Engineering habits of the mind - an undergraduate course that asks: ”What is it that makes someone an engineer?” and ”What distinguishes engineers from other professionals?”

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Habits of the Engineering Mind:  
A Study Abroad Course at Oxford

Introduction

What is it that makes someone an engineer, and what distinguishes engineers from other professionals? This paper describes a course that encourages students to think about these questions, to wonder if engineers think about the world differently than other people, and to identify these unique ways of thinking. The purpose of this joint-inquiry course was to provide an opportunity for the students and the professor to explore these questions, to identify and learn some common “habits of the mind” of engineers, to enhance their sensitivity to when these habits of the mind can be used as effective tools to think critically about the world, and to practice applying these concepts to the analysis of systems that are not normally encountered or discussed in the context of the engineering classroom. This paper describes several highlights of the course’s design and implementation, including the readings, discussions, activities, and the final term project. Also included are students’ perceptions of the course elements as told by the student co-authors of this paper, and as derived from anonymous end-of-course surveys.

We were inspired to write a paper about this course because it was well-received by the students (three of whom are co-authors of this paper), and because we felt the topic of the course is an important one for young engineers to consider. Furthermore, we believe that, for an engineering course, the way it was created and conducted is unusual. The course required a significant amount of reading, writing, and discussions, and because the course instructor, who had little prior expertise in the philosophical aspects of the course, considered himself a co-learner with the students. We hope that by sharing our experiences with this course, we will make it easier for interested instructors to create their own version of an engineering philosophy course, so that more engineers will become familiar with this important way of thinking about their profession. More generally, we hope that our story will inspire others to consider creating a new course on a topic about which they are passionate but perhaps think they lack sufficient expertise, and to participate in the course as co-learners with their students.

The course was created and taught by an Associate Professor with expertise in biomedical engineering. The sixteen students who enrolled in the course (10 female, 6 male) included 1 freshman, 9 sophomores, 3 juniors, and 3 seniors. There were 12 engineering majors (7 biomedical engineers, 3 industrial and systems engineers, 1 electrical engineer, and 1 aerospace engineer), 2 business administration majors, 1 public policy major and 1 international affairs major. The students’ average GPA was 3.45 +/- 0.35.

The six-week course was one of several offered as part of an 11-week study abroad program. For the first five weeks of the program, the students traveled to different sites and venues throughout Europe, and were enrolled in art and music courses that sought to enrich and synergize with these experiences. When the travel portion of the study-abroad program concluded, the students traveled to Oxford University where they enrolled in this course as part of the six-week residential portion of the travel abroad program. The student co-authors of this
paper believe that the travel portion of their study abroad experience helped prepare them to be more accepting of the unique nature of this course, to be more willing to critically assess their own ways of thinking, and to reconsider their pre-existing stereotypes of how engineers, and non-engineers, think about things.

**Pedagogy**

The pedagogical approach for the course was informed and inspired by Finkel’s book *Teaching With Your Mouth Shut* [1]. As the title suggests, Finkel advocates a student-centered learning environment in which the teacher is largely silent. Finkel calls for instructors to let the readings and students do the talking. The teacher and students engage with the object of learning together, as co-inquirers. When the teacher does speak, it is as a co-learner, so that students come to see themselves as equals with the instructor. In essence, the instructor relinquishes their power over the course, while maintaining their authority (Finkel defines power as “the ability to make things happen”, and authority as “that which justifies or makes legitimate a particular arrangement or set of affairs” (pp. 121)). To teach this way, the instructor must have a deep understanding of what they want their students to experience, and they must carry out a significant amount of planning to help ensure that the learning they want to happen actually happens.

**Course Design**

The first critical task of planning the course was to decide on a set of learning objectives. This required balancing the different purposes of the course. What should the relative emphasis be of challenging the students to learn and practice one or more specific engineering ways of thinking, versus encouraging the students to grapple with, and reflect on, the central philosophical question of whether there are, in fact, engineering ways of thinking, and if so, what are those ways of thinking? Ultimately, the course was designed to pursue both these threads of exploration, separately at first, but later entwined within the students’ final term projects.

The following set of learning objectives were developed to balance the two threads of the course: A year or more after having taken this course, students will (1) have an understanding of the fundamental ways of engineering thinking as evidenced by their ability to estimate unknown quantities, represent complex problems diagrammatically, engage in model-based reasoning, and employ multiple engineering habits of the mind as a set of lenses through which to view and think about real-world problems and systems; (2) be able to critically read, analyze, and discuss what philosophers of engineering have written about engineering ways of thinking, and be able to formulate and defend their own arguments about what they think are engineering ways of thinking; (3) see the value of, and be adept at, seeing opportunities for employing engineering habits of the mind as thinking tools in every day, non-engineering contexts; (4) have established a connection between the engineering habits of the mind that were identified and explored in class to their own personal interests and experiences; and (5) recognize that a person’s ways of thinking are influenced by their profession, culture, upbringing, and context, and that a much richer understanding of a problem or system is developed by employing multiple ways of thinking.
The second critical task in planning the course was determining how to balance and integrate the philosophical readings and discussions about engineering ways of thinking with exercises and activities that developed the students’ abilities to think that way themselves. Since the overall goal of the course was to encourage students to both be able to think philosophically about engineering ways of thinking and to be able to employ these ways of thinking as tools for critical thinking and problem-solving in everyday life, the instructor decided to intersperse the philosophical discussions with sessions that focused on building students’ skills with specific engineering ways of thinking. There were several engineering ways of thinking that could have been emphasized in the course. Ultimately, systems thinking and model-based reasoning were chosen as the focus, as these are two of the most fundamental and powerful engineering ways of thinking that are employed in all domains of engineering

**Designed learning experiences**

Two major kinds of designed learning experiences were employed throughout the course: open-ended seminars and conceptual workshops [1]. The philosophy-of-engineering sessions were carried out as open-ended seminars, using a number of variations of this approach. In the basic approach, students were assigned a set of readings before class. The readings were intended to stimulate student interest in the central question of the course, to introduce them to some of the seminal works that have addressed this question, to expose them to some examples of how research has been conducted to answer this question, and to encourage them to develop and defend their own thinking about this issue. After they finished each reading, the day before the discussion, students posted a set of questions they wanted the group to discuss during the seminar to their blogs, which were available for everyone in the class to read.

Each seminar was facilitated by a group of two or three students who had met the day before to discuss the readings among themselves. During the ninety-minute class session, these students shared the responsibilities of taking notes, summarizing what had been said at different points in the discussion, deciding when to probe a particular set of comments more deeply, and bringing the discussion to a meaningful close. Each seminar began with a call for questions. The students, sitting in chairs that formed an open semi-circle, suggested questions they wanted the group to discuss, which the facilitators wrote on a white board at the front of the room. Once all the questions were posted, the students, led by the student facilitators, decided which question, or set of questions, to discuss during the class. Following the class discussion, students reflected on the discussion in their blogs, and read and commented on each other’s blogs. The blogs became an ongoing discussion of the issues that spilled outside of the classroom and encouraged students to continue expressing their thoughts as they developed. These sites served as a resource for the final reflective paper in which students discussed their current perspective on engineering ways of thinking and how their thinking had changed and matured over the time period of the course.

From the instructor’s perspective, the open-ended seminars were quite successful. The students’ skill in creating questions that led to intellectually rewarding discussions seemed to improve over time. In addition, most students seemed very engaged, most likely because they were given the power to decide how to use the class time. Despite this, the instructor noticed that some students did not participate as fully as others. To encourage these students to participate more fully, the basic format of the open-ended seminar was varied from time to time. For example, when the
Nersessian paper on the use of model-based reasoning by engineers was discussed, the students were organized into groups of three to four students, with one student facilitator in each group [2]. The groups shared their questions with each other, looked for commonalities and significant differences, and then, as a group, developed two independent questions they thought would stimulate a productive class-wide discussion. Each group contributed their two questions, which were posted on the white board, and then, as an entire class, the students decided which questions to focus on for the remainder of the session.

The second type of designed learning experience that was used throughout the course are what Finkel called “conceptual workshops” [1]. In conceptual workshops, the teacher writes a document that serves as a blueprint for the learning experience for that day. The teacher hands the document to the students, who then carry out the workshop. Importantly, the teacher’s writing does not explain or tell; rather, it poses one or more problems and a set of activities to address and explore those problems. In this way, the teacher communicates to the students through his writing, once again teaching with his mouth shut. The teacher’s presence is still required during the workshop, since some supplemental oral communication and consultation is inevitably required. Conceptual workshops were frequently used to teach students systems-thinking and model-based reasoning as a fundamental engineering way of thinking, whereas open-ended seminars were the primary means by which students were encouraged to think philosophically about what those ways of thinking might be.

**Interwoven Strands**

As mentioned above, the instructor sought to create a set of learning experiences that balanced and integrated readings and discussions about engineering ways of thinking with activities that developed the students’ abilities to apply these ways of thinking in the context of systems that are not traditionally thought of as belonging to the domain of engineering. To accomplish this, the course was taught in two strands that were separate at first, but ultimately brought together through the individual and team term projects. The two strands of the course are now described in greater detail.

**Strand 1: What are engineering ways of thinking?**

The purpose of this strand of the course was to challenge the students to answer the question “Are there engineering ways of thinking? If so, what are they?” The concept of what it means to think like an engineer was explored through readings and open-ended seminars that focused on the writings of philosophers of engineering. The selections included a wide range of authors, lengths, and contexts that challenged students to be open-minded. Table 1 lists each reading assignment, the instructor’s motivation for including it, and the average rating of the students (where 1 = poor and 5 = excellent).

Students analyzed and reacted to these readings by pulling from their personal experiences, which in many cases were heavily influenced by their recent exposure to European art and music. By engaging students in open-ended discussions of a wide variety of readings on engineering ways of thinking, students were inspired to build their own personal perspective on the central questions of the course, that could be explained and defended in writing, and that was
### Table 1: Assigned readings for Habits of the Engineering Mind

<table>
<thead>
<tr>
<th>Reading Assignment</th>
<th>Instructor’s Motivation</th>
<th>Students’ Average Rating</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lazebnik (2002) Can a Biologist Fix a Radio? – or, What I Learned while Studying Apoptosis [3]</td>
<td>To hook the students’ interest in the main questions posed by the course. The paper makes the provocative claim that engineers employ a different way of thinking than biologists, and that engineering ways of thinking need to be employed in order to take the science of biology to the next level.</td>
<td>3.1</td>
</tr>
<tr>
<td>Bucciarelli (2003) Engineering Philosophy, Chapters 1 &amp; 2 [4]</td>
<td>To introduce engineering philosophy, and the concept that each of us operate within our own unique “object worlds”. Also, to provide a case study of an engineer (Beth) that uses model-based reasoning to carry out her work, to be analyzed later through the lens of Koen’s “engineering heuristics”.</td>
<td>3.6</td>
</tr>
<tr>
<td>Nersessian (2009) How Do Engineering Scientists Think? Model-Based Simulation in Biomedical Engineering Research Laboratories [2]</td>
<td>To show how cognitive scientists study the ways engineers think and solve problems. Also, to provide a second case study of an engineer at work, to be analyzed later through the lens of Koen’s “engineering heuristics”.</td>
<td>2.7</td>
</tr>
<tr>
<td>Koen (2003) Discussion of the Method, pp. 7-41 [7]</td>
<td>To provide students with Koen’s theoretical framework of engineering as heuristics, which they used to analyze the case studies of engineers at work from their readings of Bucciarelli and Nersessian.</td>
<td>4.2</td>
</tr>
<tr>
<td>Forrester (1970) Systems Analysis as a Tool for Urban Planning [8]</td>
<td>To highlight an example of an early landmark peer-reviewed paper that applies engineering ways of thinking towards the analysis of urban dynamics. Students experimented with a simplified version of this model using insightmaker.com.</td>
<td>3.9</td>
</tr>
<tr>
<td>Ghaffarzadegan, Lyneis, &amp; Richardson (2011) How Small System Dynamics Models Can Help the Public Policy Process [9]</td>
<td>To provide a modern perspective on the effective use of small models, such as Forrester’s urban dynamics model, to solve non-engineering problems.</td>
<td>3.1</td>
</tr>
<tr>
<td>Petroski (1992) Ch. 15: From Slide Rule to Computer: Forgetting How It Used to Be Done [10]</td>
<td>To encourage consideration of the impact computers and advanced engineering software has had on the ways engineers think about complex problems</td>
<td>3.0</td>
</tr>
<tr>
<td>Vincenti (1990) Ch. 7: The Anatomy of Engineering Design Knowledge [11]</td>
<td>To introduce the concept of “design instrumentalities” that describe the ways engineers know how to do things, such as procedures, ways of thinking, and judgment skills.</td>
<td>3.4</td>
</tr>
<tr>
<td>Ferguson (1992), Ch. 6: The Making of an Engineer [12]</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Baillie &amp; Armstrong (2013) Ch. 7: Crossing Knowledge Boundaries and Thresholds: Challenging the Dominant Discourse Within Engineering Education [13]</td>
<td>To stimulate students to think about the state of engineering education today, and how to improve it</td>
<td>4.1</td>
</tr>
</tbody>
</table>
based on their personal experiences, in-class discussions, and the philosophy of engineering literature.

**Student perspective on: engineering ways of thinking**

Each of these works had a clear relationship to the course objectives, yet the students were provided a great deal of freedom to interpret the material in their own way, which contributed to their learning. In other words, unlike typical reading in engineering courses where students uncritically accept the text in order to replicate definitions and procedures, in this course there was no “right” answer or method to be absorbed. Instead, this method combined research and analysis in which students were encouraged to draw conclusions from the works while analyzing their meaning and significance, guided by the course’s overall questions. Adding an additional dimension to the task, the works were quite varied, which helped ensure the students did not become too comfortable with one perspective and lose sight of the challenge at hand. For example, some essays were strongly based on a philosophical framework while others were more descriptive and open to interpretation, provoking an interesting assortment of responses from students. Therefore, the instructor allowed students to inquire about topics they connected with and be creative with their developments, which further promoted the concept of being open-minded. This way the readings served as a tactic for incorporating scholarly studies and non-engineering approaches which were appropriate for the multi-disciplinary course.

The in-class discussions facilitated this learning by providing an informal and loosely structured forum for exploring the engineering themes of the course. Students were able to bring up ideas as they saw fit and comment on others’ points to express their own feelings about a topic being discussed. The conversations started with a basic breakdown of the reading, but flowed with the interests of the class. The instructor would occasionally intervene with prompts or follow-up questions as a means to bring some student comments into relief or to spark dialogue on particularly pertinent topics. Students were frequently encouraged to relate certain points back to their own experience as well as debate their opinions with their peers. Seeking to make connections to personal experiences and being provided the opportunity to debate one’s peers are rare in engineering courses. Such a structure allowed for thorough dissection of a topic that would eventually be connected back into an overall theme, often prompted by the instructor at the end of the period. With the combined reflections and interpretations of the entire group, a detailed yet all-encompassing understanding of the material was possible, providing a means for students to truly develop their own concept of “what it means to be an engineer”.

**Strand 2: How do engineers employ systems-thinking as a way of thinking?**

The purpose of the second strand of the course was to introduce the students to what the course instructor felt was a fundamental way of engineering thinking: model-based reasoning and systems thinking. From early in the course, the students were exposed to the basics of systems thinking by reading book chapters by Donella Meadows [6] which provided an overview of the topic, and by reading peer-reviewed journal papers on systems thinking, including Jay Forrester’s model of Urban Decay [8]. In addition to reading about the fundamental concepts of systems thinking and studying how experts implement it, students also learned a tool for creating systems models called insightmaker.com. Students used insightmaker.com to engage in peer-to-
peer teaching of the basic concepts taught in the Meadows book, and then carried out in-class exercises to begin building and analyzing models of their own. The goal of this part of the course was to help the students acquire a basic vocabulary and skill set to begin to build their own systems model of a non-engineering system that they wanted to learn about in greater depth in their term projects.

**Getting Started: The First Day of Class**

Experienced faculty know that the first day of class sets the tone and expectations for the entire term and that the physical configuration of the classroom can either enhance or hinder one’s pedagogy. Unfortunately, the first day of class was held in a traditional classroom designed for lectures: chairs with desks were bolted to the floor, which slanted at a gentle angle towards the front of the room, where a podium and chalkboard were located. Despite the less-than-optimal physical environment, the instructor stuck to his plan to “teach with his mouth shut”, and began the course by asking the students to write down their thoughts and then elaborate on their ideas in an open forum style discussion, given the following three questions: (1) What is a “habit of the mind” or a “way of thinking?” (2) Do engineers have a unique “way of thinking?” and finally, (3) What are those unique “ways of thinking?” The students answered these questions individually, after which they shared what they wrote with the entire class. See Figure 1 for two representative student responses to these questions.

Some students focused on how habits of the mind were formed, while others explored how they were implemented. Several students listed “creativity” and “critical thinking” as characteristics of engineering ways of thinking. Much of the discussion centered on how a person’s individual “intellectual lenses” can heavily shape how they think about the world, something the students would later learn to refer to as object worlds [4]. It was pointed out that a botanist, an artist, and a carpenter could look at the same tree, but see significantly different aspects of the tree. A botanist might “see” (in their mind’s eye) the cells that compose the tree, an artist the shadows

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**Figure 1:** Two students’ responses to the first day questions

-I like to think of a habit of my mind as how you process information given to you, when you take enough time to think about a problem. When you delved into the problem at a greater level, you change your mind do you are thinking: Do you think about problems? Do you think about problems you can’t solve? Do you change? In general, at the root of the mind is how your mind comes to those two in progress, to recognize information. I like to think of an engineering mindset and the way engineers think in information theoretical ways, which to processing data, get stuck on a particular answer or solution. Engineers seem to work in pairs or in groups, with problems, when their mind is not clear. Any other way, no other way except maybe, mind brought sense, that I feel to be.

- I think of a habit of my mind as how you process information given to you, when you take enough time to think about a problem. When you delved into the problem at a greater level, you change your mind do you are thinking: Do you think about problems? Do you think about problems you can’t solve? Do you change? In general, at the root of the mind is how your mind comes to those two in progress, to recognize information. I like to think of an engineering mindset and the way engineers think in information theoretical ways, which to processing data, get stuck on a particular answer or solution. Engineers seem to work in pairs or in groups, with problems, when their mind is not clear. Any other way, no other way except maybe, mind brought sense, that I feel to be.
The instructor felt that this first day discussion helped to stoke the students’ curiosity about the central questions of the course, and at the same time established that this would be a different kind of engineering course, once that would require a lot of reading, philosophical reasoning and introspection, while the students and the instructor would learn and explore together. Fortunately, after the first day of the course, the instructor was permitted to hold his course in a different classroom, one that did not have an obvious center or focus of attention, and with chairs that were easy to reconfigure from a large semi-circle to facilitate discussions that involved all the students, to smaller circles to facilitate small-group discussions. These physical attributes of the new classroom made it much easier for the instructor to remove himself from the center of the students’ attention and more closely reach his goal of teaching with his mouth shut.

**Example Learning Activities**

After the first day of class, a series of learning activities were carried out to encourage students to deeply explore the central questions of the course. Table 2 provides a concise summary of the course’s learning activities:

**Table 2: Summary of the course schedule for Habits of the Engineering Mind**

*Both the content for the course and the way in which the different strands were integrated can be seen. The full bibliographic references for the readings used are included at the end of this article.*

<table>
<thead>
<tr>
<th>Strand</th>
<th>Topic</th>
<th>Reading</th>
<th>In-class activity</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Week 1</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PHIL</td>
<td>What is a habit of the mind, and are there engineering habits of the mind?</td>
<td>Lazebnik (2002) [3]</td>
<td>Class discussion</td>
</tr>
<tr>
<td>PHIL</td>
<td>Object worlds</td>
<td>Bucciarelli (2003), Ch. 1-2 [4]</td>
<td>Open-ended seminar</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Bucciarelli (1994), Ch. 3 [5]</td>
<td></td>
</tr>
<tr>
<td>SYS</td>
<td>Introduction to systems thinking</td>
<td>Meadows (2008), Ch. 1 [6]</td>
<td>Conceptual workshop – learning to work with insightmaker.com</td>
</tr>
<tr>
<td><strong>Week 2</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SYS</td>
<td>Identifying systems around us</td>
<td></td>
<td>In small groups, students shared systems they had personally observed and recorded in their ideas notebooks</td>
</tr>
<tr>
<td>PHIL</td>
<td>Model-based reasoning</td>
<td>Nersessian (2009) [2]</td>
<td>Modified open-ended seminar. Five student groups formed to post and discuss questions, after which a whole class discussion was held</td>
</tr>
<tr>
<td>PHIL</td>
<td>The engineering method</td>
<td>Koen (2003), pp. 7-41 [7]</td>
<td>Students worked in groups of four to write a “micro-paper” in one hour, applying Koen’s ideas to an analysis of engineers that had been discussed in the readings of Nersessian and Bucciarelli [2, 4, 5]</td>
</tr>
<tr>
<td>SYS</td>
<td>Generic systems</td>
<td>Meadows (2008), Ch. 2 [6]</td>
<td>Students who had committed to developing expertise in one kind of generic system taught other students what they had learned, using insightmaker.com simulations they had created</td>
</tr>
<tr>
<td>Week</td>
<td>Strand</td>
<td>Topic</td>
<td>Reading</td>
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<tr>
<td>3</td>
<td>SYS</td>
<td>Modeling urban dynamics I</td>
<td>Conceptual workshop: students worked with a simplified version of Jay Forrester’s model of urban dynamics [8] to learn more about systems modeling and insightmaker.com</td>
</tr>
<tr>
<td></td>
<td>APP</td>
<td>Modeling urban dynamics II</td>
<td>Students shared their nascent term project ideas with each other, one-on-one</td>
</tr>
<tr>
<td></td>
<td>SYS</td>
<td>Modeling urban dynamics II</td>
<td>Conceptual workshop: generated and tested, via Forrester’s model, policy recommendations for reversing or reducing the rate of urban decay</td>
</tr>
<tr>
<td></td>
<td>APP</td>
<td>Project pitch day</td>
<td>Students created posters (on blotter pad paper) of their pitch for a term project, provided each other with feedback via post-it notes, then formed teams of two around the projects that interested them the most</td>
</tr>
<tr>
<td>4</td>
<td>SYS</td>
<td>Learning to estimate I</td>
<td>Conceptual workshop: students on their own, then in teams of two, estimated quantities of materials in a fictional industrial clothes washing process.</td>
</tr>
<tr>
<td></td>
<td>SYS</td>
<td>Learning to estimate II</td>
<td>Open-ended seminar to discuss Petroski’s concerns about the modern engineer’s over-reliance on the computer and computational software packages</td>
</tr>
<tr>
<td></td>
<td>PHIL</td>
<td>Engineering ways of thinking</td>
<td>Students also read a transcript of how an expert carried out the estimation exercise of the day before, and were asked to code the transcript to identify expert strategies for making estimates</td>
</tr>
<tr>
<td></td>
<td>APP</td>
<td>Term projects</td>
<td>Students worked with their term-project teammate to apply engineering habits of the mind to their term project system models</td>
</tr>
<tr>
<td>5</td>
<td>APP</td>
<td>Term projects</td>
<td>Peer feedback: Students, in small groups, provided each other with response-centered reviews [14] of their term projects</td>
</tr>
<tr>
<td></td>
<td>PHIL</td>
<td>Engineering education</td>
<td>Ferguson (1992), pp. 165-180 [12]</td>
</tr>
<tr>
<td></td>
<td>APP</td>
<td>Term projects</td>
<td>Modified open-ended seminar. After an initial open-ended discussion, students were formed into 3 groups and challenged to identify the main issue facing engineering education today, and then to develop a set of recommendations for re-designing engineering curricula</td>
</tr>
<tr>
<td>6</td>
<td>APP</td>
<td>Term projects</td>
<td>Students conducted back-reviews of the anonymous on-line peer reviews they had received on their individual term project reflection papers</td>
</tr>
</tbody>
</table>

PHIL: philosophy of engineering, or engineering ways of thinking strand
SYS: systems thinking and model-based reasoning
APP: term project, in which students were challenged to apply engineering ways of thinking towards the analysis of a “non-engineering” system
To provide a more in-depth understanding of how the course was conducted, we describe below four of the key learning activities of the course, one that focused on reading and applying a philosophy of engineering thinking, two that developed the students’ systems-thinking and model-based reasoning skills, and one that asked the students to integrate what they had learned by working in a team of two to implement systems-thinking to better understand a real-world “non-engineering” system of their choosing (i.e., the term project). At the end of each section, one of the student co-authors of this paper provides their perspective on these learning activities.

A. Applying Koen’s Heuristics to Case Studies of Practicing Engineers

The reading, and subsequent learning activity, that received the highest end-of-course student ratings (see Table 1) was a variation of the open-ended seminar format that centered on the first two chapters of Koen’s book “Discussion of the method” [7]. Koen defines the engineering method as “the strategy for causing the best change in a poorly understood situation within the available resources” (Koen, pp. 7). Koen makes two key assertions. First, he states that all engineering problems have the following four characteristics: 1) a change is needed, 2) any solution to the problem must be consistent with the available resources, 3) it is desired that the best possible solution is enacted, and 4) there is uncertainty in the solution due to an absence of complete information about the problem (Koen, pp. 9-24). Second, he says that engineers solve problems by using heuristics, which he defines as “anything that provides a plausible aid or direction in the solution of a problem but is in the final analysis unjustified, incapable of justification, and potentially fallible” (pp. 28). To illustrate his point, Koen provides several examples of engineering heuristics, including 1) at some point in the project freeze the design, 2) allocate resources as long as the cost of not knowing exceeds the cost of finding out, 3) allocate sufficient resources to the weak link, and 4) solve problems by successive approximations.

Rather than to simply read about and discuss these concepts, students were asked to apply them to the analysis of two case studies of professional engineers that the students encountered in their earlier readings [2, 4, 5]. This challenged the students to understand Koen’s ideas sufficiently well to be able to put them to work to analyze how engineers think about complex real-world problems. Specifically, groups of four students were charged with writing a “micro-paper” in one hour about one of these two engineers’ stories and to address a set of specific questions including “Were these engineers working on an engineering problem as defined by Koen?” and “Did they use the four main engineering heuristics as identified by Koen”, and if not, to explore what it would have looked like if they had applied those heuristics.

The micro-paper assignment required students to apply Koen’s principles to real life examples, which helped them directly evaluate the usefulness of Koen’s way of thinking about the engineering method. While the topic of this mini-project was well matched to the course objectives, it was the way in which students decided to complete it that sparked interest. Upon the start of this assignment, it became clear that the main limitation for the given situation was time. Thus, in order to appropriately accomplish the task the students were required to develop an effective method for deriving ideas and compiling the information. As time expired, the students finished their papers, posted them on the course’s website for others to read and comment on, and then were asked in the final few minutes of the class to reflect how what they
had just done with their group was an engineering problem, and to think about the heuristics they had just used as a group to solve the problem.

Afterward, many students commented on how the constraints of the assignment forced them to make decisions along the way without knowing how this would affect the final results. The most significant need was the ability to complete the task, so strategies were created to help progress towards this goal even if that meant sacrificing in other areas. One student described how her group decided to change their approach in the middle of the exercise: “As I was transforming our notes into fluid paragraphs, we realized we could not keep with that approach... We quickly developed a new method in which we all worked on different portions simultaneously.” Engineering and non-engineering students alike had to adopt new approaches to meet the specifications of the assignment, often relying on engineering heuristics to help them complete their task. Consequently, many students came to see the writing assignment itself as an engineering problem that was solved through the use of engineering heuristics.

Ms. McCormick’s perspective on Koen’s “Discussion of the method” learning activity

When reflecting back on our classwork, I felt the Koen activity was one of the most unique in style and point. First, although we had done quite a bit of writing for the class, we were never given such a sudden, time-restricted assignment, so it seemed nearly impossible initially. However, it was this type of in-the-moment challenge that forced us to apply our reasoning skills in a nontraditional manner in order to approach the situation. I realized that when we were put under such pressure, it encouraged us to utilize skills we were comfortable with and therefore brought our engineering habits into the literature context we’d been discussing. This significance resonated with me, because it was a specific instance where I felt we were able to connect with the material by experience rather than pure discussion. I saw the differences in how my teammates and I responded to the scenario and brought our critical thinking into play when finding a solution. After reviewing the process, it was clear that everyone leaned on engineering heuristics to accomplish the task even though this wasn’t a requirement or even mentioned as a potential tactic. The most intriguing point I found in this was how well our assignment matched Koen’s definition of the engineering method. To me, this showed that any problem can be an engineering problem if you address it in that manner, and using the engineering approach truly makes a difference.

B. Urban Decay System Modeling

After spending the first part of the course focusing on different engineering ways of thinking, the class examined the idea that model-based reasoning and systems-thinking are quintessential engineering ways of thinking. The main topic explored in this part of the course was defining and using systems thinking to model complex systems, and then using the models to find ways to effect desired changes in how these systems behave or in what they produce. To introduce systems-thinking, students read the first two chapters of Donella Meadows’ book Introduction to System’s Thinking [6]. Meadows’ book is written to be accessible to non-engineers, which made it an excellent choice for this multi-disciplinary course. Meadows defines what a system is and is not, describes systems as being composed of stocks, flows, and feedback loops, and illustrates the main concepts with simple to understand diagrams and examples from everyday systems.
Students were also introduced to insightmaker.com, a website that enables users to easily create deterministic models of complex systems without formal training in ordinary differential equations or other higher level mathematics. This allowed students to put Meadows’ principles into action, and to learn how systems behave by experimenting with models and observing how manipulating the system’s parameters and structure affected its behavior. To encourage students to learn how to use the principles described by Meadows, students were broken into groups of four and tasked with taking an example generic system structure from the readings and modeling it using insightmaker.com. Next, new groups were formed with one member from each original group. Students used their models to teach one another about these common generic structures and to demonstrate how they behave. This jigsaw exercise introduced the class to the idea that complex systems are often composed of several simpler generic subsystems, and provided them with an understanding of what they look like, how to model them, and how they behave.

Armed with a basic understanding of systems-thinking and modeling, students participated in a two-day conceptual workshop that challenged them to understand, manipulate, and experiment with a real-world systems model of urban decay that was first described in 1970 by Jay W. Forrester in his landmark paper entitled “Systems Analysis as a Tool for Urban Planning” [8]. Students were provided with a working insightmaker.com version of Forrester’s model and asked to identify the key stocks and flows of the system, and to hypothesize how the system would behave under a variety of circumstances. Students tested their hypotheses by making changes to the system, such as adding and deleting variables, changing the initial values of variables, and changing the rates of flows. By experimenting with Forrester’s model, students discovered some of the key principles of systems behavior, which include the idea that systems often behave in counter-intuitive ways and are therefore hard to predict (without a model), and that systems often contain multiple reinforcing and balancing feedback loops that make their overall behavior resistant to change.

Ms. Haight’s perspective on the urban decay learning activity

Out of all the activities and reading assignments we had throughout the course, Forrester’s Urban Dynamics had the strongest impact on my view of engineering ways of thinking. This exercise was extremely helpful for me because it was the first time we really studied the idea of a feedback loop. His model was of an extremely complicated system, but by breaking it down into smaller pieces it became easier to make sense of. After studying the urban dynamics model, my view on how engineers approached modeling changed drastically. I now saw a more systematic approach on how to model because of the steps Forrester outlined. In Forrester’s paper he focuses on his belief that industrial dynamics are the best way to model and analyze a social system. He defines industrial dynamics as the study of how the feedback loop structure for a system then produces the dynamic behavior for the system over time. This key point was the basis that we used on our final term project. Our project was very heavily based on the ideas of Forrester because we tried to make our model as much of a closed system as possible. We experimented with the dynamic aspects of our model to create many simulations in order to see what the best policy change would be. Upon reflection, we realized we used the system dynamics way of thinking both intentionally and unintentionally. I believe that models and simulations are essential methods used by engineers and the ability to create and interpret insightful models is a habit of the engineering mind.
C. Estimation: Novices and Experts

As pointed out by Koen, a key characteristic of an engineering problem is that any proposed solution will be uncertain due to a lack of complete information [7]. Engineers must learn to solve problems despite the absence of critical information. One way of thinking that engineers use to overcome this lack of critical information is estimation. To learn more about this way of thinking, students were asked to complete a two-day conceptual workshop in which they made estimates, compared each others’ estimates and their approaches for making them, reviewed and coded a transcript of an expert performing the same exercise, and read and debated whether or not estimation is still a valuable skill that today’s engineers need to master.

First, students were asked to estimate quantities in an industrial process for washing and drying clothes. Washing and drying clothes is something all students had experience with as a batch process at a personal level, but not as a continuous process on an industrial scale. Students were asked to estimate the mass of each component (clothes, water, dirt, soap, and air) in a process designed to produce one hundred pounds of dry, clean clothes per hour. After individually generating their estimates, students paired up to share their estimates and the thought processes they used to make them. Later, a whole-class discussion was carried out during which many of the students shared their estimates and thought processes with each other.

Student estimates of the mass of dirt and soap were reasonable and remarkably similar to each other. Interestingly, the estimates of water amounts varied much more widely. Although the students recognized that the mass of the wet clothes would be significantly higher than the mass of the dry clothes, virtually all of the students water estimates were far too low, often more than 10-fold lower than what an actual process would need.

In addition to sharing the values of their estimates, the students also shared the thinking processes by which they made their estimates. Three common approaches for making estimates were identified: sketching (or diagrammatic modeling), anchoring their estimates to things they know from personal experience, and scaling the estimates they made based on their personal experiences to the industrial-sized process. Several students, regardless of their major, began the process by drawing a model or diagram of the process. Many also drew upon their personal experiences, and tried to recall how much the various items weighed when doing laundry at home. Some even attempted to scale the masses they estimated from their personal experience to the larger industrial process. Some students had taken, or were in the process of taking, an engineering course that stressed the use of the principle of mass conservation to solve problems. These students used the approaches learned in that course to help them make estimates that were consistent with the law of mass conservation, by diagramming the process as a series of flows and using equations to solve for the unknown masses. In contrast, a student who was not an engineering major wrote that she “pulled numbers practically out of thin air based on common sense.” Below we provide excerpts from two student blogs, as examples of the wide range of self-reported thought processes students employed to make their estimates.

Student 1: I began this process by modeling the flow of components from one unit in the system to the next. I modeled the system as having four units with the inputs to the
system as clothes and dirt, and the outputs of the system as clothes and hot humid air. The difficult part of this assignment came from having to estimate the weights of each of the individual components throughout the system, such as water and soap. There were a lot of unknowns and so this made solving the system more difficult. My main strategy was to keep the process simple and not over complicate things, so I made some assumptions. I began by drawing out the system in order to organize the overall system. I used conservation principles to help me in making my systems of equations, and I used personal experience and what I thought sounded reasonable for the estimations.

Student 2: This exercise was pretty difficult for me. It was pretty easy setting up the flows into each unit, but the hard part came with the estimation of the numbers for me. I know very little when it comes to things like, “How much water do clothes ‘hold’ when completely wet?” and “How much air does a dryer use?” So I guess the difficult part of it all was the estimation of the numbers of the flows. The way I did it was make it an ideal situation of producing 100 pounds of clean clothes an hour and used numbers for the total amount used in 1 hour. This made it somewhat easier to estimate the amounts for the clothes. However, when it came to estimating other amounts, I had to guess blindly and estimate based on just what I thought good numbers sounded like. I didn’t have any background knowledge of what the actual numbers should be so I am very skeptical of my estimations.

Next, the students were provided with a transcript of how an expert engineer had carried out the same exercise. The transcript was actual data from a research project that had focused on studying how experts and novices make estimates. The purpose of this exercise was two-fold: to provide students with an example of how an expert goes about making estimates so that they could contrast the expert’s approaches with their own, and to expose students to the idea that engineering ways of thinking can be studied through research. Students were introduced to the basics of how to code qualitative research data, asked to code the transcript that night as a homework assignment, and then discussed the results of their work the next day with their classmates.

In addition, students read a book chapter that discussed the importance of estimation to the practice of engineering [10]. The author raised the concern that too much reliance on computers and computational software packages may adversely affect the judgment skills of engineers and increase the likelihood that poor or unsafe design decisions will be made. Most students agreed with the author that estimation was an important skill to develop. At least one student did not agree, however, stating in his blog: “if there is already a standard of what to do and it is proven to work then I don’t think estimation is necessary.” Another student posted the following counter-argument to the first student’s blog posting: “you can look up a lot of things, but if it is worth finding, it won’t be easy. You have to know what you are looking for in order for Google to be useful because there is so much information out there.”

Ms. Haight’s perspective on the estimation learning activity

The main idea that resonated with me during the estimation activity was the importance of experience. During the activity and class discussion, it became overwhelmingly clear that
applying personal experience to the situation was necessary in order to make accurate and reasonable estimations. A follow-up assignment on the estimation activity tasked students with reading through and coding an expert engineer’s thought process on the same laundry machine problem. Similar to my approach and most of the other novice engineers in my class, the expert used her own personal experience with everyday objects and her experience with washing clothes to help her model the system. We also read articles from other authors, for example Petroski, who shared the same belief that experience is vital when solving engineering problems [10]. This idea stayed with me throughout the course, leading me to apply my own personal experience to making educated estimations and assumptions in our final term project.

D. Term Project - Can engineering ways of thinking be applied to non-engineering systems?

One activity was worked on and developed throughout the entire term: the term project. The term project required students to apply what they had learned in class to settings outside of the classroom. Each student had an “Ideas Notebook” that they carried with them in Oxford and throughout their travels in England and Europe. They were charged with finding non-engineering systems of interest and to take notes and make sketches of how they thought these systems worked. The ideas notebooks encouraged students to sketch out their ideas for modeling real-world systems without trying to make them perfect. One purpose of the ideas notebook was to increase the student’s sensitivity to “seeing” the real-world systems that are all around them, and to encourage them to continuously use engineering ways of thinking as a tool for improving their understanding of these systems and how they behave. The knowledge and ideas gained from this portion of the course helped students develop their final term project idea, which required them to model a real-world system and to make recommendations for how to cause the system’s behavior to change in some desired way.

To develop their term-project ideas, students shared their ideas with each other and received peer-to-peer feedback that helped strengthen and develop their thinking. About midway through the course, a project-pitch day was held where students presented their term project ideas via a poster gallery walk. Students read each others posters and used post-it notes to share their comments and provide feedback. Students then formed teams of two around the project ideas they liked the best. Term-project ideas ranged from predicting corruption of policemen, to store-stocking and profit optimization, to the psychology that drives people’s decisions about whether or not to gamble.

The term-project teams worked together for three weeks on their chosen project. The project reports consisted of two main sections: 1) the model, and 2) the written summary of the design. Although the students were required to construct and carry out working simulations of their systems using insightmaker.com, most of the emphasis of the project was placed on getting the students to think about the different engineering ways of thinking they were using to create their models, and the justifications they developed to support their recommendations for how to change the behavior of their system.

To create their models, the students employed many of the engineering “ways of thinking” that were identified and discussed earlier in the course, which included 1) defining the problem, 2)
breaking the problem into smaller, more manageable sub-parts, 3) identifying the major stocks and flows of their systems and how they interact through feedback loops, and 4) drawing on their own personal experiences, and those of experts, to iteratively revise and check the design of their models for the desired outcome.

In addition, students conducted literature reviews to deepen their understanding of the relevant theories regarding their system of interest, and to help them to identify the key factors that must be considered in order to capture their system’s behavior in a model. For example, one team studied young people’s interest in engineering. The idea was based on recent reports that the United States produces too few math and science majors. The model examined the possible factors that have led to the decreased interest in STEM (science, technology, engineering, and math) careers over time. This team had to research the existing statistics and structure of the education system and “desired” careers. As they read the literature on their chosen topic, they had to iteratively evaluate if the material they were reading was relevant and, if so, how to integrate that information into their existing model.

While researching existing literature and theories on many of the projects, the students often found it necessary to simplify their models as the class progressed when they noticed that their more complex, initial models were not useful in building their understanding of the system they were investigating. Instead, they found it more useful to reduce their models to the simplest possible form that could still reasonably capture the behavior of the original, much more complex, real-world system. For example, the team that developed the gambling psychology model initially created a model that was too complicated, and which included stocks and flows that were not well-defined. To improve the model, the team implemented the model in insightmaker.com, and consciously tried to use some of the engineering ways of thinking that had been discussed in the course. Below (see Figure 2) we show the initial and final diagrammatic representations of their model. A comparison of the two models shows that the team became more selective in terms of which variables they included. The team iteratively created at least 10 different versions of their model before finishing their project. Ultimately, the team was able to reduce the number of stocks from 5 to 2 (stocks are the main variables that the model keeps track of over time; they are depicted as rectangles in Figure 2).

To help drive this process of model iteration, students were provided with multiple rounds of feedback that came from discussions with experts, their peers, and from comments on their project blog posts. The student blog posts provide some insight into how they experienced the modeling process. For example, some students commented that in order to create a model of their system, they “made a judgment” and “used their intuition” in order to produce “reasonable” or “expected” results. Students blogged about the process stating that they had a “feel” for the “anticipated results.” Not only did the students realize the importance of first defining the non-engineering problem and its boundaries, but they also used rules-of-thumb and educated guesses to modify and improve their models, which are, arguably, forms engineering ways of thinking.

In summary, the idea behind the design of the term project learning activities was to challenge the students to put into practice some of the engineering ways of thinking they had read about and discussed in the engineering philosophy thread of the course, and to encourage them to explicitly implement these ways of thinking in all phases of their lives and with all types of
problems, not just within the context of the engineering classroom or with traditional engineering problems. The instructor believed that by allowing students to find their own systems to explore, they would be more intrinsically motivated to carry out the assignment at a high level. He also thought that by having students work in teams of two, students would be exposed to students from different majors (sometimes with an engineering major paired with a non-engineering major) and therefore be exposed to a wide range of perspectives and ways of thinking. Finally, the instructor believed that by challenging the students to transfer engineering ways of thinking

**Figure 2:** A comparison of early and late versions of a student team’s model of the psychological processes that drive a person’s decision whether or not to gamble. An early version of the model is on top; the final version of the model is on the bottom.
to a non-engineering context, the students’ understanding of these ways of thinking would be significantly strengthened.

Ms. Borinski’s perspective on the term project

In the team project, I learned the importance of language and object worlds rooted in different disciplines. My partner was a Business Administration major and I am an Engineer, which created opportunities for us to create a more comprehensive model, but also raised the possibility that our process for creating the model would be plagued by communication challenges. With our vastly different object worlds and experiences, we approached the non-engineering problem with different emphases on engineering methods; I had experience with complex engineering problems, allowing me to form my own process. While I preferred to break the problem down and research the individual parts, my partner was interested in the applications and overall model. My partner relied on verbal feedback while I concentrated on literature reviews and the model simulations. The most interesting parts of the modeling project were our interactions and communication hiccups. Terms and feedback relationships that were intuitive to an engineer were foreign to a Business major, and vice versa. In the context of modeling a non-engineering system, we were able to articulate the essential aspects of our own specialties without diving into extraneous technical detail. As a team, we drew from different experiences and produced a model that drew from both disciplines after merging our different perspectives.

Student feedback on the course

Feedback from the students regarding their experience in the course was obtained via two anonymous end-of-course surveys: the standard online end-of-course survey given at the end of all university courses, and a written survey that the students complete on the last day of the course. Twelve of the sixteen students complete the online survey and all sixteen students completed the written survey. The quantitative data from these surveys are summarized in Table 1 (the ratings of the readings), and in the Table 3:

Table 3. University end-of-course survey results
Means of student responses to the eight Likert-scale questions asked in the online survey (1 = very poor; 5 = exceptional)

<table>
<thead>
<tr>
<th>Question</th>
<th>Mean response</th>
</tr>
</thead>
<tbody>
<tr>
<td>Instructor’s clarity in discussing or presenting the course material</td>
<td>4.417</td>
</tr>
<tr>
<td>The instructor clearly communicated what it would take to succeed in this course</td>
<td>3.917</td>
</tr>
<tr>
<td>Instructor’s respect and concern for students</td>
<td>4.583</td>
</tr>
<tr>
<td>Instructor’s level of enthusiasm about teaching the course</td>
<td>4.750</td>
</tr>
<tr>
<td>Instructor’s ability to stimulate my interest in the subject matter</td>
<td>4.083</td>
</tr>
<tr>
<td>Instructor’s availability for consultation</td>
<td>4.200</td>
</tr>
<tr>
<td>Helpfulness of feedback on assignments</td>
<td>4.083</td>
</tr>
<tr>
<td>Considering everything, the instructor was an effective teacher</td>
<td>4.667</td>
</tr>
</tbody>
</table>

The following themes emerged from the surveys’ qualitative data. Fourteen of the sixteen students (87.5%) responded positively to the question “Was the topic of the course interesting, and is it worthy of a full semester course?” One student wrote “I am not an engineering major, so at first I thought it wasn’t helpful at all. But after learning about the different methods that
engineers use to think: estimation, using models, heuristics, etc., I realized it can be applied to many aspects of life, not just in an engineering setting.” Another student wrote “I think it’s important for engineers to take time to think about their ways of thinking and process of solving problems because it can help them improve their process [of thinking]”. The two students who responded negatively to this question were concerned that there was not enough material to discuss for a full semester course.

When asked what was the most valuable thing they took away from the course, three major themes emerged. Six students said the most valuable thing they took away from the course was an appreciation and understanding of systems-thinking and modeling. Said one student “I had no idea [systems models] existed before the class, but it is a very powerful and efficient tool”. Another six students said that the most valuable thing they took from the course was a broader understanding of what it means to be an engineer, and another claimed to have “picked up new problem solving techniques of my own”. In a related point, another student wrote that they came away with a “heightened awareness that people think differently – and how that should influence the way that you communicate”. Two students wrote that the course helped them develop their scientific reading and writing skills, including an improved ability to “draw key points and questions” from their readings, “a skill we do not practice often in science and math based courses”.

Finally, when students were asked what could be done to improve the learning experience in the course, two major themes emerged. One common theme was that the students wished they had more time to master systems-modeling. Some students suggested assigning the modeling exercises earlier in the course, while others suggested having the students study and practice with more example models before engaging them in the term project. A second common theme was a call for more structure. Some students felt that the initial reading assignments “were a little too loosely formatted”, some wanted “a little more structure with the connection between the readings and the discussions”, and others called for topics to be “specified to discuss”. In one particularly revealing comment, a student said “Before the reading, maybe you could give us a little more information on it. Some of it was a little difficult to know what main points or details you wanted us to take from it. It was difficult for me to frame questions that I thought you would like”. These sentiments suggest that many students have a different epistemology of learning than the instructor. They expect the instructor to take control and dictate to them what they should be learning. It is assumed that the instructor has a set of correct answers in mind and it is the students’ job to figure out what those answers are. Finkel alluded to this phenomenon in his book when he wrote “We have seen that students want to be taken care of by their teacher. They will try to get the teacher to take control of the class when things get difficult, and they will treat him as the one and only member of the class whose reactions matter. In sum, they will try to return to him the power he has handed over to them”. Finkel recommends that when this happens, the teacher must “make the students aware of these behaviors” but admits that “there is an art to doing this effectively”. The instructor for this course tried to make it clear to the students that he was not an expert in the course topic, and that he was a “co-inquirer” with them into the central questions of the course, but these students’ comments suggests that his efforts were not entirely successful.
Student co-author and instructor reflections on the course

To conclude this paper, the three student co-authors and the instructor for the course, share their overall reflections on their experience with the course.

Ms. McCormick's reflection:

Coming into this course after taking art and music classes abroad, I felt open-minded and ready to start on another relatively new area of study uncommon to my traditional engineering courses. However, when it came time on the first day I realized how different the thought process for the class would be, as we sought to look at engineering thinking from an objective point of view. In around two hours, we discussed our initial thoughts and listed out characteristics about engineering that would have been my answer to the whole question if I had taken this course individually. It shocked me how much more there was to understand and that our goal was to expand on the idea, not to simplify it. In my final reflection I wrote about this feeling, “It was not that I was unaccustomed to thinking about a question before answering, but more so that I was not used to approaching a problem that did not seem to have a clear goal”. In the beginning I was deeply confused with the concept of the course, but as the class progressed with specifically chosen assignments I learned to open my mind to this new type of analysis. First, I saw how to look at engineering from another’s viewpoint then connect it back to my own experiences instead of the other way around, which opened many new ideas to me. From there, I became comfortable incorporating opinions from people with different backgrounds and seeing how their fields compared to engineering. By the end of the course, we were challenged to utilize our knowledge to connect engineering to a system seen in our travels, which brought us back, full circle, to our first-day discussions about “engineering ways of thinking”. This development did not happen all at once, but continuously developed throughout the course with each new reading and discussion bringing unique insights to the table. By the end of the course, I felt I had a deep basis for understanding the way engineers think about and solve problems, which I have seen repeatedly in the courses I have taken since I completed the Habits of the Engineering Mind course. My thoughts on the topic are still forming with each day and every new problem I am asked to solve provides me with additional opportunity to explore and develop my thinking on what constitutes an engineering habit of the mind.

Ms. Borinski’s reflection:

As an engineer having spent five weeks living and breathing music and art, my engineering mind was colored by my recent experiences. On the first day, we were all prompted to answer “what is an engineering habit of the mind?” As my examples consisted of Leonardo da Vinci and Bach, I realize now just how much I was relying on my music and art working memory. Teaching an engineering habit of the mind requires the same finesse as teaching art or music. I remarked that all teaching dances on the line between limiting ideas and fostering creativity. Sculptors do not learn simply by watching their mentor, they sculpt. Composers do not just listen to other people’s compositions to learn, they find their rhythm through trial and error. This course’s readings, estimation assessment, blogs, and modeling project highlighted the strategies, tools, and skills characteristic of an engineering mind. Looking back at my descriptions of “engineering habit of the mind” pre- and post-course, I expanded my initial art and music...
colored lens, emphasizing experience with clear strategies from the examples showing the experiences of others, as well as my own experiences through the modeling project. As a rising fourth year engineering student, this course brought to light just how many “engineering habits of the mind” I have developed through my courses and experiences.

Ms. Haight’s reflection:

Beginning this course with only two years of engineering education and experience behind me, I was originally confused by the essential question, what unique ways of thinking distinguish engineers from others? After the activity done on the first day, it became clear that my answer to this question, as well as the opinions of many of my classmates, was very closed-minded. I saw engineering ways of thinking as cut and dry calculations and critical thinking. Many students seemed to have the same opinions, arguing the validity of engineering stereotypes. However, my view began to change as the course progressed. The course readings and activities showed how similar an engineering mind can be to a non-engineering mind. On the other hand, many activities showed how unique and extensive engineering techniques and habits really are. I learned first-hand how important it is to work with people with different skill sets and experiences in order to reach a common goal. On the final project, I was paired with a student studying liberal arts and with no engineering or technical background. It was interesting to see how differently we approached our project and the varying strengths we each had. At times these differences made working together difficult, but we eventually found a way to utilize both of our skill sets to complete a successful project. Above all, this course showed me that engineering habits of the mind go beyond the conventional methods taught in all my engineering courses to date. I learned new problem-solving strategies and was challenged to think in ways that I have never done before. Going forward, I now have more useful experience and a stronger knowledge base, and I know that my personal engineering habits of the mind are going to continue to expand.

Professor Le Doux’s reflection

The opportunity to develop and teach this course was a unique and extraordinary opportunity. First, let me explain why I had the opportunity to develop this course. About one year before I taught the course, I decided I wanted to participate as a faculty member in our institution’s study abroad program at Oxford University. When I inquired about the program, I found out that each faculty member was expected to teach two courses that would be of reasonably broad interest to the Oxford program’s students, which is a young and highly multi-disciplinary group of students. Unfortunately, only one of the courses that I had previously taught fit the bill. Therefore, I had to propose to teach a course I had never taught before. Taken with a sense of adventure, I decided to teach a course on a topic that I had been thinking about for some time, and had discussed multiple times with two of my learning sciences colleagues at my home institution. The idea was to explore the possibility that engineers have a characteristic way of thinking, informed by a set of acquired schemata, sensibilities, and dispositions, similar to Pierre Bourdieu’s concept of habitus [15]. In addition, I wanted to create a course that stressed the importance of, and gave students the chance to exercise, the practice of critical reflection in the design process [16]. The problem was – there was no textbook, there was no syllabus, and my
ideas about the course and my conceptions of what constituted an engineering habit of the mind were not well-developed. Nevertheless, I felt that by committing to teach the course, it would provide me with an excellent opportunity to do something I had never done before: develop a course from scratch, without the aid of any pre-existing conceptions or guidelines for how to teach it. I sensed that teaching such a course would not only improve my content knowledge on the topic of the course, but it would also provide me with an extraordinary opportunity to develop my skills and experiences as a teacher. Soon after my decision to teach this course, I read and was inspired by Donald L. Finkel’s book “Teaching With Your Mouth Shut” [1]. The book discusses Finkel’s unique approach to teaching humanities courses, but I believed the principles he espoused would be equally effectively in an engineering course. I am pleased with how it turned out. The course exceeded my expectations, and I certainly never expected to co-author a paper about the course with several of my students, which has been a very rewarding experience.

In light of the positive experience with teaching this course, it is interesting to consider if it could be taught as a permanent offering at my home institution. Where would such a course fit in a typical engineering student’s curriculum? Would the course credits count towards meeting the students’ graduation requirements? For the most part, engineering students’ schedules are jam-packed with required courses, many of which are technical in nature that provide them with depth in their chosen field. Most engineering students take several humanities and English courses, but these are usually taught by humanities and English professors, not engineering professors. Is there any room in a typical engineering curriculum for this kind of course? Fortunately, for the biomedical engineering students who took this course as part of their study-abroad experience, the course was counted as a depth elective, primarily because of the course’s emphasis on systems thinking and model-based reasoning. Nevertheless, a significant fraction of the course’s content is philosophical, rather than technical, in nature, which might make it challenging to get it approved as a permanent depth-elective course at our home institution. This would be unfortunate, because the reflective pieces of my former students and co-authors of this paper, indicate that they learned a great deal about what it means to be an engineer by reading and reflecting on philosophical writings about engineering, and by learning and applying engineering ways of thinking to make meaning of systems that they encounter in their everyday lives. I believe these students are now more aware of their own thinking processes and those of other engineers, and are more sensitive to how these thinking processes affect the work they do and the designs they create, which will, in the end, make them more effective engineers and problem solvers.

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References


