.2.1 Objective

This is the first session of the program, and will serve to set the tone for the remainder of the program.

The most important element to focus on for this lesson is establishing a safe and supportive learning environment for the students. As discussed in the instructor moves for wilderness education, an effective learning environment will require that students feel supported in a small peer-group setting.

Students in GLP have already completed a weeklong intensive leadership development program (Leadershape), removing much of the need for teambuilding, which is reflected in the planned curriculum. Additionally I was a faculty member for Leadershape, removing the need for me to build trust with the participants.

There are two generative questions inherent in the delivery of this lesson and introduction to the overall program. The first (naïve) generative question is focused purely around the wilderness education objective of the program, and will serve to provide the grounding and motivate the students for many of the activities that are throughout the program:

*You will be embarking on a 3-day backcountry-hiking expedition in the White Mountains of New Hampshire. What knowledge, skills, and equipment do you need to thrive in the wilderness?*

The second question is the main thrust of this specific lesson, and is used to help the students practice applying a technical scientific and engineering mindset to everyday phenomena.

*How can an engineering science worldview help us construct understanding of the world around us?*

### A.2.2 Understanding Goals

Students will understand the insight and clarity that can be obtained by examining everyday situations and experiences through the lens of engineering science.

Students will understand how to constrain a situation to define a system, recognize the underlying scientific basis of phenomena, and construct a mental model.

Using the mental model that students have constructed, they will understand how to apply the engineering design process to effectively solve problems.

Students will understand how much technology is still used to comfortably survive, even when visiting a wilderness area.

On a very basic level, students will consider the evolution of engineering and technology that allowed society to progress to its current state. This consideration will inform the understanding that society today is represented by a complex world filled with social, environmental, political and economic systems all affected by engineering and technology.

#### A.2.3 Background Information

To demonstrate the insight available from applying engineering science to everyday activities, students will be guided through a brief review of some thermodynamic properties, given an introduction to materials used in clothing and appropriate approaches to layering, then given the opportunity to synthesize the choice of clothing for layering as a solution to a thermodynamic heat transfer problem.

For a review of the thermodynamic properties:

Sonntag, Richard E and Claus Borgnakke and Gordon J. Van Wylen. (2003). *Fundamentals of Thermodynamics* (6<sup>th</sup> ed.) Hoboken, NJ: John Wiley & Sons, Inc.

Pages 101-102 reviews heat transfer modes and pages 490-493 reviews wet bulb and dry bulb temperatures.

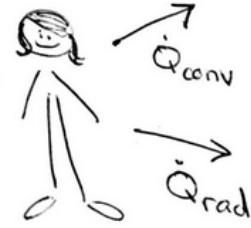
The material looking at layering as a heat transfer problem is derived from:

<http://hyperphysics.phy-astr.gsu.edu/hbase/hph.html>

The worked examples on the following pages can be used as handouts.

A girl is standing naked in a 20°C room. Assuming her average skin temperature is 32°C, how much heat must she produce to maintain her body temperature?

Both radiation and convection carry heat away from the girl's body. Because she is naked, there is no conduction in the system. The thermal resistance due to convection is a function of the convection coefficient, which is assumed to be 10 W/m^2-K for unforced air, as well as the surface area, which is assumed to be 1.5 m^2.



$$R_{conv} = \frac{1}{hA} = \frac{1}{10 * 1.5} = \frac{1}{15} = 0.067 \frac{K}{W}$$

The radiative heat transfer is a little more complicated. It depends on the temperature of both the room and her skin, as well as the emissivity of skin (0.97) and the surface area of her skin.  $\sigma$  is the Stefan-Boltzmann constant, which is  $5.67 * 10^8 \frac{W}{m^2 \cdot K}$ .

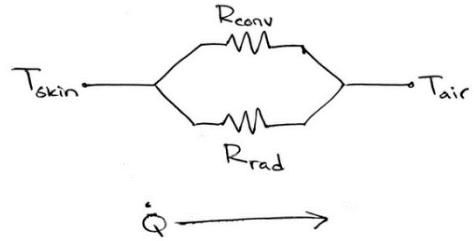
$$T_{avg} = \frac{(T_{skin} + T_{air})}{2} + 273 = \frac{20 + 32}{2} + 273 = 299 K$$

$$R_{rad} = \frac{1}{h_r * A} = \frac{1}{4 * \varepsilon * \sigma * T_{avg}^3 * A} = \frac{1}{4 * 0.97 * 5.67 * 10^{-8} * 299^3 * 1.5} \\ = 0.11 \frac{K}{W}$$

The heat transfer  $\dot{Q}$  is related to the temperature difference between her skin and the air in the following equation:

$$\dot{Q} = \frac{\Delta T}{R}$$

The bigger the thermal resistance is, the smaller  $\dot{Q}$  must be to maintain the temperature difference. Because  $R_{conv} < R_{rad}$ , convection contributes more to the heat loss of the girl than radiation. However, both resistances are on the same order of magnitude, meaning they are both important factors in her heat loss.

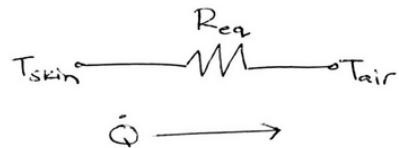


The girl's heat transfer can be modeled like an electrical circuit, where the resistors are the thermal resistance, the voltage drop is the temperature change, and the current is the heat transfer rate.

Because the radiative and convective resistances happen in parallel, the equivalent resistance can be found in the same way it is found in a circuit diagram.

$$R_{eq} = \frac{1}{\frac{1}{R_{conv}} + \frac{1}{R_{rad}}} = \frac{1}{\frac{1}{0.067} + \frac{1}{0.011}} = 0.042 \frac{K}{W}$$

Now the new circuit diagram looks like this:



The heat transfer can be solved for using the temperature change between the skin and air and the equivalent resistance.

$$\dot{Q} = \frac{\Delta T}{R_{eq}} = \frac{12}{0.042} = 290 W$$

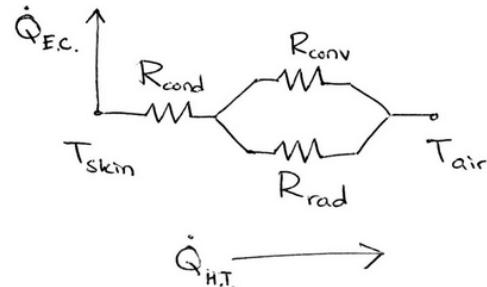
The girl's heat output must be 290 Watts in order to stay warm!

Now there's a boy in the same room, but he's wearing a thin cotton shirt and pants. If he's exercising and producing 350 Watts, how much water will he lose through evaporative cooling so he doesn't overheat?



If the boy is producing more heat than necessary to maintain his skin temperature, he will sweat and the remainder of the heat produced is expended through evaporative cooling. First, we'll calculate the amount of heat necessary for him to stay warm, and then, if that number is less than the 350 Watts he's producing, we'll calculate how much he must sweat to maintain his body temperature.

In this case, because the boy is wearing clothes, there is conduction through the fabric as well as convection and radiation outside of the fabric.



The thermal resistance due to conduction is dependent on the material thickness, L, the thermal conductivity of the material, k, and the surface area, A. Assume the thickness of the shirt is 2 mm and its thermal conductivity is  $0.04 \frac{W}{m \cdot K}$ .

$$R_{cond} = \frac{L}{k * A} = \frac{0.002}{0.04 * 1.5} = 0.033 \frac{K}{W}$$

The convective thermal resistance is found the same way as in the previous example:

$$R_{conv} = \frac{1}{hA} = \frac{1}{10 * 1.5} = \frac{1}{15} = 0.067 \frac{K}{W}$$

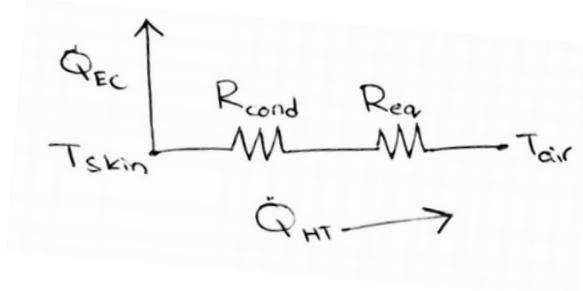
For this scenario, since the radiation occurs on the outside of the clothing, the emissivity for cloth, 0.77, must be used:

$$R_{rad} = \frac{1}{h_r * A} = \frac{1}{4 * \epsilon * \sigma * T_{avg}^3 * A} = \frac{1}{4 * 0.77 * 5.67 * 10^{-8} * 299^3 * 1.5} \\ = 0.14 \frac{K}{W}$$

Since the radiation and convection happen in parallel, their equivalent resistance must be found:

$$R_{eq} = \frac{1}{\frac{1}{R_{conv}} + \frac{1}{R_{rad}}} = \frac{1}{\frac{1}{0.067} + \frac{1}{0.014}} = 0.045 \frac{K}{W}$$

Now the conductive resistance and the equivalent resistance are in series, and adding them together results in the total resistance.



$$R_{tot} = R_{cond} + R_{eq} = 0.033 + 0.045 = 0.078 \frac{K}{W}$$

The heat transfer,  $\dot{Q}$ , can be solved for with the following equation:

$$\dot{Q} = \frac{\Delta T}{R_{tot}} = \frac{12}{0.078} = 150 W$$

Since the boy outputs 350 W and 150 W are needed to maintain the temperature differential between skin and air, he produces an excess 200 W. This excess energy is expended through evaporative cooling: the boy sweats and the energy taken to evaporate the sweat comes from this excess heat generation. You can find the amount of sweat that must be produced to correspond to 200 W. The heat of vaporization of water is 533 cal/gram, so after converting units, the power the boy outputs can be converted to the amount of water (sweat) he produces.

$$200 \frac{J}{s} * 3600 \frac{s}{hr} * 24 \frac{hrs}{day} * \frac{1 cal}{4.186 J} * \frac{1 gram}{533 cal} * \frac{1 mL}{1 gram} = 7660 \frac{mL}{day}$$

If the boy is exercising for 2 hours, he produces  $7660 \frac{mL}{day} * \frac{1 day}{24 hrs} * 2 hrs = 638 mL$  of sweat. Stay hydrated!

#### A.2.4 Assessment

Students will be guided through small group discussions, and volunteer explanations to phenomena that are not fully explained.

#### A.2.5 Materials

- Poster paper and markers
- Examples of clothing layers and sleeping systems

#### A.2.6 Route Plan

##### Introduction & Course Overview (10 minutes)

A short introduction to yourself as the instructor, the course overview and progression, expectations, and overall provocation of the 3-day wilderness expedition to encourage student motivation.

Your credentials and ability to lead students safely through the entire course progression should be emphasized from the perspective of students feeling supported and safe. Students should be excited about the challenge and feel that it is a lot, but also that it is possible and they will have good guidance!

##### Heat Transfer (20 – 30 minutes)

Give students a chance to calm down, find their seats and settle.

Explain to the students that you want them to put their engineering science hats on now (*it may help to have an actual hat*). The first engineering concept we want to start thinking about is heat transfer. This will be a mini-lecture reviewing / introducing the basic concepts of heat transfer from a thermodynamics perspective.

What are the mechanisms of heat transfer? (convection, conduction, radiation)

Let's do some thought experiments!

Does an insulated ice cube melt slower or faster?

What reading will a dry bulb have? What about a wet bulb?

Layering Presentation (20-30 minutes)

This lecture will serve as an introduction to the concept of using layers to stay comfortable in the backcountry.

Explanation of the properties of different materials (cotton, synthetic fibers, down, gore-tex)

Explanation of the ways in which you would want to layer for different climates.

Warm. Cold. Rain. Winter. Summer. Bugs.

Things like hats, cold feet, staying warm at night etc.

### **Synthesizing Layering as Heat Transfer Management! (30 minutes)**

*Materials: Flip Chart Paper, Markers*

Break the students into groups of 6-10. Have them work on a poster for the class explaining the process of layering as the thermodynamic heat transfer problem that it is. Knowing the properties of various materials, and the type of thermoregulation that is used by the human body, a scientific explanation of layering systems is quite possible from ‘first principles’. To encourage a diversity of ideas and discussion each group could be assigned a different circumstance in which they have to describe the thermodynamic heat transfer problem and their ideal solution.

High physical activity in the winter? Sitting in camp in the winter? High physical activity in warm rain? How effective are the fabrics? Can you be warm and wet? What might you want to test first before relying on the real world? What assumptions are you making?

After giving the groups time to prepare their posters, have volunteers present their discussion and conclusions to the group.

This activity is encouraging students to apply an engineering science mindset to a real world problem to be able to better understand the why and how behind behavior that can often become rule rather than judgment based. Being able to apply this engineering science mindset in novel situations will be a reoccurring theme throughout the course, and develop within students the

ability to examine a situation, define a problem, and apply scientific and technical principles to solve it in a thoughtful manner.

### **Hopes, Fears and Burning Questions** (20 minutes)

This activity will give you a good indication as to where the students currently are, and help get lots of easy questions out of the way quickly. It is also a safe way to start to build emotional safety within the cohort, as students are able to anonymously share personal feelings.

Have each group member write down any hopes, fears or burning questions they have on separate post it notes. These can be collected anonymously or placed on a table or wall where everyone can see them. You can go through the hopes and fears - addressing any fears that may emerge - or by having students read a fear and then brainstorm ways to deal with this fear. The same can be done for hopes in order to brainstorm how others in the group can help this hope be accomplished.

If it works with the framing you have provided, you can use a break to organize the post-its into themes and common questions and then once students return from the break you can go through the themes of hopes, fears and questions that have emerged. This can both simplify the debrief process with this activity, and show students that many others are feeling and thinking similar things – they are not alone.

### **Introduction to Navigation** (20 minutes)

Ask the students: How did you (and others) navigate yourself to this room?

This activity encourages students to start to consider the level of invisible technological sophistication that pervades our world today. As we begin to spend more time removing technology from our environment it will be important to understand the amount of technology we are still relying on.

A quick introduction to the map and compass:

- Cover the development of maps.
- Navigational aids such as the compass, stars, sun, sextant, gps.
- A short introduction to map and compass navigation.

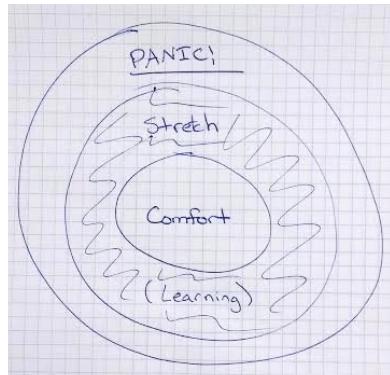
### **Break** (10 minutes)

*Have students meet outside for the next activity*

### **Comfort Circles (5 minutes)**

*(Amir Erez / Judith Robertson)*

This activity returns the focus to creating an effective learning environment for the course. Giving students a language with which to discuss emotional challenges they may be facing.



Begin by drawing a series of concentric circles. The inner circle is the comfort zone, the next circle out is the stretch (or learning) zone, the furthest circle out is the panic zone. The comfort zone is the place where we feel both emotionally and physically safe, the learning zone is where we can grow as individuals because we are willing to take a calculated risks and experience discomfort and learning. The panic zone is the zone where we feel it is no longer safe to venture either emotionally, or physically, because the perceived risk is too great and the fight or flight response takes over and overwhelms the rational conscious mind.

Everyone will have different boundaries to these zones. It can be a helpful activity to have students stand in a circle, then run through a series of scenarios (giving a presentation to 1000 people, rock climbing, skydiving, cooking thanksgiving dinner, being alone in the forest, etc.) and have students take a step forward if that is comfortable for them, or take a step back if that would put them in the panic zone.

## **A.3 Lesson 2 – Engineering for a Wilderness Environment**

### **A.3.1 Objective**

What does it mean to engineer **for** a wilderness environment?

This lesson guides students through a project-based learning activity to understand the engineering design principles that are critical for artifacts that are designed to be used in a remote wilderness setting.

The stoves made and tested in this lesson will follow the students into the wilderness section of the course. When students are using the stoves in a wilderness environment, they will be able to interact with them as users of engineering technology, rather than designers. At that time we will consider the relationships that people form with the technology they use, and the importance of considering this in the design.

### **A.3.2 Understanding Goals**

Students will understand the insight and clarity that can be obtained by examining everyday situations and experiences through the lens of engineering science.

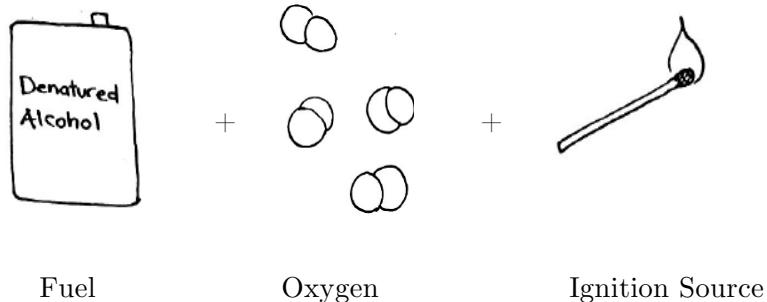
Students will understand how to constrain a situation to define a system, recognize the underlying scientific basis of phenomena, and construct a mental model of the system interactions.

Using the mental model that students have constructed, they will understand how to apply the engineering design process to effectively solve associated problems.

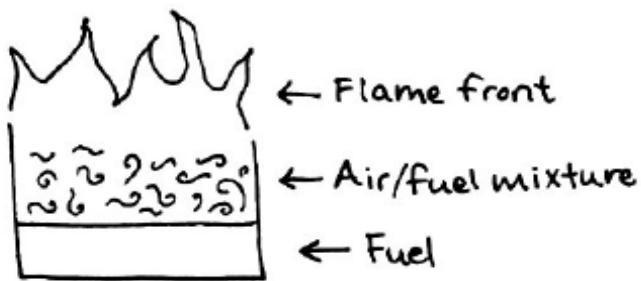
### **A.3.3 Background Information**

For an excellent introduction to everything regarding single burner alcohol stoves including multiple design possibilities reference <http://zenstoves.net/>

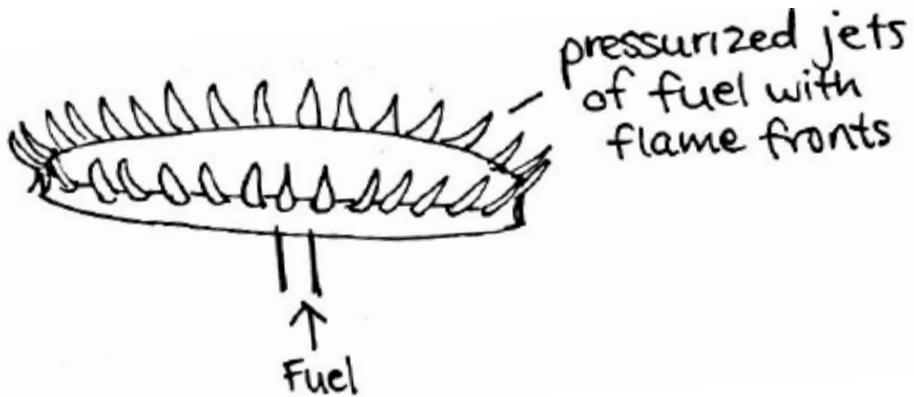
To start a fire, you need:



At room temperature, the vapor pressure of denatured alcohol is high enough to start and sustain a flame front with an ignition source.



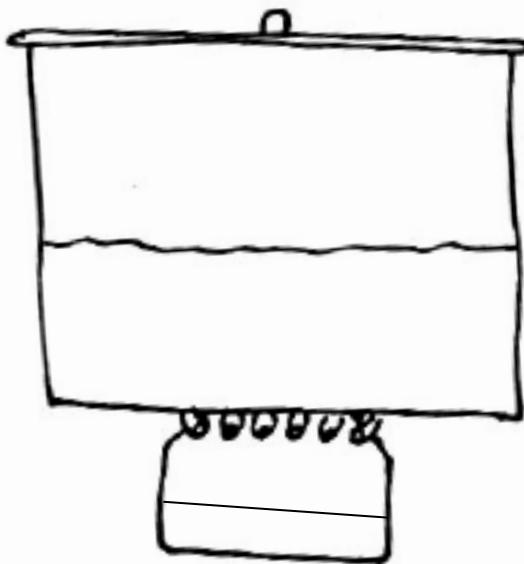
At 60°C, the vapor pressure is approximately atmospheric pressure. We can take advantage of this to create a pressurized stove, just like a gas stove at home.



For many soda can stoves, the first step is priming. While the stove warms up, the flame front will maintain itself in the large opening.



After the fuel has warmed up to at least  $60^{\circ}\text{C}$ , the vapor pressure of the fuel is greater than 1 atm so it will force itself out of the small holes in your stove if the big hole is covered. This makes the jets pressurize, just like your stove at home!



This general principle allows you to build pressurized stoves, and you can change many characteristics.



Big hOles



Small hOles



stoves with  
external priming



weird stores

#### **A.3.4 Assessment**

Students will demonstrate their understanding by creating an artifact and articulating how their design choices meet the both the goals of embodying the general properties of artifacts for natural environments and the specific scientific properties of alcohol based stoves.

#### **A.3.5 Materials**

- A variety of aluminum cans and tins of various shapes and sizes.
- Tools to cut, punch, and drill holes.
- Denatured Alcohol
- Lighters
- Fire Extinguisher
- Cookie trays to contain any spills of burning alcohol.
- Pots
- Pot grips
- Food for cooking
- Flip Chart Paper, Markers

#### **A.3.6 Route Plan**

In this lesson students will be continuing to apply an engineering science mindset to problems encountered in a wilderness environment. The design characteristics that students are able to develop and apply in this lesson will reflect, in a more technical sense, the considerations for equipment that an expert would have when applying the lens of an experienced backpacker. Students should be made aware of the understanding in an unfamiliar area (backcountry cooking and backpacking equipment design) that they are able to gain from the application of the engineering science mindset.

#### **Introduction (5 minutes)**

In this lesson students will apply their engineering science perspective to the design and construction of artifacts for use in a wilderness environment. This will be accomplished by prototyping a potential solution to one of the challenges that they will face while camping: cooking delicious and nutritious meals. By the end of the class students will be expected to construct an alcohol

based stove on which they will cook their lunch. A meal such as pasta and pasta sauce will be provided for the students to make.

### **Project Definition (10 minutes)**

Now that students are aware of the challenge posed to them for the class, it is necessary to further define and constrain the problem space to ensure that the task is appropriate for the timeframe and understanding goals.

A short presentation introduces students to different techniques for cooking in the wilderness (campfire vs. stove system), and reminds them of the importance of unpurified water reaching a boil when cooking. Explain some of the advantages of using a camp-stove, such as safety, convenience, efficiency, and land use regulations. Given these considerations, the focus of this lesson will be on stove systems.

By examining a variety of commercial and homemade camp stoves students will identify the characteristics that could be said to be generally present in artifacts for a wilderness environment, and the scientific principles underlying the design choices present in stoves specifically. Demonstrating this understanding, students will construct their own alcohol-based stoves on which to cook their meals.

### **Property Identification (20 minutes)**

*Materials: Flip Chart Paper, Markers*

Students will be provided with an assortment of stoves to examine including a Coleman stove, gas canister stove, pressurized burner stove, and a variety of single burner alcohol stoves. In small groups (6) students will be developing two lists of properties that can be identified from the stoves - general properties, and properties that exist to make the stoves work efficiently for their purpose of cooking.

General properties would include simplicity, reliability, field maintainability and reparability, durability and safety.

Properties of stoves would include fuel storage, oxygen flow, pressurization and stability.

### **Group Discussion (15 minutes)**

A facilitated discussion within the class will serve to combine the perspectives of the individual groups into a list of the general principles guiding artifacts for the wilderness as observed through the stoves, and a list of the scientific principles guiding design elements specific to a stoves operation.

### **Single Burner Alcohol Stove Construction (110 minutes)**

In small groups (2-3 students) students will design and construct a stove on which to cook their lunch, using the general engineering science principles previously identified. Students will be expected to justify their design choices and consider if their design is really appropriate for use in a natural environment.

Students should be encouraged to assess the success of their prototypes, and learn from their peer's experimentation as well. A metric such as how long it takes to bring 1L of water to a boil could be introduced as an effective method for comparing efficacy.

### **Debrief (15 minutes)**

While sitting in a circle eating a delicious lunch (*or something approaching that state...*) have students reflect on their experience. Given the large number of students in the program (36) it could be most beneficial to allow the students to break into smaller group discussions then have each group provide some headlines from their discussion.

Questions you could pose include:

- What do you need to consider when designing for a wilderness environment?
- How do those characteristics you've identified evoke responses by the users?
- What if you were using an artifact with the opposite characteristics in the wilderness? What would your relationship with it look like then?
- How do your design choices affect how you interacted with your stove?
- How would you do things differently?

- What would happen if you had to use only that stove to eat for three days?

What did you learn about backpacking today? How can you apply these lessons to other challenges you may face?

#### **A.4 Lesson 3 - Return of the Fire!**

The next class session was a continuation of the previous session on stove making. In the beginning of the class I gave a review on combustion, and discussed some problems that students ran into in the previous session.

## **A.5 Lesson 4 – Bear Hangs**

*(Mechanical Advantage, Friction Reduction, and Progress Capture)*

### **A.5.1 Objective**

What does it mean to engineer **in** a wilderness environment? How does this differ from engineering **for** a wilderness environment? How is it similar?

In Lesson 2, students participated in a project-based learning activity to understand the engineering design principles that are critical for artifacts that are built to be used in a remote wilderness setting. This lesson will ask students to instead begin to consider how to design something that you will be later building in a wilderness setting.

The characteristics of creativity, communication, agility, resilience and flexibility will become more apparent when working under these conditions.

### **A.5.2 Understanding Goals**

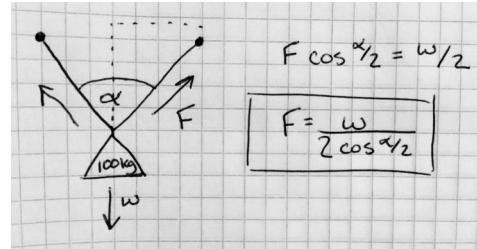
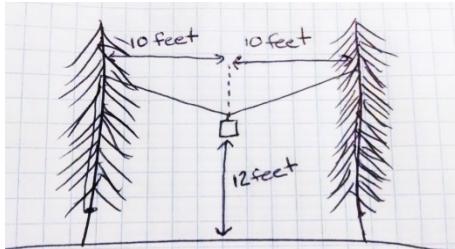
Students will understand the necessity to be creative, agile, and flexible when planning and participating in design activities in the natural world.

Students will understand the insight and clarity that can be obtained by examining everyday situations and experiences through the lens of engineering science.

Students will understand how to constrain a situation to define a system, recognize the underlying scientific basis of phenomena, and construct a mental model of the system interactions.

Using the mental model that students have constructed, they will understand how to apply the engineering design process to effectively solve associated problems.

### **A.5.3 Background Information**



The project for this lesson is to design a hauling system to haul 100lbs (or a suitably challenging weight) of “food” into a “tree” before the end of this session. In terrain with active bear populations (and other smaller critters who like human food) it is common practice to suspend food between two trees so that it is inaccessible to any curious creatures.

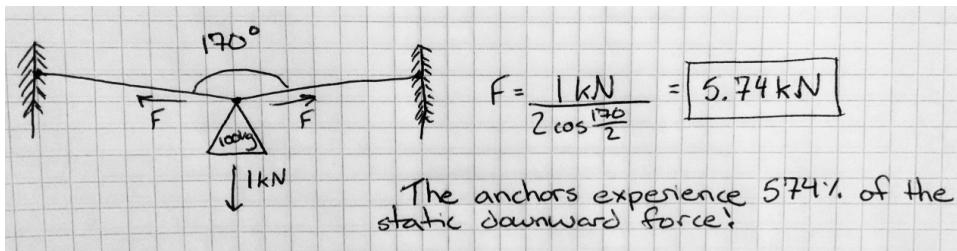
A well-designed bear hang places the food between 2 trees, approximately 10 feet from each, with the bottom of the container holding the food (likely a pack) at least 12 feet off of the ground. Just as in the wilderness, it is unlikely that you will have a classroom space available that supports this exact setup. A high ceiled area with exposed load bearing beams may serve as an appropriate substitute.

When hauling large amounts of food, such as in the case of a multi-day large group trip – pulley systems benefiting from mechanical advantage are often used to make the task more manageable. The task today will be for students to examine the forces present in such a system, develop a pulley system that will provide mechanical advantage, and determine what diameter of rope is required to have sufficient safety built into the system.

### Forces

The situation depicted in the diagram to the right is a general form that is common to many applications that one may come across. A downward force attached to, and being supported by, two anchors. The internal angle between the supports determines how much force each anchor experiences.

If we consider the case of the bear hang described above we will find that tensioning the rope tightly between the trees to minimize the droop in the system will require a very large amount of force and place a lot of strain on the anchors (trees).



It may not (really, it's quite unlikely to) be possible to apply enough force to the system to increase the internal angle to 170 degrees. A smaller internal angle, while requiring substantially less force, will also require higher placement of the anchors on the trees to ensure that there is still 12 feet from the ground to the foot accounting for the droop that will be present in the system. This discussion does not consider the stretch that the rope will experience under tension as explored in the previous session.

*Play around with calculating the force distribution of various internal angles to understand how the forces vary. At an internal angle of 90 degrees each strand only supports 71% of the downward force.*

### Mechanical Advantage

Using pulleys (or just carabiners resulting in higher system friction), students can construct systems that provide mechanical advantage. Most students have come across simple 3:1 mechanical advantage systems in physics textbooks. These systems typically assume perfect frictionless pulleys. *What does the output look like when friction is present in the system? If you only have one efficient pulley, where should you place it?*

There are many ways hauling systems with mechanical advantage can be constructed, and while common systems are typically 3:1 or 5:1 any ratio can be achieved with the proper design.

Rope Rescue Books are great resources for this lesson:

Frank, James A (Ed.). (2010) *CMC Rope Rescue Manual* (4<sup>th</sup> ed.) Santa Barbara, CA: CMC Rescue, Inc.

Tyson, Andy and Amy Loomis. (2007) *Climbing Self Rescue: Improvising Solutions for Serious Situations*. Seattle, WA: The Mountaineers Books.

Smith and Padgett's *On Rope* also has a brief but insightful section on pulley systems.

*When working with high mechanical advantage it is very important to keep in mind the breaking strength of individual components. The rule of thumb is that one person can exert about 50lbs of pulling force.*

#### A.5.4 Assessment

Before the end of the session students will be able to calculate the forces present and determine the mechanical advantage of a hauling system. They will find that friction is a significant force to overcome when not discussing ideal pulleys.

Students will explain their design choices and critique both the benefits and drawbacks of their specific hauling system implementation(s).

#### A.5.5 Materials

- Lengths of static line (2-5 of various lengths / group)
- Carabiners (5-6 / group)
- Pulleys (1-2 / group) (*A carabineer can be used as a high-friction ‘pulley’. Real pulleys are expensive.*)
- An anchor system / way to set up an anchor / group
- A backpack and heavy stuff to put in it approximating ‘food’.

#### A.5.6 Route Plan

##### Recap of Lab Session (15 minutes)

Have students briefly discuss their findings from the previous session. Some sort of collaborative document should exist that allows all students to share an understanding of the important properties of rope that were discovered and confirmed in the previous session. Be sure to fill in any information that was not touched upon that you feel will be important for todays lesson.

##### Introduction (5 minutes)

It may be helpful to have a few sample hauling systems set up, or you may want to give students the freedom to experiment and figure out how to build the systems themselves without pre-loading towards specific systems. Bear

hangs require a specific sort of setup given that the anchor is out of reach, up high, and you are pulling from the ground. You can give less helpful examples by constructing systems that will not directly translate to application as a bear hang, but still provide examples of force multiplication.

Students should be introduced to the concept of bear hangs and their use in wilderness environments.

### **Vector Forces** (10 minutes)

Refresh students understanding of vector forces, and provide some examples of systems and the forces preset in the system. Using the background information provided, consider the forces present in a bear hang, and develop why ‘system droop’ is such a problem.

### **Problem Solving and Implementation** (~120 minutes)

Students get to play around with designing various hauling systems. An on-paper design should be done, calculating the forces in the system and predictions made regarding ease of use, before systems are implemented in actuality.

Students will find that overly complex systems will quickly introduce a lot of friction into the system, reducing the mechanical advantage. If students are taking an overly formulaic approach to this task, encourage them to really consider different ways of approaching the problem, and perhaps introduce them to a few non-obvious systems that you have ready to go in your back pocket.

### **Debrief** (30 minutes)

Each group can present their final implementation and a discussion of pro’s and con’s – including how effective they think their solution will be in a wilderness environment.

Questions that may be helpful to consider include:

- What forces are on the anchor, what forces exist in the system?
- What surprised you about hauling systems?
- What would be different if you had to build this in a forest?

- What materials would you want to carry if you were backpacking considering both weight and how easy the system is to build and operate?

For a future problem it will be really helpful for students to know how to capture progress using a munter hitch and how to tie off the munter. It would be a good idea to go around and teach this technique to students as they are experimenting with various configurations of hauling systems.

Students will be really frustrated when trying to set up these systems in the wild. It is very rare that you can find trees that cooperate with position and branch selection, compromises often (always) have to be made and even a task as simple as hanging a rope over a branch quickly becomes quite complex (and requires a good throwing arm).

## **A.6 Expedition Activities**

All of the previous lessons are designed to build capacity that can be taken advantage of while on a wilderness expedition, the meat and potatoes of wilderness education. Many of the progressions continue into activities while on trail. The following is a sampling of some of the important activities that will take place.

Effective framing, facilitation, and debriefing will be essential for the following activities.

### **A.6.1 Shelter Building**

#### **Objective**

We will not be bringing tents on the expedition. Instead students will be responsible for setting up shelters using tarps and string.

#### **Understanding Goals**

Students will understand the emotional aspect that interactions with technology can evoke.

Students will understand the necessity to be creative, agile, and flexible when planning and participating in design activities in the natural world.

Through the physical and emotional challenge of a wilderness expedition students will understand that displaying boldness, courage, resilience and perseverance can allow students to complete tasks they thought were not within their ability or current skillset.

#### **Assessment**

Direct and from nature. If lucky, some rain will test out the effectiveness of the tarp systems. Coaching and peer-feedback can be given through students giving ‘tours’ of their homes. Coaching can be provided to students who need more direct, but more gentle feedback than nature would provide.

#### **Materials**

- Many pieces of plastic tarp (construction material)
- Many pieces of string

#### **Route Plan**

Students should be challenged to use their engineering science mindset as they have been doing in the campus-based environment.

Depending on the comfort and skill of the students, framing could be simply giving them a tarp, groundsheet, and 4 pieces of string, before sending them off. A less confident group would benefit from some modeling of one potential tarp setup, introduction of a few helpful knots such as the truckers hitch and taunt-line hitch, and demonstration of how to use a hiking pole or stick as an effective support.

Concepts that the students should be bringing into this activity include thinking about heat transfer - a smaller tarp shelter will be able to capture body heat and prevent heat loss to convection. Students should also think about where rain may pool or be captured in the case of inclement weather, and how wind may affect their design. They will have to be creative to make the natural area and distribution of trees serve their needs.

### **A.6.2 Cooking with Stoves**

Students will be cooking meals with the single burner alcohol stoves that they have constructed.

#### **Understating Goals**

Students will understand the social and environmental impact of technological artifacts produced by engineers.

Students will understand the emotional aspect that interactions with technology can evoke.

Students will understand the necessity to be creative, agile, and flexible when planning and participating in design activities in the natural world.

#### **Assessment**

Direct from the environment and their stomachs.

#### **Materials**

Stoves

#### **Route Plan**

Students will be cooking meals on the stoves that they have constructed themselves. It is likely that they missed some considerations like uneven ground, wind, working on the ground instead of a table, etc.

This will be a great activity to debrief and dig into how the use of engineering technology affects people, especially if they are not working well.

### **A.6.3 Constructing Bear Hang**

#### **Objective**

Students will be constructing the bear hangs that they designed and prototyped on campus in a natural environment.

#### **Understanding Goals**

Students will understand the necessity to be creative, agile, and flexible when planning and participating in design activities in the natural world.

Students will understand the emotional aspect that interactions with technology can evoke.

Students will understand what forms leadership can take, through different contexts throughout the course including risk management, group problem solving and effective group process.

#### **Assessment**

Effectively hanging the groups food at the end of the evening. Self-assessment of teamwork and group process used to achieve the task.

#### **Materials**

- Rope
- Carabineers
- Pulleys

The group should have thought about exactly what material they would want available to construct the bear hangs ahead of time and have packed it.

#### **Route Plan**

Students will likely find the construction of a bear-hang in a natural environment particularly challenging. Trees are never in the right places, and never have branches that are good for holding up food. It is a challenge just to throw the ropes over the branches that you want to use. Clove hitching a rope to a rock or water bottle is an effective way to accomplish this.

This is a good activity to begin to debrief the team process if you haven't started already.

Their preferred complex pulley system may not work – it could also be a good time to discuss the benefits and trade offs of simplicity when approaching problems. Why not just throw 1 rope over a tree and have everyone pull instead of worrying about some silly mechanical advantage system.

#### **A.6.4 Design Challenge**

Students will be challenged to build a rope bridge to cross a bottomless canyon or raging river, to evacuate an instructor with a broken leg. Well, really they will be challenged to span a creek of ankle deep water, or maybe the space between two trees. This is the capstone of the series of lessons related to ropes. Many of the same principles of building the bear hangs will have to be used – but on a horizontal plane rather than vertical.

#### **Understanding Goals**

Students will understand that characteristics such as creativity, communication, leadership, boldness, courage, dynamism, agility, resilience and flexibility are valuable as professional engineers.

Students will understand what forms leadership can take, through different contexts throughout the course including risk management, group problem solving and effective group process.

Students will understand the necessity to be creative, agile, and flexible when planning and participating in design activities in the natural world.

Students will understand the insight and clarity that can be obtained by examining everyday situations and experiences through the lens of engineering science.

Students will understand how to constrain a situation to define a system, recognize the underlying scientific basis of phenomena, and construct a mental model of the system interactions.

Using the mental model that students have constructed, they will understand how to apply the engineering design process to effectively solve associated problems.

#### **Assessment**

As a team successfully cross the river. The activity should be debriefed as the capstone of the course with self-reflection, peer-feedback and instructor feedback.

## **Materials**

- Static line
- Carabineers
- Pulleys
- A few harnesses

## **Route Plan**

The constraints of the materials available will limit the possible solutions quite a bit. Students should be able to figure out how to tension a rope between two trees, and then use the harness to traverse across the rope by hanging from it. The necessary concepts and understanding are all available from previous activities – but not necessarily entirely obvious.

Safety is an important consideration of this activity. Make sure students consider forces in the system, and all design decisions should be approved by an instructor before implementation and loading.

## **Appendix B     Interview Guide**

What is your prior experience with design based education?

- setting? length of time?

What is your previous experience with wilderness education?

- setting? length of time?

Briefly describe what you learned during the DBWE program?

What things during the course surprised you?

What aspects of the experience did you enjoy?

What aspects of the experience did you struggle with?

What could be changed to make a better learning experience?

How did this compare with your previous design experience?

What lessons are you taking away?

Do you think you will change how you approach design in the future?

Would you recommend an experience like this to your peers?

Do you have any other further comments or feedback?

## **Appendix C Leadership Survey Questions**

Participants were asked to respond to the following inventory of questions (on a 4-step likert scale) designed to allow students to self-assess leadership, change and synthesis within the context of engineering education from Ahn et al., 2014:

I actively seek leadership opportunities in and out of the classroom.

I establish goals for a project and explain the best way to accomplish these goals to my team members.

I independently initiate new individual or team projects.

I am a confident person.

I can organize and structure a group to accomplish a common goal.

I am not afraid to take risks when making project-related decisions.

I motivate my team members to accomplish predefined goals.

I facilitate developmental opportunities for my team members during a project.

I clearly visualize a project even when I am given limited information

I effectively delegate projects and authority to other people.

I actively encourage my peers to solve problems.

I easily explain and discuss the fundamental elements of a project with other team members.

I look for opportunities to share my knowledge with my peers.

If I see the need, I take on responsibilities that are not assigned to me.

I identify conflicts in a team project and solve them before they harm the project and the people involved.

I am able to solve problems in nontraditional ways.

I take ownership of a project in which I am involved.

I manage and organize my time efficiently.

I clearly explain technical matters to people who are not familiar with my area of study.

Change is a smooth and easy process for me.

I perceive myself to be technically competent.

I believe that engineering design is affected by issues related to social and business environments.

I am aware of the impact that engineers have on society.

I believe societal issues affect how engineers do their jobs.

I believe that changes in the economy will impact my job.

I anticipate having to learn new skills over the course of my career.

I understand the business implication of product development

I consider my work as helping people to live better lives.

I am aware of competition among companies in my field.

I am primarily aware of cost and revenue when designing a product

I feel responsibility for the success and failure of a project.

I am passionate about achieving my goals.

I pay attention to environmental issues while designing new products.

When making decisions, I take into account opinions of all the people involved in the project.

I listen to my peers' concerns and opinions even if they are different from my own.

I treat my peers with respect and dignity

I can acknowledge when I am wrong and learn from my mistakes.

I gather as much input as I can before making decisions.

I create an environment of trust among my team members.

I do my best to make my team members feel important and get involved in a project.

I work well with people who have backgrounds that are different than my own.

I believe that how engineers do their jobs does not change over time.

My job is to design products only. I am not concerned with business aspects.

I hesitate to make crucial decisions on project-related issues.

I am comfortable with personnel changes on a project.

I define effective leadership primarily by successful completion of a task.