Introducing Engineering and Design to Homeschooled Middle and High School Students

by

Hannah Huynh

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

Bachelor of Science in Mechanical Engineering

at the

MASSACHUSETTS INSTITUTE OF TECHNOLOGY

June 2017

Author .... Signature redacted ....
Department of Mechanical Engineering
May 12, 2017

Certified by .... Signature redacted
Maria Yang
Associate Professor of Mechanical Engineering
Thesis Supervisor

Accepted by .... Signature redacted ....
Rohit Karnik
Associate Professor of Mechanical Engineering
Undergraduate Officer

Introducing Engineering and Design to Homeschooled Middle and High School Students

by

Hannah Huynh

Submitted to the Department of Mechanical Engineering
on May 12, 2017, in Partial Fulfillment of the
Requirements for the Degree of
Bachelor of Science in Mechanical Engineering

Abstract

In this thesis, the researcher organized and taught an introduction to engineering and design course to her local middle and high schools. Inspired by an industry experience and MIT resources, she developed a curriculum that incorporated interactive activities and culminated into a design challenge for these homeschooled students. She surveyed their interests in and perceptions of engineering and design before and after this introductory course, and the students were 81% percent more interested in engineering and 80% in design after having taken the course. Both student and parent feedback, formally through surveys or informally through conversations, shared about the positive influence this course has had on bringing exposure of engineering and design to the students. This program achieved the researcher's goal of exciting students to consider pursuing engineering and design. The researcher hopes to continue this program in the future with some revisions like cutting back some taught material to allow for more build time or developing a separate more specific and advanced engineering course for students already interested in engineering.

Thesis Supervisor: Maria Yang
Title: Associate Professor of Mechanical Engineering

Acknowledgments

The author would hereby like to acknowledge the students, parents, and families of Saddleback Christian Academy who made this study possible. Their excitement and willingness to learn brought encouragement to the researcher during the classes. The author acknowledges MIT Society of Women Engineers for providing financial support for this program, Carmen Castaños for reviewing and supervising this thesis, and Professor Maria Yang for providing guidance and encouragement on this study.

The author would also like to thank her family and friends who supported her through this endeavor. From hosting her for the month in California to offering advice for the study or just listening to her share about her plans for the classes, every person contributed to her experience.

Contents

List of Tables

List of Figures

Chapter 1

Introduction

1.1 Saddleback Christian Academy

The researcher was homeschooled from K-12th grade in the suburbs of south Orange County in Southern California. There were a wide variety of public and private school options available, but homeschooling was chosen to allow for a cultivating environment of shared family values for the researcher's upbringing. She belonged to an umbrella school for homeschoolers called Saddleback Christian Academy (SCA). SCA is composed of around 120 families and over 250 students from the south Orange County region. SCA was established in 1987 and is classified as a private school satellite program under an affidavit with the state of California. SCA is a Support Group Member of Christian Home Educators Association of California (CHEA). SCA is also affiliated with the Association of Christian Schools International, and this allows for its students to be involved in math olympics, spelling bees, and piano festivals with other students from private Christian schools. SCA families must also be members of the Home School Legal Defense Association (HSLDA) in the case of legal protection [1]. Over its 30 years of existence, SCA has become an established organization with support from many external communities.

SCA offers classes, field trips, and events for the enrolled students. Classes are generally offered on Tuesdays for high school students only and on Fridays for all students. They are typically taught by parents in SCA and held at a local church facility. SCA offers classes ranging from Literary Analysis to Choir to Algebra, and most are taught from prescribed homeschooling curriculum textbooks like Abeka and Saxon. SCA students can attend school field trips like an overnight stay on a pilgrim ship or a day trip to an apple farm for fun learning experiences. SCA also hosts its own events from a barn dance for community bonding to an annual science fair for educational learning. At this fair in particular, students display experiments they conducted using the scientific method: make an observation, ask a question, form a hypothesis, conduct an experiment, then accept or reject the hypothesis. These activities are organized and planned by parents in SCA, thus creating a strong sense of community at the school.

1.2 Motivation

Even with the opportunities at SCA, the researcher observed a lack of engineering initiatives at the school, especially in high school. In her time there, there were no classes, opportunities, or events that encouraged students to considering pursuing engineering, making the pursuit of engineering solely dependent on the individual student's ambition. The researcher individually sought out and took Advanced Placement classes through an online provider and volunteered at a local science center to build upon her interest in engineering. She personally had an interest in DIY projects and paper crafting, so she decided to pursue mechanical engineering in college to continue a hands-on career.

Upon arriving at MIT in fall 2013, the researcher was fascinated at the vast variety of engineering resources and opportunities available. She found herself surrounded with like-minded engineering students and an abundance of mechanical engineering classes and research opportunities. From her experiences at MIT, she decided she wanted to bring back some of those resources to her homeschooling group in hopes to excite the students about engineering. She saw and personally experienced a need for engineering initiatives for homeschooled students, and she sought to fulfill it. These experiences and observations culminated into the Introduction to Engineering and

Design class that she taught to 43 middle and high school students in SCA during January 2017. The goal of this project was to access how the introduction of a hands-on, project based design workshop might impact students' and parents' perceptions of engineering and design. Her expectation was that the impact would be positive because the material itself would be unlike those from other classes normally offered at SCA and the teaching style would be interactive and engaging.

Chapter 2

Background

2.1 Homeschooling

Homeschooling is a non-traditional schooling method in which students learn outside of a designated public or private school. From surveys run by the National Center for Education Statistics, the percentage of homeschooling students in the US from ages 5-17, grades K-12, has increased 1.7% to 3.4% from 1999 to 2012. One potential reason may be the appeal of a more academically flexible career - students can individualize their curriculum to suit their interests. In 2012, homeschooled students were 83% white, and 86% were from families with income above the poverty line. Homeschooled students came from both cities and rural areas and spanned all grades from kindergarten to twelfth grade [10]. Some students are homeschooled for part of their learning career and then move to a more traditional method for the rest.

Students may be homeschooled for a variety of reasons, but in nine out of the ten cases, parents decide to homeschool their students because of a concern of the local schools' environments. Homeschooling allows parents and students to have control over what and how the students learn. To prepare for homeschooling, about a quarter of the parents take a course before deciding to homeschool their own child [10]. However, even then, not all parents were academic experts, teachers, or well-educated, and thus have relied on alternative teaching sources. Homeschooling curriculum is derived from websites, homeschool catalogs, and libraries. About a third of middle and high school homeschooled students took online courses as part of their curriculum [10].

A study on homeschooled students' academic performance during their stay at a doctoral institution in the Midwestern U.S. showed that homeschooled students achieved higher American College Testing (ACT) grades, grade point averages, and graduation rates compared to traditionally educated students [3]. Students who were homeschooled for more than seven years were more likely to have earned college credit before attending college, participated in community service, and voted in the past five years compared to the general US population. Despite this, homeschool students are often perceived as lacking in social interactions. This study cites a perception of homeschooled families:

> Experience and anecdotes have led many people to believe that homeschool parents are either move-to-the-country anarchist goat herders, or right-wing Bible thumpers, and their children were mathematically-limited, due to Mama's fear of math, or child prodigies in rocket-science who were unthinkable socially hindered [3].

Though a relatively harsh statement, this reflects stereotypes of homeschoolers. The researcher has noticed from personal experience that homeschoolers generally fall in the spectrum of trying to disprove the stereotype by showing both academic knowledge and social skills or potentially limiting themselves by not venturing past their comfort zone.

2.2 Pre-College Education

2.2.1 Sesame Workshop

During January 2016, a year before the start of her study, the researcher participated in a month long internship at Sesame Workshop in New York City. The mission and environment at Sesame Workshop served as an inspiration for the researcher's study. Sesame Workshop, the non-profit behind Sesame Street, champions itself in helping children grow to be smarter, kinder, and stronger. Through a variety of nonconventional ways like videos, apps, and games, Sesame Workshop brings education to all types of students from all types of backgrounds. In 2013, an institution compiled data from 24 studies conducted with over 10,000 children in 15 countries that showed that children who regularly watch one of the international versions of Sesame Street gained on average 12 percentile points on learning outcomes compared to those who did not. Some of the learning outcomes include literacy, numeracy, health, safety, and social reasoning. Sesame Workshop has proven that education for students can occur in ways more than sitting and learning in a traditional classroom. The work of Sesame Workshop generally targets preschool children, but the data shows that it can make a significant difference in a child's life [8].

2.2.2 STEM

Pre-college science, technology, engineering, and math (STEM) education is crucial as it is useful for increasing the number of students pursuing advanced degrees and careers in STEM fields, expanding the STEM-capable workforce, and increasing STEM literacy for all students [4]. However, in 2015, 15-year-olds in the United States ranked just average in science literacy compared to their equivalents in 69 other nations, but their math literacy was lower than average [6]. The US recognizes this need to improve STEM education as 41 of the 50 states in the US have implemented some sort of engineering standard [2]. However, the execution of this standard is not clearly defined. Furthermore, there is a lack of a cohesive vision for engineering education, making it hard for teachers to teach and students to learn.

Many instructors have made an effort to integrate science, technology, engineering, and math into students' educations before college. They sought ways to integrate lesson components to engineering design challenges that allow the student to apply their knowledge [4]. However, this has been challenging and practically hard to execute. Instead, instructors can interest their students in STEM by being passionate about the material themselves. Studies have shown that having a passionate math teacher is more likely to influence the student to pursue a math based major [7]. There is a host of teacher educational resources available, and allowing teachers to get better developmental education will lead to better education for the students.

2.3 Engineering and Design Education

2.3.1 Design Notebooks

In academia and industry, documentation is emphasized in many projects, experiments, and design work. Commonly, this documentation is kept in a notebook or journal. In the context of this study, design notebooks were introduced. In a classroom setting, design notebooks are useful for both the students and teachers. For students, design notebooks teach them to abstract and visually communicate their ideas through drawings and text. It can help them process their thoughts, and it provides a space for reflection on previous work. Because students keep their design notebooks with them outside of class times, it allows them to learn outside of the preset classroom by encouraging them to document important ideas at any point in the day. It also encourages students to actively participate and learn by doing [11].

These design notebooks are not only important to students but also to teachers. Teachers can use this tool to understand students' learning progressions and thought processes. Design notebooks can help teachers understand what roles a student had in a group project. When introducing design notebooks, students may not be receptive or understand of their necessity, so instructors should reinforce best practices for keeping it in order to help the students see the value in this tool [11].

2.3.2 Team-Based Learning

Team-based learning is a common method used in a flipped classroom style. A flipped classroom style has students learning a bulk of the material outside of class by having them read the textbook beforehand or watch online videos. This allows for class time to be used for working through group problems with the teacher facilitating. This study did not employ a flipped classroom style, but it took many principles from team-based learning. In many cases, team-based learning allows for accountability in work and greater understanding and application of exercises. Teams should be composed of 5-7 students, with a diverse mix of talent [5].

Students may initially be averse towards teamwork because of negative impressions of working with others who may not have the same level of ambition. In implementing team based learning, the instructor needs to focus on the importance of team goals and learning objectives. Students should all be working towards the same goal and have dedicated tasks or else certain students will do a majority of the work [5].

2.3.3 Interactive Teaching

For the most effective learning style, research has shown that interactive learning contributes best to students' understanding. A study differentiated four types of learning - passive, active, constructive, and interactive. Passive is most accurately represented in typical classrooms with the instructor lecturing at the students. Active learning requires the student to participate in the learning somehow, like by answering questions. Constructive learning asks the student to do an extra activity to extrapolate their knowledge into an applied principle. Finally, interactive learning engages the student to work with others and collaborate on a solution to a problem. Students scored the best on tests after participating in interactive learning, followed by constructive, active, then passive. On more complicated questions, interactive learning lead to much deeper learning than constructive or active [9].

Chapter 3

Methodology

3.1 Program Inspiration

3.1.1 Sesame Workshop

In January 2016, the researcher participated in a month-long internship at Sesame Workshop, the nonprofit educational organization behind Sesame Street, in New York City. Sesame Workshop aims to help kids grow smarter, stronger, and kinder, and it does so with non-conventional methods like television shows, games, and apps. The researcher was inspired by this mission and their proven success to pursue her own initiative with a non-conventional teaching style that could impact a child's education.

3.1.2 MIT Resources

After that Sesame Workshop internship, the researcher returned to MIT's campus and consulted with experts at the Martin Trust Center for MIT Entrepreneurship to seek advice on starting an educational initiative. The researcher was encouraged to evaluate the entrepreneurship steps to creating an engineering education start-up. She also consulted with a member of the MIT Education Technology Club, instructors at the Edgerton Center, and other entrepreneurs who could help her get her idea started. From these conversations, the researcher decided she wanted to teach an introduction to engineering and design course. This class would be like a summer camp or workshop with much interactive learning and active doing. She reached out to MIT professors who teach product design courses to undergraduate and graduate students and talked to many peers both in and out of MIT's Department of Mechanical Engineering for feedback on the idea of this course.

During the spring 2016 semester, the researcher participated in MIT's 2.744 Product Design class, taught by Professor David Wallace. This graduate-level product design course taught many characteristics of user-centric design and design principles. Every lecture in 2.744 was a surprise. A syllabus for the course was published online, but the professor planned each class with unique and engaging activities that no student could anticipate. On any given day for lecture, there could be index cards, modeling clay, or papers in front of each student's desk that would be used for an activity later. The interactive teaching style engaged the researcher and effectively reinforced understanding of the taught material. This course served as a model for the proposed homeschool course.

3.1.3 Saddleback Christian Academy

Having come up with the program initiative of teaching an introduction to engineering and design course, the researcher now had to find an audience for the class. The researcher had felt a lack of engineering and science initiatives when she grew up through SCA, and she now could provide more engineering resources for the future generation at her school. The researcher chose her homeschool group as the audience for this class because she understands how the students are used to being taught and can better convey the information to them. She saw that there was a need there for engineering and design opportunities, and she could run her class without having to be a certified teacher in California or having a graduate degree in education. The goal of the course was to introduce students to engineering and design material. In addition, the course would demonstrate possible paths beyond homeschooling to these students.

3.2 Program Planning

3.2.1 Planning and Funding

The original study planned for four separate courses of 12 students, reaching a total of 48 students. These would be designated by grade: a class for 7th graders, one for 8th graders, one for 9-10th graders, and one for 11-12th graders. The study intended to target middle school students because they still have time in their pre-college schedules to plan classes to pursue engineering in college. The goal for the curriculum was to cover how to brainstorm, sketch, innovate, ideate, prototype, problem solve, create refined mock-ups, and present professionally. The original idea was to have students work on individual design projects so they would be able to keep something they were proud of making by the end of the course. The course would be a four-week long program with classes twice a week. Changes to this program are mentioned in Section 3.2.3. With the idea of the course in place, the researcher decided to teach during MIT's January Independent Activities Period (IAP) 2017 term to prevent scheduling conflicts with the researcher's school terms.

In February 2016, MIT Society of Women Engineers (SWE) started a new program to fund MIT student initiatives, a great opportunity for financial support of the researcher's program. She pitched her month long introduction to engineering and design class to the executive committee of SWE and created a budget to show how much she would need for different parts of the program (see Table 3.1).

Item	**Amount**
48 students x $40 each for supplies	$1920
Round-trip plane tickets to California	$600
Food	$500
Car rental	$1000
School rent	$400
Housing with a relative or friend	$0
Overhead	$112
Total	**$4700**

Table 3.1: Funding proposal budget breakdown.

On top of her requested funding from SWE, each student participating in the course would be charged $10. The fee was requested to help contribute to miscellaneous costs from teaching the course and to ensure that students participating in the course would be committed to completing the material. The amount was chosen to be high enough that students would not want to miss a class, but not so high to be a financial barrier to those wishing to participate. For reference, full semester classes at SCA generally range from $30-50 a month.

3.2.2 Logistics

After funding from SWE was finalized, she proposed her class to the Saddleback Christian Academy Board of Trustees. They approved. The SCA Board of Trustees is composed of around 10 parents of families in the school who typically serve until their youngest child graduates from SCA, which can range from 2-15+ years. To join the Board of Trustees, parents must be nominated by current board members.

It was decided in partnership with SCA that for this month-long course, there would only be two classes, one for students from 6-8th grade and one for students from 9-12th grade. Logistically, there was not available time and space at the school for more classes. These classes would meet for two hours twice a week each. The course would happen Wednesdays and Fridays from January 11-Feb 3, 2017 with the high school class from 8:30-10:30am, and the middle school class from 10:45am-12:45pm. The 15-minute break would allow for set-up and clean-up time between classes.

After the logistics of the course were finalized, the course was advertised via the school's monthly newsletter that gets emailed to the families the week before their monthly mandatory parent meeting (see Appendix A). Updates and relevant information are shared with the members of the school at these parent meetings, and depending on the month, registration for classes may happen. To bring more visibility to this new engineering and design course, a parent at SCA, who is an engineer, advocated for this course. This engineering parent pitched the course at the May meeting for SCA parents, and afterwards, parents could walk to a designated table to write down their student's name to express interest in the class. This sign-up was not the official registration and not binding, but it provided an initial estimate of the number of interested students. The preliminary list of interested students had 32 people. There were 7 females and 25 males, with an age breakdown of 17 5-8th graders, and 15 9-12th graders. An exception was made to allow two 5th grade students into the class as they were younger siblings of other students signed up for the class (see Table 3.2).

Gender Distribution of Interested Students	
Male 25 (78%)	Female 7 (22%)
Grade Distribution of Interested Students	
5-8th 17 (51%)	9-12th 15 (49%)

Table 3.2: Gender and grade distribution of interested students.

To open registration, the same advertisement that went out on the May newsletter was slightly modified for the June parent newsletter (see Appendix A). Parents would pay $10 on their SCA account and email their student's information to the correspondent at SCA who was working with the researcher. The SCA correspondent handled most of the preliminary logistics in collecting the funds and organizing the registration list for the researcher. Registration closed at the end of September to allow for sufficient time to finalize logistics of the course and to purchase the appropriate amount of supplies. The final roster included 43 students with 11 females and 32 males. The middle school class had 24 students and the high school 19 (see Table 3.3).

Gender Distribution in Final Roster	
Male 32 (74%)	Female 11 (26%)
Grade Distribution in Final Roster	
5-8th 24 (56%)	9-12th 19 (44%)

Table 3.3: Gender and grade distribution in final roster.

After registration closed, the parents of students enrolled were emailed and asked to sign up to volunteer for at least one of the eight classes. Volunteering duties would include help setting up for class, scribing during in-class activities, and supervising the use of potentially dangerous tools like paper-cutting knives. The researcher's goal was to have at least two parent volunteers a lecture, and ideally at least four during the build classes. Volunteering for general SCA activities is mandatory, so parents were very willing to sign up and help out in this class. All needed positions were filled.

3.2.3 Edgerton Center

After ensuring sufficient interest in the course, the researcher wanted to gain more practical teaching experience and sought to volunteer at the MIT Edgerton Center. The Edgerton Center hosts hands-on classes for K-12 students, providing the researcher with experience teaching engineering concepts to students younger than college undergraduates. She went during a class in May 2016, and in this class, elementary school students were taught a short lesson on gears, and then they worked in pairs to play with Legos to build systems that apply those principles. By working hands-on in pairs instead of having the instructor lecture to them the entire time, the students were able to stay interested and move at their own pace. There were instructions on a piece of paper telling the students what to build, but the teams of students were able to progress through each step at their own pace. At the very end of this course, students were challenged to apply the principles they learned to create the fastest moving robot. Students enjoyed using their creativity and newly learned engineering principles to have fun.

From this experience, the researcher took note of several effective teaching strategies for her proposed class. First, the researcher decided against her original idea of having students do individual work. She chose to have students work in teams so that if a student was not interested in a particular aspect of the project, teammates could work together to distribute tasks according to their interests. The researcher also realized it would be unreasonable to expect a 9th grade student to achieve and understand the same as a 12th grade student could, so working in teams would balance out the skill differences as teams would consist of students from mixed grades. Second, the researcher also decided she wanted to teach some material in the more traditional lecture style, and then allow the students to hands-on apply the material and move along at their own pace through in-class activities.

3.2.4 2.00 and 2.009

In the fall 2016 semester, the researcher participated in MIT's 2.009 Product Engineering Processes class, taught by Professor David Wallace. This undergraduate class is a senior capstone course for mechanical engineers at MIT, and students actively learn and participate in the product design process. Material in this class is taught in a fun and engaging way with teams, competitions, and prizes. Like 2.744 Product Design that the researcher took in a previous semester, the syllabus for 2.009 was posted online, but each day in lecture was a surprise. There were unexpected activities on writing specifications for different fruits, throwing darts at a target, building a hot wire blue foam cutter, and searching through the MIT library database for information - all to engage students in different aspects of the product design process. The researcher took note that the professor's and teaching assistants' attention to detail made the class into an experience.

Also in the fall 2016 semester, the researcher became a mentor for MIT's 2.00 Introduction to Design. The researcher's graduate student advisor Carmen Castaños suggested the role so the researcher could understand better how college-level sophomores learn design, gain teaching experience, and gauge how to scale similar material for the middle and high school students she would be teaching. Mentors were required to attend weekly three-hour lab sessions and staff meetings with the other members of the teaching staff. Mentor responsibilities included helping students with their projects and providing feedback and insight on their work and the material covered in the course. In these sessions, the researcher observed how students interacted with each other and guided them through their design decisions. This experience allowed the researcher to understand how college underclassmen approach the course material and gave her a sense of timing in how long it takes to design and build a preliminary design project.

To learn more from this class, the researcher sat in during one of the lectures of 2.00 and saw what material was being taught, in what order it was being taught, and how it was being taught. In that particular lecture, students brought in physical models from the past class' homework and walked around the room to observe other students' models. Later in that lecture, the students had an in-class activity to draw out certain items on a piece of paper to demonstrate a design principle. From watching this class, the researcher sought to mix teaching material and interactive activities in each class session of her program.

The first half of 2.00 culminated to a design challenge where the students worked in teams to design and build a device from limited supplies to complete a particular challenge. The design challenge was an egg catch where the students had to protect a 3-D printed egg from a drop of two stories. This challenge took advantage of the architecture of surrounding MIT buildings and brought students outside of the classroom. The learning and building time for the first design challenge of 2.00 was similar in length of the researcher's planned month-long program, so the teaching and project outline from 2.00 would provide the outline for the researcher's planned course.

Aside from serving as inspirations and baselines for the researcher's own course, 2.00 and 2.009 were learning experiences for the researcher herself. Through these classes, she was able to learn more about the product engineering process and experience it first hand, enabling her to be a better teacher after the experience.

3.2.5 Syllabus

The researcher pitched a preliminary syllabus for the course with design material pulled from 2.744 and the product design process order pulled from 2.009 and 2.00 (see Appendix B). The researcher formulated the syllabus and lesson order from some of the key steps of a product design process. However, after conversations with Castaños and Professor Yang, the suggestion was to scale the syllabus down as this syllabus was relatively ambitious to cover a large amount of material in a short amount of time. She revised her syllabus after her experience from being a mentor for 2.00 that fall semester, and that syllabus better fit the time frame and the audience of the IAP course (see Table 3.4). With another review of this syllabus with Castaños, the plan was more feasible and ready to be formalized so the researcher could start purchasing supplies.

I. Introduction, Why Engineering and Product Design are Important
II. Ideation: Brainstorming and Sketching
III. Team Building and Ideas Discussion
IV. Prototyping and Testing
V. Building I
VI. Building II
VII. Design Challenge
VIII. Looking Forward

Table 3.4: Condensed version of final syllabus.

3.2.6 Supplies

In November 2016, the researcher looked into buying the specific supplies needed. She wanted to provide each student with a design kit that they could keep to continue creating even after the course was over. She determined that they would include a 5.5x8.5" design notebook, pencil case, 2H pencil, Pilot Fineliner, Pentel Sign Pen, 6" ruler, Staedtler white eraser, and photo keychain (see Figure 3-1).

Figure 3-1: Design pouch and contents.

The design notebook would be used for documentation and development of their design ideas. The pencil case would hold all the writing utensils. The pencil and white eraser would be used for simple scratch work, and the pens for permanent writings in their notebook. The different thicknesses of the pens, fineliner thin and sign pen thick, would allow for the students to emphasize different parts of their drawings. The 6" ruler fit inside a pencil case and would be used to assist students in drawing straight lines. The researcher also bought a photo keychain and printed the program logo to go inside. The program logo was a brown ship steering wheel with a black gear in the middle, as the researcher decided on an ocean voyage theme for the class to unify the course experience. On the first day of class, the researcher had the students write their names at the back of the circular paper with the program logo and then stick that piece of paper inside the keychain. Because each student received exactly the same materials, the researcher wanted a way that the students could identify which pouch was theirs. The majority of these supplies were ordered from Blick Art or Amazon.com due to discounted prices or free shipping.

3.2.7 Design Challenge

Aside from the supplies for each student's kit, supplies were needed for the design challenge. The school that the researcher would be teaching at has an outdoor playground, and the researcher decided to bring the challenge outside the classroom and utilize the local setting (see Figure 3-2).

Figure 3-2: Playground outside school for design challenge.

Figure 3-3: Preliminary design challenge schematic.

With the ocean voyage theme in mind, the researcher settled on a flag retrieval challenge to mirror taking down a flag from the mast of an enemy ship. A long pole around 12' would be attached to the center of the playground, and students would have to retrieve flags that would be velcroed to different heights on the post (see

Figure 3-3). The researcher decided that Velcro would be a good adhesive for the flags because it is easy to enough rip apart and could be put back together easily for the next team. The researcher estimated that standing around 5' away from the base of the flagpole would be a sufficient challenge for the high school students. The middle school class would do the same retrieval challenge, but instead stand just 3' away from the base of the pole.

On January 9th, two days before the first class, the researcher flew to California to finish up the final preparations for the course. She visited to see the classroom that she would be teaching in and the playground to get a physical feel of the dimensions for the design challenge. When in person at the playground, the researcher realized that mounting a tall pole to the playground would be a challenging task to do safely and securely, but she noticed that there were many flat surfaces around the playground that could be used to attach the flags directly to instead. The researcher thus chose 5 locations to place the flags to fit more naturally and conveniently on the playground without having to buy, mount, and secure a long pole (see Figure 3-4). The flags would be velcroed to a piece of foamcore which would be securely taped to the playground since there was not a convenient way to stick the Velcro to the slippery surface of the playground.

(a) High school schematic (b) Middle school schematic

Figure 3-4: Design challenge schematic.

While determining the flag locations, the researcher also decided the distances the students should stand away from the flags. The researcher's initial estimate was that the students would stand at a 5' radius away, but when actually 5' away in person, she realized that was close to the location of the flags and would not be challenging enough for the students. There is a curb at the edge of the playground, and the researcher decided to designate that to be the distance the older students must stand to retrieve the flag. This was 14' away from the flags, but as the researcher stood with a colleague to observe the distance, after factoring a student's height and arm length, the decision was made that it would doable but challenging for the students. The researcher wanted the same challenge for the high school and middle school students, but she varied the difficulty by changing the distance the students must stand away from the plane of the flags. The yellow slide that protruded out dictated the distance the younger students would have to stand away from the rest of the flags, and that measured to be just over 6'.

For this design challenge, students would be working in 4 teams of 4-6 students in each class. The researcher chose to assign teams that size because of literature and personal experience recommendations. The design challenge would be held on the second to last class, and the students would get 5 minutes to present about their design and 2 minutes to use their device to retrieve the flags. The researcher emphasized the presentation part to the students to allow them to practice communication skills. She wanted them to be aware of the design decisions they made for their project and how to communicate them to the audience. The students would be judged on creativity in design, originality of the use of supplies, successfulness, crowd entertainment - wow factor, and team presentation. These five criteria were created from categories that the researcher found important to their learning and the challenge. Crowd entertainment - wow factor - is perhaps an unusual criteria, but it was included to provide incentive for students to think of creative ideas and consider visual interest of their device.

The flag that the students would be retrieving was a black 21x21" bandana. These bandanas would be fastened at the top two corners with Velcro to the foamcore attachment to the playground. This would allow for the students to retrieve the flags by pulling on the free hanging end at the bottom or sneaking a part between the two

Velcro pieces to pull out. There was also a large eyelet that was punched through the center of the flag. This eyelet allowed for students to hook into the bandana and pull it off the playground. However, because the researcher wanted to allow for creativity and not make it the easy option to hook, she placed that hole in the very center of the bandana where it had little structural support (see Figure 3-5).

Figure 3-5: Physical design challenge set-up.

The students would be given a limited set of supplies which included foamcore, string, foil, paper clips, rubber bands, clothespins, slap bracelets, toy propeller, and plastic hanger (see Table 3.5). Each team would be given 6 20x30" sheets of foamcore for the base material of the projects. Most of the other supplies were chosen since they were common items, and the researcher wanted to get the students thinking creatively about simple items. The plastic hanger specifically was chosen because the diameter of the rod was just small enough to fit through the eyelet in the center of the flag. The students were limited in their amount for their final device, but were able to use the supplies freely for prototyping purposes. Regular tape, duct tape, and hot glue was provided to the students for unlimited use. They were told they could use as much of those binding supplies as they wanted assuming it was not an integral part of their final device, e.g. making the full product out of duct tape.

6 sheets of 20x30" foamcore
6ft of aluminum foil
16ft of string
5 paperclips
4 rubber bands
2 clothespins
2 slap bracelets
1 plastic toy propeller
1 plastic clothes hanger

Table 3.5: List of supplies per team.

3.2.8 Survey

A month before the start of the class in the beginning of December 2016, the researcher sent out a survey to the parents of the students enrolled in the class and asked them to have their students fill out the survey. The researcher did not have the students' email addresses, and she mostly communicated with the parents and expected the parents to relay information down to their students. This pre-class survey was designed to gauge the students' interest and understanding of engineering and design. Their responses would be used to compare against a post-class survey the researcher would have them later fill out and to give the researcher a sense of what the students knew coming into the class. The students only knew information from the class from the short paragraphs that were shared in the newsletter, assuming their parents shared that information with them. The students did not have access to the syllabus and did not know what they were learning aside from an introduction to engineering and design, but this allowed for genuine responses on what they thought engineering and design would be.

The pre-class survey (see Appendix C) started with questions about the student - name, gender, and grade. The next section of questions asked the students to list words that they associated with engineering and words that they associated with product design. A note was added under each of these questions noting that "I don't know" is a completely valid response. The goal for these questions was to understand what the student's perceptions of engineering and product design were. The following question asked the students to rank their agreement with certain statements. The statements were "I am interested in engineering," "I already know a specific field of engineering that interests me (biomedical, electrical, mechanical, etc)," "I am interested in design," "I am interested in art," "I have experience with engineering (any type)," "I am personally interested in this course (Disagree if your parents signed you up just because)." The students could chose the options "Strongly agree," "Slightly agree," "Neutral," "Slightly disagree," "Disagree," and "I don't know" for each of those statements. These simple rankings would allow for the researcher to gauge how interested the students were in the class and its material. The next question was a long answer question in which the students could explain their experience in engineering and design. A note was added that crafting, sewing, drawing, helping parents fix things around the house, building, and programming are just a few examples of experience with engineering and design. This question would allow the students to elaborate on their answers to the statement-ranking question before. The final question asked the students to share any other relevant information to the researcher that they might find necessary about their background in engineering, design, and art.

The post-class survey (see Appendix C) asked for the student's name as this would be used to compare the before and after responses. The first questions mirrored those in the pre-class survey in asking what words the students associated with engineering and product design. The second group of questions asked the students to rank their agreement to certain statements. The statements were "I am interested in engineering," "I am more interested in engineering than I was before this course," "I am interested in design," "I am more interested in design that I was before this course," "I am interested in art," "I am more interested in art that I was before this course," "This course taught me skills I previously did not know," "I enjoyed taking this course." Each of these statements could be ranked with "Strongly agree," "Slightly agree," "Neutral," "Slightly disagree," "Disagree," and "I don't know." This question also mirrors one in the pre-class survey, but the researcher wanted to know here if the students' interest and skills were enhanced in this course. The next two questions asked the students to check mark which of the in-class activities they enjoyed and which contributed to their learning. The activities listed were "Mini quizzes," "Drawing a symbol for adventure," "Individual brainstorming challenge to get Hannah to the top of the rock," "Group brainstorming challenge to design an enclosure for electronic parts/a house," "Team building activity building the tallest tower from post-it notes and tape," "Pugh chart about what to wear when it's raining," "Final design challenge to retrieve the flags," "Dental floss teardown to understand manufacturing techniques," and "Other." These two questions in parallel would help the researcher understand which activities were effective in the class. Ideally activities would be marked as both enjoyed by and educational for the student. The following question asked the students to describe in text what they did and did not like in the class. This question would allow the students to elaborate on their answers to the questions before that only allowed them to check certain boxes. Finally, the last question asked if the students wanted to share anything else with the researcher about their understanding of engineering and design.

3.3 Program Execution

3.3.1 Class 1: Introduction

January 11th was the first day of class. Students and parent volunteers assisted in rearranging the room to have the projector and its screen at the front and the tables and chairs in arch shapes around so every student would be able to see (see Figure 3-6). The researcher, to be referred to as the instructor, created stand-up name tags for each student. Each student would grab theirs on the way into class and set it up on the table in front of them. This way, the instructor could quickly learn the names of the students. In front of each seat was an index card, pencil case, and design notebook.

Figure 3-6: First day class layout.

The class started with a welcome and introduction of the course objectives: gain exposure to design and engineering, experience a product design process, enhance creativity, and have fun. Immediately after covering the course objectives, the students took a mini-quiz about the course objectives and what they were hoping to learn out of this course. This mini-quiz was a 2-minute quiz that the students answered on an index card in front of them. It was anonymous and ungraded, but the purpose was to remind the students to pay attention in class and review previously covered material. After the mini-quiz, the instructor reviewed the solutions to the mini-quiz. She then discussed what engineering and design were and why they are important, with the goal of emphasizing what students should focus on during the course.

The students had to do an in-class activity in which they drew out a symbol that describes adventure. This activity allowed the students to apply some of the design characteristics that were just taught in lecture in clearly communicating their concept. They were challenged to draw pictorially and avoid writing specific words to describe the image. After students drew out their designs for adventure, they posted them up on the wall and the entire class surveyed the spectrum of drawings. There were commonalities in many with a compass, map, ship, or mountains, but several took more creative interpretations. In discussing the many different results from the same prompt, students were able to share what stood out to them as distinctive trademarks of a design and which designs were more effective in communicating the "Adventure" message (see Figure 3-7).

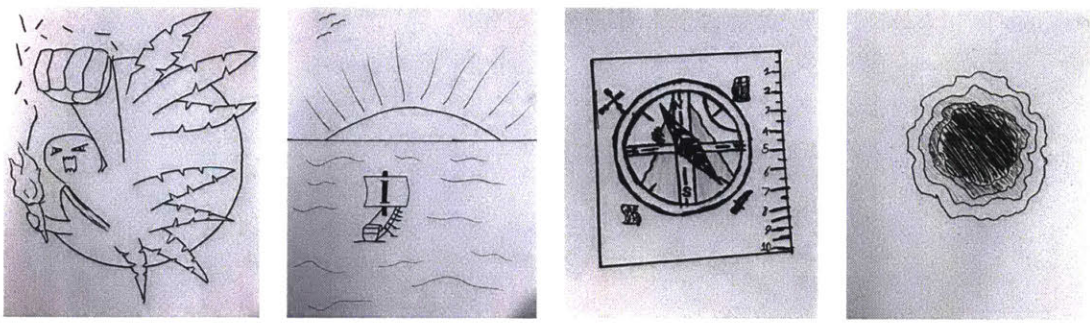


Figure 3-7: "Adventure" symbol exercise.

After reviewing the exercise, the product design process was covered as problem/user need, ideation, prototyping/testing, engineering feasibility, business case, product. Each lecture in this study would correlate to a step in the product design process, so the students could experience the process first hand. This process would lead to the final design challenge. In talking about the challenge, the instructor discussed documentation in the design notebook and her expectations for it. To close the class, the students were given two assignments. The first was to take a picture of something that was either good or bad design, bring that image to class, and be ready to share about it. This assignment challenged the students to open their eyes to the products around them and critically think about their form and function. The second assignment was to write a haiku about design and engineering and send it to the instructor. This was intended to be a fun and short assignment to get them interested about engineering and design and to show the instructor what they thought about the first class. The high school and middle school classes were run in the same manner and taught the same materials for this lesson.

3.3.2 Class 2: Ideation

The second class on Friday, January 13th was about ideation, which was broken down into brainstorming and sketching. The room layout was the same with the projector screen in the front and chairs and tables surrounding it in a semicircle. On the desk in front of each student was an index card and some sketching worksheets (see Appendix D). Students used their name tags again from the first class. At the start of the class, the students shared about the products that they saw that had good and bad design characteristics. Students were able to find many relevant examples from their local playground to their laundry room set up at home. The instructor reviewed some of the haikus that were sent to her, and then gave the students a mini-quiz on the steps in a product design process, the three items that must go on every page of the design notebook, and a challenge question about the meaning of an emoji symbol (see Figure 3-8).

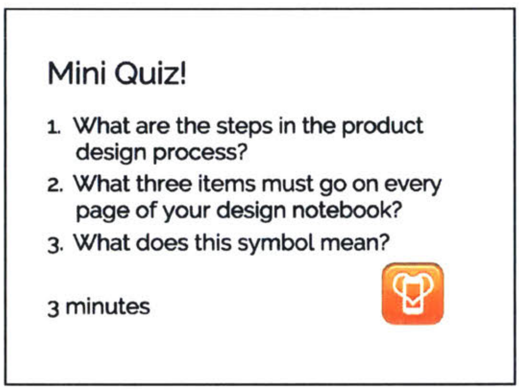
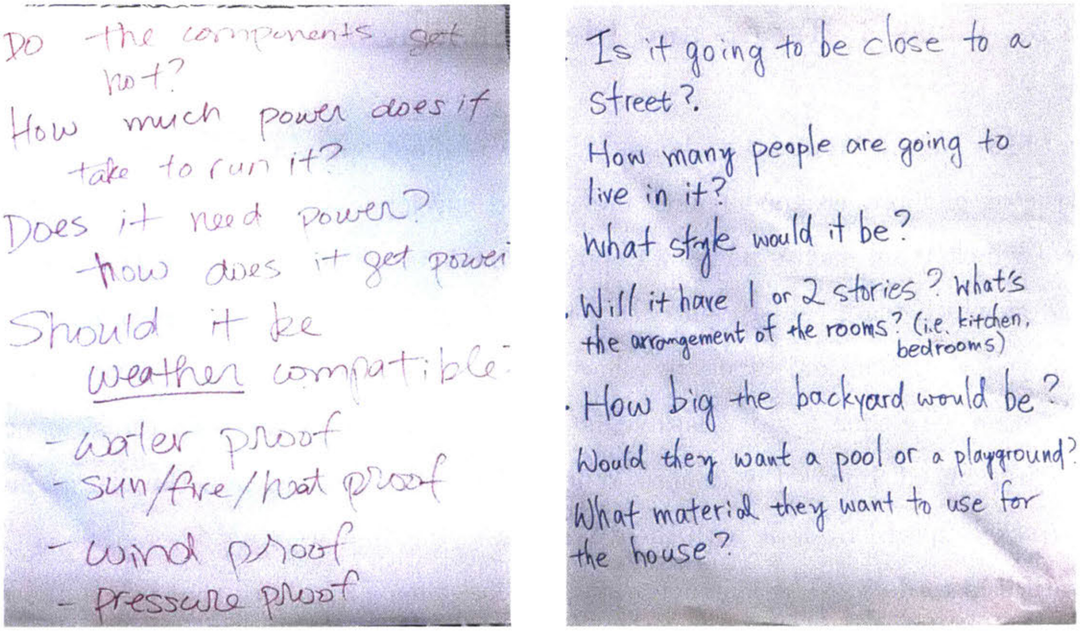


Figure 3-8: Example mini quiz.

This mini-quiz was administered to not only challenge the students to pay attention in class as they may be quizzed in the future, but also to remember what was covered in previous classes. These three questions were asked to highlight the class lecture material, the importance of keeping a good design notebook, and characteristics of a design. After the mini-quiz, the instructor reviewed the answers to the questions and some of the basic material covered in the previous class.

The material for this class was about ideation. The instructor defined ideation as the creative process of generating, developing, and communicating ideas. Generating and developing were taught via brainstorming, and communicating through sketching. For brainstorming, she taught them some general methods like a free form intuitive method, a structured logical method, an association relational method, and a new perspectives innovative method. The students learned about putting away their biases, building upon each other's ideas, staying focused on the topic, encouraging wild ideas, and valuing quantity over quality while brainstorming. With these methods and strategies, they were allowed to practice them in individual and group brainstorming activities. The individual brainstorming activity was brainstorming ways to get someone to the top of a tall rock. The students were shown a picture of the researcher and a large rock behind her and then given 8 minutes to come up with as many ways as they could to get the researcher to the top of the rock. On average, high school students were able to come up with 15 ideas, and middle school students 14 ideas. Their ideas ranged from riding a billygoat to the top or flooding the valley and swimming to the top (see Appendix E). Not every idea was realistic or feasible, but the students were encouraged to think of wild ideas for this exercise to practice creative thinking.

After this activity, the students were introduced to four creative strategies for brainstorming - look for the next right answer, look from multiple viewpoints, defer judgment, and challenge assumptions. They practiced them in a group brainstorming activity. The prompt for the high school students was "What questions would you ask if you had to design an enclosure for electronics?" and for the middle school students was "What questions would you ask when designing a house?" (see Appendix F). The high students prompt was inspired by a corporate interview question, and the middle school question adapted from the high school question to their level of understanding. Students split up into groups and spread around the room to locations where large Post-it notes were hung, and the instructor and parent volunteers acted as scribes (see Figure 3-9). Teams in both the high school and middle school classes brainstormed on average 26 ideas a team in 15 minutes.



(a) High school group brainstorming (b) Middle school group brainstorming

Figure 3-9: Results from the group brainstorming activity.

The class ended with a sketching tutorial. The students were taught how to draw arcs, straight lines, circles, ellipses, and 1-point perspective. Premade worksheets were given for the students to draw on and practice sketching (see Appendix D). The practiced skills would be used on the homework assignment to draw out at least 10 ideas for their device to capture the flag. They then choose their top three and redraw on a full sheet of paper and bring to class to share with their teammates. The instructor challenged them to be creative in coming up with the ideas and reminded them that the categories they would be judged on were creativity in design, originality of the use of supplies, successfulness, crowd entertainment - wow factor, and team presentation. The second assignment was to draw a flag that represents the student's personality. The students were not told the purpose of this assignment yet, as this would be used for their introduction to their teammates in the next class. A flag was chosen to be consistent with the ocean voyage and flag retrieval theme of the course.

3.3.3 Class 3: Teams and Ideas Sharing

The third class on Wednesday, January 18th was about teams and idea sharing. The instructor had pre-assigned teams and stuffed envelopes with colored bandanas to reveal which team each student was on. A bandana was a convenient wearable to show off which team the student was a part of. They were divided into four teams - red, yellow, green, and blue - to allow the students to have a feeling of pride and association with their team. Class years and engineering experience for the students were distributed among the teams. When each student walked into the classroom, they picked up an envelope with their name on it, but they were not allowed to open it until told to do so. The instructor started class with a mini-quiz that asked about what ideation means and what were some of the creative strategies in brainstorming. Again, this mini-quiz was 2 minutes long, and it challenged the students to recall what was previously learned and allowed for the researcher to review that material again.

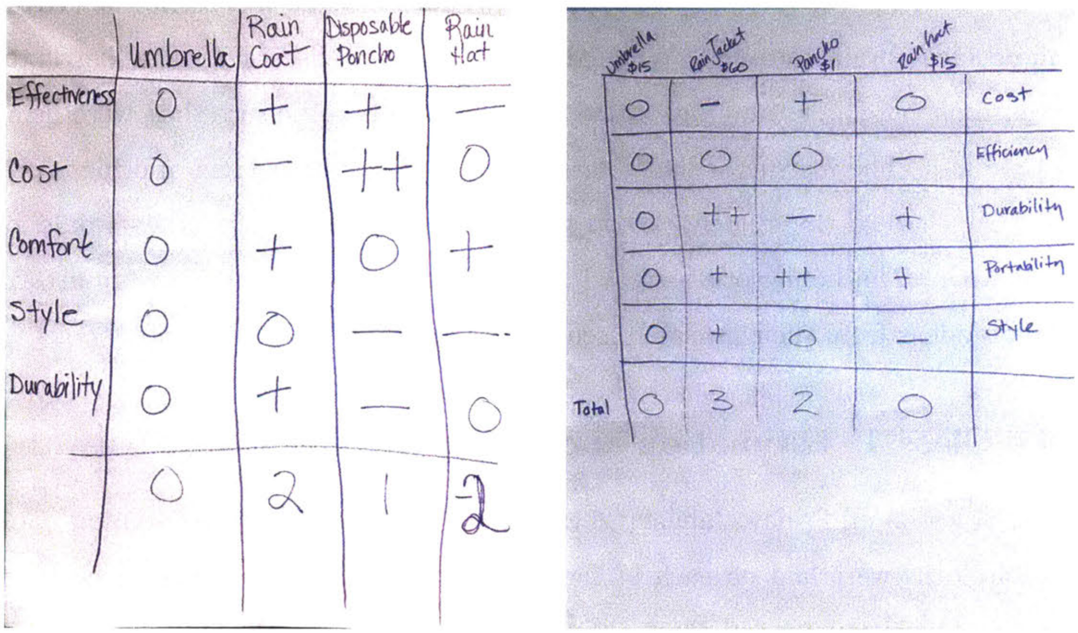
Next, the researcher covered some characteristics of a good team like clear performance goals, well-defined work approach, complementary skills, mutual accountability, communication, and shared values. After this, the students were allowed to open their envelopes. Based on the colored bandana, the students rearranged their seats to now sit with their teammates. Their first activity was to participate in a team building activity. Each team was given 200 Post-it notes of their team color and 24" of tape, and the students had to build the tallest simply supported tower in 15 minutes. The tower could not be fastened to or touching anything aside from the ground. The instructor chose to give the students post-it notes because they are each relatively small, and because the room isn't very tall (around 12' high), small notes would result in a smaller tower. An alternative that was considered was to take the challenge outside, but the weather that week was rainy and windy and would not be conducive to a challenge about building the tallest tower. The students were limited in tape add an extra challenge to building. The instructor thought that this tower-building team-building activity would be fitting because it challenged the teammates to work together in a time crunch and evaluate some basic engineering principles about stiffness to create a structurally sound tower.

After having fun with the activity, the students more formally introduced themselves to their teammates by talking about the flag that they drew about themselves as part of their last assignment. The rest of the time in class was for ideas sharing and more ideas brainstorming. While the students were discussing, the instructor reviewed their notebooks and gave some small comments to be sure they were using good practices. The instructor had some of the supplies, like the flag and foamcore, during that class so the students could get a sense of the materials they would be working with. The homework assigned at the end of this class was to brainstorm three more ideas from their in-class discussion and draw them in their notebooks.

3.3.4 Class 4: Estimation and Prototyping

The fourth lesson on Friday, January 20th covered estimation and prototyping. Colored tablecloths were laid on each of the four tables to designate where each team should sit. The instructor put three questions - how heavy was the 6' plastic table in front of them, how many basketballs fit in the classroom, and how many volts comes out of a US wall port - on the mini quiz to challenge the students to estimate properties of items around them. This mini quiz was unlike the previous ones, because the students had to guess as no material covered in the previous lesson would equip the students with the right answer. The reason for these questions was to give the students an understanding of common units and feasibility considerations.

Following estimation, the goal of the class was to allow for the students to narrow their many ideas and chose their final idea to make during the following week. Thus, the instructor taught the students how to use a Pugh chart. A Pugh chart is a quantitative technique used to evaluate the relative advantages of different concepts based on determined characteristics. Most of the students were already narrowing down their ideas for their device, but a more formal method would be useful for future decisions. Because it was raining outside, the students were tasked to decide to wear a rain jacket, disposable poncho, umbrella, or rain hat on a rainy day. The students were split up to 3-5 teams depending on how many parent volunteers were present for the class. Each group was spread around the room where large Post-it notes were hung on the wall, and a parent volunteer scribed as the students discussed (see Figure 3-10).



(a) High School Group Pugh Chart (b) Middle School Group Pugh Chart

Figure 3-10: Some results from the Pugh chart activity.

After the Pugh chart was covered, the instructor gave a safety demonstration on how to use an Olfa knife. Having two students as young as 5th grade, safety was an important factor for the class. After the demo, the students were allowed to use the knife to cut foamcore. For the rest of class, the students were allowed to bring the knives and cutting mats onto their team tables to cut material for prototyping, but they were only allowed to cut if a parent volunteer or the researcher was watching the student. The researcher supervised the rest of the class as the students experimented with the supplies. There was no assignment given at the end of this class.

3.3.5 Class 5-6: Building

The third week with class on January 25th and 27th was solely focused on allowing students time to build their devices (see Figure 3-11). No new material was taught during either of the two classes, but instead the students had free time to build their devices. Each of the four tables were lined with colored table cloths that signaled where each team should sit. Students used the two hours to test the different supplies, construct their mechanism, then clean-up. The students used more duct tape than the instructor originally anticipated by using it for both support and decoration. During the time the students were building, the instructor also had the flags hanging outside like they would be for the challenge, so the students could test their devices. For the middle school class, every team was nearly done and ready to go by the end of this week. Each of the middle school teams had time to test their products to retrieve the actual flags on the playground. For the high school class, only one team was able to test their functioning device. The original intent of the challenge was to design and build creative grabbing mechanisms to retrieve the flags, but as the build time progressed, the older students were having trouble building an arm stiff enough to span the distance to the flags. They spent most of their build time trying to create a beam or handle stiff enough to span the 14' before designing the actual mechanism to retrieve the flag. The younger students had many more inventive ideas for the flag retrieval because they had less concern about beam stiffness.

Figure 3-11: Middle school and high school students building their devices.

3.3.6 Class 7: Design Challenge

The seventh class on Wednesday, February 1st was the design challenge (see Figure 3-12). At the start of class, students were given another 30 minutes to fix any last-minute changes for their product. All the high school teams needed the extra time as most were doing last-minute gluing and taping. The middle school students had less trouble building successful devices and did not need time to finalize their devices. Instead, they spent the time making duct tape flags and other items to demonstrate team spirit. The researcher encouraged the students to wear their team colors as that would add to a feeling of team pride. For both classes, the challenge order was arbitrarily decided to be green, blue, red, then yellow. For the high school class, the challenge ran such that two teams were able to retrieve three flags, and the other two teams were not able to retrieve any flags because of insufficient beam stiffness. The challenge for the high school students came down to which team had a beam stiff enough to span the distance of the playground to reach the flags. Their time was also lengthened to 3 minutes as the teams were having a hard time retrieving flags in the original 2 minute time limit. Many parents came to watch the design challenge and enjoyed seeing the work of their students. For the middle school class, all the teams were able to retrieve all 5 flags, and the challenge came down to which team could do it the fastest, with the fastest team being just under a minute. After the design challenge, everyone went back into the classroom, discussed the designs, and talked about what lessons they had learned from this process. The class finished with clean-up time.

Figure 3-12: Middle and high school students during the design challenge.

3.3.7 Class 8: Looking Ahead

The very last class on Friday, February 3rd was a "looking ahead" class. The instructor taught the students some practical applications and uses for engineering and design beyond the scope of their design challenge. She shared about MIT's five main topics in mechanical engineering: mechanics and materials, dynamics and controls, thermal-fluids engineering, design and manufacturing, and product design. Each of these main topics was introduced to the students with relevant examples.

For mechanics and materials, the instructor shared about beam bending and the factors that go into the forces felt on a cantilevered beam. This was related to the problem many of the high school students were having in creating a stiff enough beam to support reaching the flag. Regarding dynamics and controls, the instructor talked about the moving carriage in Disneyland's Mickey's Fun Wheel ride. She shared about modeling and predicting motion. The researcher wanted to avoid talking about cars and robots because she didn't want to reinforce the misconception that engineering is only cars and robots. For thermal-fluids engineering, the instructor explained how a refrigerator works with fluid flow and heat transfer.

For design and manufacturing, the instructor taught the students some of the main manufacturing techniques like extrusion, injection molding, and thermoforming. By now, the students have been sitting and listening for an hour, so hands-on examples were introduced. To demonstrate an extrusion, the researcher made a small square mold from foamcore and pushed play dough through the hole to show a change in shape. The researcher also brought a yo-yo that shows both injection molding and thermoforming techniques. The researcher gave each student a dental floss box (see Figure 3-13) and had them take it apart to determine how each of the parts were made. She covered ways that the students could recognize different manufacturing processes.

Figure 3-13: Dental floss packet.

Finally, the instructor talked about product design. Most of the course had been covering the product design process through an engineering lens, but the second half of this lecture focused on the design side. Material was pulled from MIT's 2.744 Product Design, and the instructor shared elements of successful design. The main example was exploring what font and size to make a particular caption for an image. The instructor then briefly described a few other types of engineering to show the diversity in engineering. To conclude the class, the researcher had the students fill out the post-class survey to ensure high response rates.

Chapter 4

Results

4.1 Pre-Class Survey

An online pre-class survey was sent out to the students in December 2016, a month before the first class of the study. Every question on the survey was optional, and the intent of this pre-class survey was to gauge students' interests in and perceptions of engineering and design. The responses from this survey would be compared to the responses from the post-class survey to evaluate the effectiveness of the taught material. Of the 43 students in the course, 38 students completed the pre-class survey. Eleven of the respondents were female, and 27 were male, with the grade distribution of 21 middle school students and 17 high school students (see Table 4.1).

Gender Distribution of Pre-Class Survey Reponses	
Male 27 (71%)	Female 11 (29%)
Class Distribution of Pre-Class Survey Reponses	
5-8th 21 (55%)	9-12th 17 (45%)

Table 4.1: Gender and class distribution of pre-class survey responses.

In the survey, students were asked to list adjectives or words they associated with engineering. A note was added that "I don't know" was a completely valid response. Five of the responses were "I don't know," and the rest of the varied responses fell under three categories: characteristics, things, and people. There was a relatively equal distribution of positive words like "creative" and "exciting," negative words like "hard" and "work," and neutral words like "necessary" and "practical." In total, students came up with 99 words or phrases, including repeated answers from different students, to describe engineering (see Table 4.2).

None	I don't know x5		
Characteristics	Math/ematical x6	Creative/ing/ity x5	Difficult x3
	Fun x3	Design x3	Building x2
	Interesting x2	Work x2	Cool x2
	Technology x2	Forethought	Function
	Planning	Challenging	Futuristic
	Development	Intelligence	Rewarding
	Improve	Precise	Necessary
	Complex	Ok	Exciting
	Brainstorming	Teamwork	Failure
	Awesome	Interesting	Hard
	Looking	Find the solution	Practical
	Efficient	Looking at the problem	STEM
	Invent	Finding the solution	Complicated
	Critical thinking	Trying again	Science
	Intriguing		
Things	Robotics x5	Computers x2	Tools x 2
	Cars x2	Engines x2	Wood
	CAD	Geometry	Machinery
	Bridge	Toothpicks	Glue
	Fire	Hydroelectric Dams	Metals
	Wires	Gravity	Scale Models
	Puzzle	Architecture	Construction
	Battery	Electronics	
People	Neighbor x2	Family x2	Mechanic x2

Table 4.2: Words associated with engineering from pre-class survey.

Students were also asked to list adjectives or words they associated with product design. A note was added that "I don't know" was a completely valid answer. Sixteen responses were "I don't know," and the rest of the varied responses fell under three categories: characteristics, things, and people. Most of the words associated had positive, like "intelligent," or neutral, like "car" connotations. In total, students came up with 71 words or phrases, including repeated answers from different students, to describe product design (see Table 4.3).

None	I don't know x16		
Characteristics	Sketching x2	User-friendly x2	Creative/ing x2
	Useful x2	Design/ing x2	Brainstorming x2
	Test/ing x2	Originality	Intelligent
	Architectural	Aesthetic	Project managing
	Inventing	Innovation	Interesting to learn
	Eye-catching	Smart	Designed to simplify
	Improvement	Measuring	Collaborating
	Building	Lots of lines	Sturdy
	Reliable	Cost Effective	Not heavy or light
	Functional	Form	Fun to watch
	Efficient	Elegant	
Things	Drawings x2	Blueprints	Shapes
	Car	Plastic	Decoration
	Invention	Art	Trade dress
	Graphics	CAD	3D-printing
	Ideas	Concept	
People	Sibling		

Table 4.3: Words associated with product design from pre-class survey.

The next category of questions asked the students to rank their agreement with certain statements. The statements were "I am interested in engineering," "I already know a specific field of engineering that interests me (biomedical, electrical, mechanical, etc," "I am interested in design," "I am interested in art," "I have experience with engineering (any type)," and "I am personally interested in this course (Disagree if your parents signed you up just because)." For each of these statements, they could chose one of the following options: "Strongly agree," "Slightly agree," "Neutral," "Slightly disagree," "Disagree," or "I don't know." More than half the students expressed some sort of interest in engineering, design, and art (see Tables 4.4, 4.6, and 4.7). 42% of students knew what type of specific engineering they wanted to pursue (see Table 4.5). In contrast to the interest, only 10 students (26%) of the respondents said to have experience with engineering (see Table 4.8), and 13 students (34%) were not personally interested in taking the course (see Table 4.9).

	Str Agree	Slt Agree	Neutral	Slt Dis	Disagree	IDK
Middle	9 (24%)	8 (21%)	4 (11%)	0 (0%)	0 (0%)	0 (0%)
High	4 (10%)	8 (21%)	2 (5%)	1 (3%)	1 (3%)	1 (2%)
Total	**13 (34%)**	**16 (42%)**	**6 (16%)**	**1 (3%)**	**1 (3%)**	**1 (2%)**

Table 4.4: Pre-class interest in engineering.

	Str Agree	Slt Agree	Neutral	Slt Dis	Disagree	IDK
Middle	1 (3%)	6 (16%)	4 (10%)	1 (3%)	2 (5%)	2 (5%)
High	2 (5%)	7 (18%)	0 (0%)	0 (0%)	6 (16%)	7 (19%)
Total	**3 (8%)**	**13 (34%)**	**4 (10%)**	**1 (3%)**	**8 (21%)**	**9 (24%)**

Table 4.5: Pre-class specific field of engineering interest.

	Str Agree	Slt Agree	Neutral	Slt Dis	Disagree	IDK
Middle	7 (19%)	6 (16%)	6 (16%)	2 (5%)	0 (0%)	0 (0%)
High	5 (13%)	8 (21%)	1 (2%)	1 (3%)	2 (5%)	0 (0%)
Total	**12 (32%)**	**14 (37%)**	**7 (18%)**	**3 (8%)**	**2 (5%)**	**0 (0%)**

Table 4.6: Pre-class interest in design.

	Str Agree	Slt Agree	Neutral	Slt Dis	Disagree	IDK
Middle	4 (10%)	2 (5%)	2 (5%)	4 (11%)	2 (5%)	0 (0%)
High	6 (16%)	9 (24%)	3 (8%)	3 (8%)	3 (8%)	0 (0%)
Total	**10 (26%)**	**11 (29%)**	**5 (13%)**	**7 (19%)**	**5 (13%)**	**0 (0%)**

Table 4.7: Pre-class interest in art.

	Str Agree	Slt Agree	Neutral	Slt Dis	Disagree	IDK
Middle	4 (10%)	4 (11%)	5 (13%)	3 (8%)	2 (5%)	3 (8%)
High	0 (0%)	2 (5%)	1 (3%)	5 (13%)	6 (16%)	3 (8%)
Total	**4 (10%)**	**6 (16%)**	**6 (16%)**	**8 (21%)**	**8 (21%)**	**6 (16%)**

Table 4.8: Pre-class experience in engineering.

The following question asked if the students had experience with engineering and design. In this question, students were able to explain their answer choices to the

	Str Agree	Slt Agree	Neutral	Sly Dis	Disagree	IDK
Middle	12 (32%)	3 (8%)	2 (5%)	1 (3%)	1 (3%)	0 (0%)
High	8 (21%)	2 (5%)	4 (11%)	1 (2%)	4 (10%)	0 (0%)
Total	**20 (53%)**	**5 (13%)**	**6 (16%)**	**2 (5%)**	**5 (13%)**	**0 (0%)**

Table 4.9: Pre-class personal interest in class.

earlier questions in short-answer form. The question noted that crafting, sewing, drawing, helping your parents fix things around the house, building, and programming were just a few examples of experiences they could write. Many students listed experiences from this suggested list (see Table 4.10). Most students mentioned experience from helping their parents fix items around the house. Nine students listed involvement with the SCA robotics team for First Lego League (FLL), a relatively new activity available to SCA students.

Housework x13	Sewing x10	SCA Robotics FLL x9
Simple building x8	Drawing x7	Legos x7
Art x5	Programming x4	Tearing down/repairing x3
Making a robot x2	Crafting	Knitting
Designing posters	Computer animated design	Woodworking
3D Software	Architecture	Industrial design camp
Painting	Designed a building	Boy Scouts

Table 4.10: Experience with engineering and design from pre-class survey.

Finally they were asked to share any other information that might be relevant to the researcher in understanding students' perceptions of engineering and design. Most students used this question to elaborate on some of their answers to the earlier questions. One student signed up for the class because of his interest in math, and another female wrote that she enrolled for the course because the teacher was also female.

4.2 Brainstorming Activities

4.2.1 Individual Brainstorming Activity

After learning some brainstorming techniques during the second class in this study, students were given 8 minutes to brainstorm as many ideas as they could to get someone to the top of a rock several thousand feet high (see Appendix E). Students in the high school class brainstormed from 8-24 ideas with an average of 15 ideas each. Students in the middle school class brainstormed from 6-25 ideas with an average of 14 ideas each. Generally the first half of their ideas were feasible and realistic like climbing or being flown to the top. Around half way through the time, as students ran out of practical and realistic ideas, they were encouraged to practice some of the brainstorming strategies they were taught by thinking creatively and challenging assumptions. Many of the latter ideas were more unrealistic like "reverse gravity" or "that antigravity juice from the original Willy Wonka movie." Several innovative ideas that challenged the assumptions in the prompt included "TNT blowing up the rock so you're already at the top" or "flood the valley and float to the top."

4.2.2 Group Brainstorming Activity

For the group brainstorming activity, the high school class was challenged to come up with as many questions as they could in 15 minutes for the given prompt "What questions would you ask when designing an enclosure for electronic parts?" (see Appendix F). On average, teams came up with 26 questions. Questions included "What is the enclosure being used for?" and "What materials should it be compatible with?" The middle school class was challenged to come up with as many questions as they could in 15 minutes for the given prompt "What questions would you ask when designing a house?" On average, teams came up with 26 questions. Questions included "How many people are living in the house?" and "Does the house need security protection?"

4.3 Post-Class Survey

The post-class survey was printed on paper and administered to the students at the end of the last day of class. Several students missed that class due to another conflict but filled out the survey later online. Of the 43 students who participated in the class, 37 completed the post-class survey.

Like in the pre-class survey, students were asked to list words they associated with engineering. However, this time, there was no note saying "I don't know" was an acceptable response in the hopes the students learned something about engineering from the class. The varied student responses fell under two categories: characteristics and things. Some words referenced direct activities that were done in class like "Pugh chart" or "floss/floss containers." In comparison to the pre-class survey responses, students mostly attributed positive words to engineering. In total, students came up with 148 words or phrases, including repeated answers from different students, to describe engineering (see Table 4.11).

Characteristics	Fun x17 Math/ematical x6 Teamwork x3 Product design x2 Challenging x2 Complicated x2 Prototype/ing x2 Hard x2 Thoughtful process Necessary Good for the brain Rewarding Movement Scaling Productivity Plastic Metallic/Grey/Black Industriousness Technology Testing Innovating	Create/ing/ive x12 Interesting x4 Hands on x3 Technical x2 Helpful/ness x2 Brainstorming x2 Mechanical/ics x2 Fascinating x2 Intricate Intriguing Electrical Stressful Comprehensive Product Goals Rough Hot/Cold Wanted Workability Architecture Aesthetic Chemical	Design x10 Thinking x4 Work x3 Building x2 Build x2 Drawing x2 Function x2 Swag Complex Engaging Smart Cool Intuitive Sketching Likable Feasibility Needed Application Form Mechanical
Things	Product x2 Structure x2 Problem needing solving Golden Gate Bridge Thermoforming Experiment Infrastructure Floss/floss containers	Electronics x2 Tool x2 Machine Forklift Robot Yo-yo Pugh chart Energy	Car x2 Material Bending Extrusion Calculus Pole Mold Mass

Table 4.11: Words associated with engineering from post-class survey.

The students next were asked to list words that they associated with product design. This was the exact same question as in the pre-class survey, but this time there was no note saying "I don't know" was an acceptable response in the hopes that the students learned something about product design from the class. The varied student responses fell under three categories: characteristics, things, and people. Several words related to the manufacturing processes like "bending" and "thermoforming" may have been written as those processes were taught in the same class period that the survey was administered. In total, students came up with 119 words or phrases, including repeated answers from different students, to describe product design (see

Table 4.12).

Characteristics	Fun x7	Creative/ity/tion x7	Aesthetic x4
	Form x4	Function x4	Sketch/ing x4
	Ideation x3	Prototype/ing x3	Design/ing x3
	Color/ful x2	Calculations/ing x2	Challenging x2
	Hard x2	Usefulness/ability x2	Interesting x2
	Ideation x2	Brainstorming x2	Draw out/ing x2
	Engineering x2	User Necessity	Progressive
	Trial and error	Natural	Helpful
	Likable	Communication	Needed
	Wanted	Mass Production	Hands-on
	Frustrating	Demand	Learning
	Workability	Effectiveness	Imagination
	Originality	Green	Hot/Cold
	Small	Smooth	Graphic
	Modeling	Well-fashioned	Manufactured
	Measured	Forming	Understanding
	Orderly	Specific	Making things
	Problems	Solutions	Math
	Marketing	Ideas	Art
	Skillful	Difficult	Business Case
	Elegant	Simplistic	Defer all judgment
	Thinking outside the box		
Things	Product x3	Tools x2	Money x2
	Shape	Pole	Flag
	Tape	Plastic	Mold
	Books	Supplies	Production Lines
	Paper	Pen/pencil	Thermoforming
	Bending		
Person	Sibling		

Table 4.12: Words associated with product design from post-class survey.

The next set of questions had the students rank their agreement with different statements. The statements were "I am interested in engineering," "I am more interested in engineering than I was before this course," "I am interested in design," "I am more interested in design than I was before this course," "I am interested in art," "I am more interested in art than I was before this course," "This course taught me skills I previously did not know," and "I enjoyed taking this course." Students could choose from the options: "Strongly agree," "Slightly agree," "Neutral," "Slightly Disagree,"

"Disagree," and "I don't know." A majority of students reported to be interested in engineering, design, and art (see Tables 4.13, 4.15, and 4.17). A majority of students also are more interested in engineering and design after taking the course than before (see Tables 4.14 and 4.16). Students did not agree strongly with a greater interest in art (see Table 4.18), but art also was not a crucial component or focus of this course. 97% of the survey respondents learned new skills from this course and enjoyed taking the course (see Tables 4.19 and 4.20).

	Str Agree	Slt Agree	Neutral	Slt Dis	Disagree	IDK
Middle	11 (30%)	6 (17%)	0 (0%)	1 (3%)	1 (3%)	0 (0%)
High	5 (14%)	9 (25%)	2 (5%)	0 (0%)	1 (3%)	0 (0%)
Total	**16 (44%)**	**15 (42%)**	**2 (5%)**	**1 (3%)**	**2 (6%)**	**0 (0%)**

Table 4.13: Post-class interest in engineering.

	Str Agree	Slt Agree	Neutral	Slt Dis	Disagree	IDK
Middle	9 (25%)	5 (14%)	4 (11%)	0 (0%)	0 (0%)	0 (0%)
High	10 (28%)	5 (14%)	1 (3%)	0 (0%)	2 (5%)	0 (0%)
Total	**19 (53%)**	**10 (28%)**	**5 (14%)**	**0 (0%)**	**2 (5%)**	**0 (0%)**

Table 4.14: Post-class increased interest in engineering.

	Str Agree	Slt Agree	Neutral	Slt Dis	Disagree	IDK
Middle	7 (20%)	7 (19%)	4 (11%)	0 (0%)	1 (3%)	0 (0%)
High	8 (22%)	6 (17%)	3 (8%)	0 (0%)	0 (0%)	0 (0%)
Total	**15 (42%)**	**13 (36%)**	**7 (19%)**	**0 (0%)**	**1 (3%)**	**0 (0%)**

Table 4.15: Post-class interest in design.

	Str Agree	Slt Agree	Neutral	Slt Dis	Disagree	IDK
Middle	6 (17%)	6 (17%)	4 (11%)	0 (0%)	0 (0%)	0 (0%)
High	7 (20%)	9 (26%)	0 (0%)	0 (0%)	3 (9%)	0 (0%)
Total	**13 (37%)**	**15 (43%)**	**4 (11%)**	**0 (0%)**	**3 (9%)**	**0 (0%)**

Table 4.16: Post-class increased interest in design.

	Str Agree	Slt Agree	Neutral	Slt Dis	Disagree	IDK
Middle	5 (14%)	7 (19%)	2 (6%)	0 (0%)	3 (8%)	1 (3%)
High	7 (19%)	2 (6%)	4 (11%)	2 (6%)	3 (8%)	0 (0%)
Total	**12 (33%)**	**9 (25%)**	**6 (17%)**	**2 (6%)**	**6 (16%)**	**1 (3%)**

Table 4.17: Post-class interest in art.

	Str Agree	Slt Agree	Neutral	Slt Dis	Disagree	IDK
Middle	2 (6%)	7 (19%)	3 (8%)	1 (3%)	4 (11%)	1 (3%)
High	2 (5%)	4 (11%)	6 (17%)	1 (3%)	5 (14%)	0 (0%)
Total	**4 (11%)**	**11 (30%)**	**9 (25%)**	**2 (6%)**	**9 (25%)**	**1 (3%)**

Table 4.18: Post-class increased interest in art.

	Str Agree	Slt Agree	Neutral	Slt Dis	Disagree	IDK
Middle	13 (36%)	5 (14%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)
High	14 (39%)	3 (8%)	0 (0%)	0 (0%)	1 (3%)	0 (0%)
Total	**27 (75%)**	**8 (22%)**	**0 (0%)**	**0 (0%)**	**1 (3%)**	**0 (0%)**

Table 4.19: Post-class learned new skills

	Str Agree	Slt Agree	Neutral	Slt Dis	Disagree	IDK
Middle	17 (44%)	1 (3%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)
High	16 (47%)	1 (3%)	0 (0%)	1 (3%)	0 (0%)	0 (0%)
Total	**33 (91%)**	**2 (6%)**	**0 (0%)**	**1 (3%)**	**0 (0%)**	**0 (0%)**

Table 4.20: Post-class enjoyed the course.

The next question asked what activities the students enjoyed in the course. Each of the activities was listed, and students could check the box for each activity they enjoyed. A total of 36 students responded to this question. 97% of the respondents enjoyed the design challenge. A majority of students did not enjoy the mini-quizzes, but the quizzes were meant to be more instructive than enjoyable (see Figure 4-1). Some students filled out the "Other" box with sharing flag ideas, building the flag-retrieving device, flag building from duct tape, cutting skills and creating, free materials/supplies, having fun, a yo-yo which was brought to class on the last day as a prop, and design notebooks.

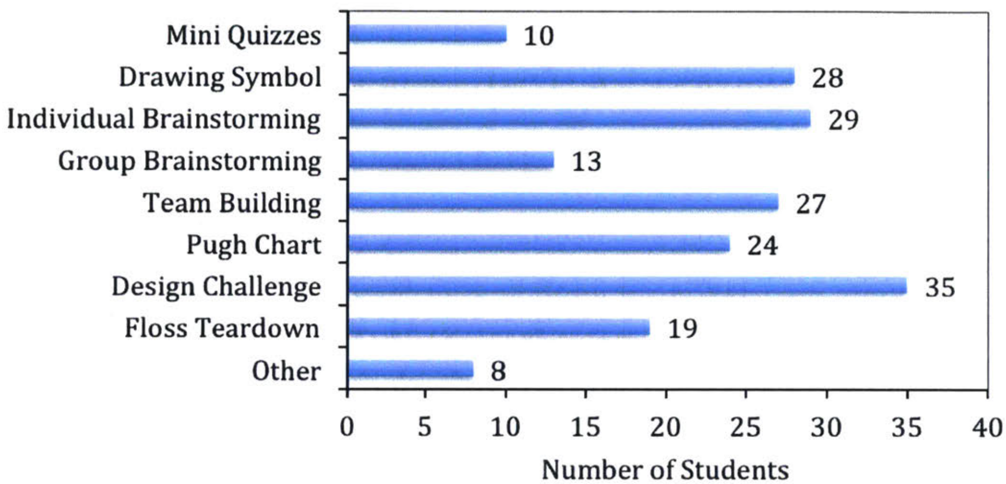


Figure 4-1: Activities that students enjoyed.

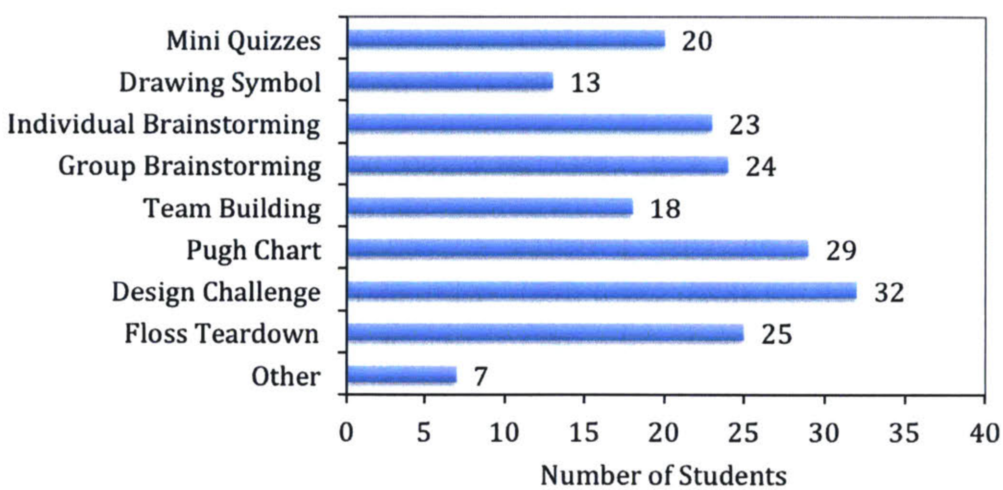


Figure 4-2: Activities that contributed to the students' learning.

Parallel what activities the students enjoyed, the following question asked the students which activities contributed to their learning experience. Each activity was listed, and they could check the box for the activities that they felt like contributed to their learning. A total of 36 students responded to this question (see Figure 4-2). Some students filled out the "Other" box with cutting foamcore, learning to sketch better, learning from mistakes, and the actual lecture/teaching portion of the class.

The students were then asked to share more explicitly what they did and did not enjoy about the course. Since the previous questions only allowed them to check options, this text-based question allowed students to elaborate on their reasoning for their responses to previous questions. In general, students enjoyed learning about engineering. Some wrote about enjoying the design challenge, and others wrote about enjoying the hands-on approach of teaching. For feedback, some students suggested more building time to create their device and making the design challenge a little simpler.

The final question asked if the students wanted to share anything else with the researcher about their experiences in this course. Most students used this section to share about how the class had positively impacted them. One high school student responded, "My experiences as a student in this class have deepened my understanding of the design process as well as helped me learn to efficiently brainstorm ideas, clearly convey those ideas to others, and adapt to different circumstances."

4.4 Parent Responses

Throughout the term of the course, parents approached the researcher before or after class to share stories of their students enjoying the class. One parent shared that her student would excitedly share about what was taught in class all day, and it would always be the topic of discussion at the dinner table. Parents shared that this course was the highlight of their student's day, every day the class was offered. One parent requested if this course could be continued independently for the rest of the semester because her student was particularly interested in this field of study. Another parent mentioned wanting to start an engineering club at the school. With all the current excitement about engineering, the parent believed there was no better time to start the club. After the class concluded, two other parents mentioned in emails that their students have found a new appreciation for engineering and were now considering pursuing it for the future. Some parents said that this class was the push that their student needed to develop an interest in engineering, and others said that this hands-on teaching style of the class was the type of learning that engages their student. By the end of the course, at least 25 parents had reached out to the researcher with positive feedback and encouragement about this course.

Chapter 5

Discussion

5.1 Surveys

5.1.1 Perception of Engineering and Product Design

The pre-class and post-class surveys asked parallel questions, and the responses to these questions were compared. In total, students associated 49 more words, 49.5% more, with engineering after taking the course than before. In general, the words describing engineering in the post-class survey were more positive than the pre-class survey. For example, "fun" was listed 17 times in the post-class survey but only 3 times in the pre-class survey. "Hard" was listed twice in the post-class survey, but "hard" and "difficult" together were listed four times in the pre-class survey. Words like "complicated" and "complex" appear in both surveys, but those are attributes to the nature of the subject. There were 19 more unique words, 27.5% more, in the post-class survey than in the pre-class survey, potentially meaning the students' perceptions of engineering have widened.

For words associated with product design, in total, students came up with 48 more words, 67.6% more, after taking the course than before. Sixteen students originally wrote "I don't know" to describe product design, and after the course, every student wrote at least a couple descriptive words. The content of the words in both surveys were similar, meaning that students who had previously known about product design did not have a major change in perception and many new students learned about this subject.

5.1.2 Interest in Engineering, Design, Art, and the Class

Prior to taking the class, 76% of the students expressed some sort of interest in engineering but only 46% said they knew what specific type they wanted to pursue. These numbers were higher than the researcher had anticipated from this group of students. The researcher had assumed the lack of engineering opportunities at the school paralleled to a lack of engineering interest, but instead perhaps students who were interested in engineering were students who signed up for this course. After the class, 86% of the respondents said they were now interested in engineering with 81% saying they are more interested in engineering than they were before the course. These results show that this class successfully interested more students in engineering. The researcher achieved her goal of introducing engineering to students, and she believes the interactive and engaging manner in which she presented the material helped disprove some stigmas about engineering being solely about numbers and calculations.

Prior to taking the course, 69% of students were interested in design, and 78% were interested after the class. Along with that, 80% were more interested in design after the class than before the class. The researcher was again surprised that the interest rate in design was so high before the class, but students still felt more interested after taking the class. The increased interest in design may have resulted from an increased knowledge of design or an enjoyment of the teaching style of the class.

Prior to taking the course, 53% of students were interested in art before the class, and 58% were interested after the class. Only 42% said there were more interested in art after the class than before. The interest rate after the class in this category had a much lower yield than the engineering and design interest. However, this was expected, as the researcher did not focus on art in this class. The only major art component in this course was a lesson on sketching and a few of the following classes practicing sketching warm-up techniques. Even then, sketching was taught in the context for communication of design and not for artistic purposes.

Regarding learning new skills, an overwhelming 97% of students agreed that they learned new skills in the course. The researcher anticipated a 100% agreement, because she personally did not learn the material she was teaching about to these students until her time in college. The 97% turnout may have resulted from the fact that in a homeschooled community, each student has a diverse background and skill set due to different educational experiences. Just because the researcher did not have these skills prior to college, that does not mean every other homeschooled student did not have those skills.

From the pre-class survey, 34% of the students were not personally interested in the course. These students may have still been enrolled in this class because of their parents. Some parents may have signed up their students to get them learning about engineering and not because of the student's personal interest. However, after the course, 97% of the respondents enjoyed the course. Despite an original lack of interest in the course from some students, most students ended up enjoying the course. The researcher's goal was to introduce engineering and design in a fun and interactive manner so that even if the students decided they did not want to pursue engineering, as long as they enjoyed their time in the course and learned something about engineering, the goal of the course was met.

5.1.3 Enjoyment and Educational Value of In-Class Activities

In the post-class survey, students checked off which in-class activities they enjoyed and which contributed to their learning experiences (see Figure 5-1). The design challenge was the clearly the most enjoyed activity. The entire course was built around the design challenge, with the skills learned and material covered during every lecture related to the challenge. The design challenge ended with a nice final showcase, so the large build-up may have increased the enjoyment of that project. Other activities that ranked highly were the individual brainstorming activity, the drawing out a symbol to represent adventure, the team building activity, and the Pugh chart. Interestingly, the individual brainstorming activity was enjoyed much more than the group brainstorming activity. This could be the case that the individual brainstorming activity had a more interesting prompt with the related picture or that the individual brainstorming activity happened before the group one, so by the time of the group brainstorming activity, students were already tired of brainstorming. The students may have also enjoyed the drawing out a symbol activity because that was the very first interactive activity of the entire course. The students had little, if any, expectations of these activities in the course, and thus the drawing out a symbol activity may have been particularly memorable. After all the students drew out their symbols, the class reviewed the designs, and students may also have enjoyed admiring each other's works. The team building was a fun fast-paced challenge to create the tallest tower with post-it notes. Students typically enjoy competitive challenges, and this was a fun, reasonable, and open-ended challenge. The Pugh chart also ranked highly, and that may be because it was something the students had never learned before this course. The items for comparison for the Pugh chart were rain-related items, and it was raining the day of the activity, so the students could have also found the activity relatable to a decision they would normally make. The students also seemed to have enjoyed discussing their opinions for ranking the items with their teammates as they were able to challenge other student's opinions and stand for their own. The mini-quizzes were by far the lowest ranked enjoyed activity, but the researcher's main goal for the mini-quizzes was to be educational even if it lessened enjoyment.

Mini-quizzes were rated much higher as an activity that contributed to the student's learning than an activity that they enjoyed. Twice the number of students claimed that the quizzes were educational rather than enjoyable. The researcher planned the mini-quizzes to have the students recall and review previous lessons, giving students several chances to see the material, and therefore, a higher chance of remembering it. The dental floss teardown also ranked higher as an activity that contributed to their learning than one that they enjoyed. Students were taught manufacturing techniques with this activity, and those were not techniques a majority of the students were familiar with. Thus, this activity paired well with the newly learned material in getting a practical look at the effects of different manufacturing processes.

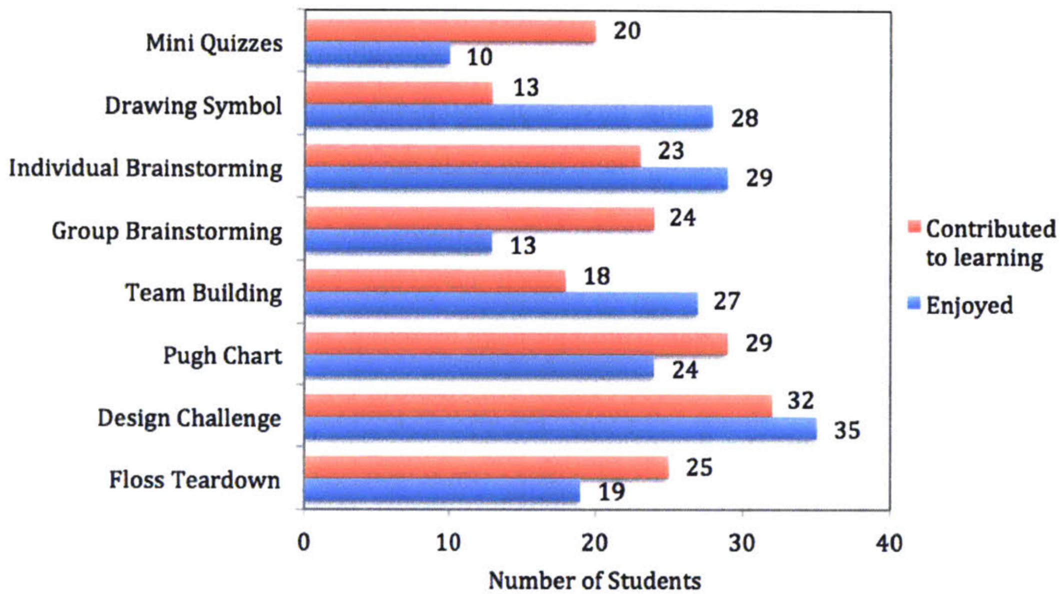


Figure 5-1: Comparison of activities students enjoyed to activities that contributed to their learning.

On the flip side, the team building activity did not rank as well in activities that contributed to their learning as it could have been perceived as a solely entertaining activity. Building a simply supported tower subtly covered engineering principles in creating a structurally sound tall building, but most students instead perceived it as a fun competition. Drawing out the symbol for adventure also ranked much lower as an educational activity. This activity was to challenge the students to be creative and smart in their communication of a design, but the activity was introduced immediately after a brief discussion of design, so students may not have had time to process the relevance of the material. Even though the students enjoyed the individual brainstorming activity much more than the group brainstorming activity, they both were rated similarly for educational value. Two students listed the lectures as another source of learning through the "Other" option, and the researcher realized after the fact that she should have listed that as one of the activities.

Specific feedback from the students ranged from more time to build to more concrete rules for the design challenge. Students were given half a class period to prototype and two and a half class periods to build their final product - six hours total. The researcher did not allow for the students to work on their project outside of class, potentially contributing to students feeling rushed on their projects. More prototyping time to test design ideas could have eliminated the problems some teams were having near the end when building their large-scale device without any validation of its successfulness.

Especially for the high school class, their challenge was complicated with the distance they were standing away from the flags as teams struggled to create a long and steady arm to span that distance. The researcher did not anticipate the arm to be the challenge but instead the flag-grabbing mechanism, so she did not appropriately equip the students with sufficient knowledge to easily create a sturdy arm. The researcher did not have a good enough gauge to what the students were capable of, so the design challenge ended up being slightly too challenging for the high school class and slightly too easy for the middle school class. The researcher changed some of the rules for the high school class, like allowing for two separate parts for a device or extending the challenge time to 3 minutes, throughout the build process of the class to accommodate for its complexity. The change in rules may have caused some students to be confused and frustrated with the challenge, so getting a better sense of what students may be able to achieve in the month-long class could have prevent this. For future reference, the researcher should have made a quick simple prototype to complete the challenge herself to see what the challenges in retrieving the flags would be.

5.2 Brainstorming Activities

The goal of the two brainstorming activities was to allow the students to practice creative brainstorming techniques. The researcher told the students that she valued quantity over quality of ideas. For the individual brainstorming activity, student's ideas can be grouped into several categories - realistic, past experiences, and innovative (see Appendix E). Many of the realistic ideas pulled from common experiences like elevators, stairs, and climbing. Realistic ideas were consistently the first ones on students' lists as that was the most direct way of answering the prompt. But about half way through their time, when they started running out of ideas, they often diverged into two different options - inspired from past experiences or innovative. The first pulled on unrealistic things that the students have seen from past experiences like movies - using the force from Star Wars, drinking the antigravity juice from the original Willy Wonka movie, or riding roadrunner to the top. The second group were innovative ideas to answering around the prompt question like TNT blowing up the rock so you're already at the top or flooding the valley and floating to the top. Given this was the first time many of the students participated in a brainstorming activity in this manner, there was a wide variety of results and high number of ideas per student. In the following class, the researcher shared some of the brainstormed ideas to the students, and they enjoyed seeing what creative ideas other students in the class came up with.

The group brainstorming activity was similar to the individual one, but it focused more on building upon other student's ideas. In this activity, instead of coming up with solutions to a question, they were coming up with questions for a solution. The researcher scribed ideas down for a team of students, and she found that as each student mentioned a question, others would come up with related thoughts and ask another question (see Appendix F). For example, when a student asked "Do you see it?" with regards to designing an enclosure for electronic parts, another students chimed in "Is it eye-catching" or "Does it have to be interesting, colorful, aesthetic?" Sometimes a student would have an idea for a question, but be unsure how to phrase it so would explain the concept to his teammates. But as the student is describing the concept, the teammates interpret the intended question differently, and so the original one idea ends up being listed as several questions. For the middle school students, every team assumed the house they were designing was for humans, which was not necessarily part of the prompt. The researcher found this group brainstorming activity much quicker paced than the individual brainstorming activity, and the limiting factor for coming up with more ideas was not running out of ideas but instead the time it took for the scribe to write out each idea.

5.3 Parent Responses

Over 25 parents reached out to the researcher during both the planning and execution of this course. Prior to the study, many parents expressed over email their excitement for this opportunity for their students. The researcher did not disclose much of her teaching plan to the students or parents, and so much of the parent communication revolved around excitement and curiosity for what the class would entail. During the teaching of the class, many parents expressed their appreciation of the course both in person and over email.

SCA was deficient in engineering opportunities, and having such a unique and hands-on class was unlike anything that was previously taught at the school. Occasionally SCA would offer science classes that may include a dissection experiment, but those often followed a prescribed homeschool curriculum from an established publisher. This course that the researcher taught was an independent venture that was unlike any traditional homeschool curriculum textbook. Many parents were curious as to how the researcher got this idea and about student life at MIT. Parents asked if the style that this course was being taught was how all MIT classes were taught or if the male to female ratio at MIT was as uneven as it was in this course. With homeschooling, parents often guide the students into their future from what they know, so the researcher used these opportunities to share with parents her experiences so they could be stepping-stones to getting their students into pursuing engineering.

5.4 Personal Reflection

The researcher had been planning this course for over a year before the actual start date of the course. With all this investment, the researcher was pleased with the final result. Given that this was the researcher's first time teaching and SCA's first time offering a month-long course, the course was successful. The researcher was nervous on the first day to see how the students would respond to the different material and teaching style, but she was thrilled that they gave her their best attention and interest in the material. The course achieved the goals the researcher planned.

However, there were many lessons learned in this experience. Though the researcher did not get this feedback directly from this course, the researcher has often been told she is a fast talker. Sometimes the researcher noticed from the looks on the student's face that the material was being covered too quickly, and the researcher would slow down and re-explain concepts until she felt like students understood. Parallel to speaking slower, the researcher would like to cut back on some of the material being taught or extend the length of the course while still covering the same material. Whether it could be achieved by going less in depth in certain material or cutting out some topics, the researcher believes she covered some material too quickly at the expense of covering a wide range of topics. She tried to cover breadth and depth together in one course, but this introduction course would be better served if it just addressed breadth.

One student's feedback was to have more building time for the design challenge. This feedback was a result of the design challenge being too complicated for the high school students. The researcher had intended for the challenge to be how to retrieve the flags, whether the students would use a clamp, clip, or hook device. However, for the high school students, the students were not concerned about retrieving the flag, instead they were concerned with creating a long, structural pole. Because they were 14ft away, they could not simply glue foamcore pieces together. They really had to understand the structural engineering it takes to create a rigid beam. Most of the students were not previously exposed to this material, and thus by chance whichever teams ended up with rigid beams were the teams that were successful in the challenge. One of the high school class teams had an innovative clip to retrieve the flag, but because they could not create a structurally sound beam, they were unable to retrieve any flags.

Another student gave feedback that the material that was taught in the last class about more in depth engineering principles would have been useful to have learned before the design challenge. Perhaps if the researcher tried to build a device herself first to retrieve the flags, she would have anticipated the challenge of creating a sturdy beam when standing 14' away and been able to teach material more relevant to the students earlier for building their devices.

Aside from the design challenge, the researcher was pleased with the reception of the other interactive activities in the classes. She had at least one activity for each major topic covered in the lectures. The researcher felt that every activity was relevant to the students, but she could do a better job communicating to the students why it was relevant so the students find more interest and value in the activities. Some activities may not have been rated highly by the students as having educational value because the researcher did not emphasize the importance of the activity.

During every class, the researcher also gave something to the students, like supplies or worksheets for them to keep or supplies that the students could use for their design challenge. The students enjoyed having free supplies to play with, and the researcher would take note to provide materials in abundance for a future class.

If the researcher were to teach this program again, she would teach in a very similar manner as the program ran nearly exactly how she planned. The planning of the program itself was much more time-consuming than expected, but teaching the program again would mean the core material would already be planned. The researcher was pleased with the month-long duration of the program. Extending the course to an entire semester would result in much more in-depth material, but this month was sufficient time for an introduction course. Alternatively the researcher would consider a two-week long program with classes Monday, Tuesday, Thursday, and Friday of each week to still result in the eight classes. However, a two-week program would most likely have to be part of a summer program and not during the school year as it would be hard to fit into student schedules. The researcher would stick to at least two classes a week if the schedule allows so the students do not go more than a few days before another lecture.

With the feedback of which activities the students enjoyed and which contributed to their learning, the researcher would keep the same activities, except provide more instructions, guidelines, and reasons why a particular activity is significant. The researcher believed that some of the activities may not have been as impactful to the students as intended because the researcher did not fully explain to the students why the particular activity was valuable in practicing a skill. The researcher was so focused on teaching the students the material that she did not cover why it was important to be learning what she was teaching.

The researcher would also be more wary of any academic phrases she used to communicate to the students. At one point during a high school class, she said the phrase "simple geometry" to reference how to find the hypotenuse of a triangle from the two side lengths. A parent later told the researcher that she laughed at that comment because geometry is not simple to many people. The researcher would want to be wiser with her words so as not to discourage any students if they do not understand.

If the researcher went back to SCA to teach again, she would want to offer this introduction class again to the same age groups - middle school and high school - with the changes mentioned above. At least one parent has already asked the researcher to let her know if she would be teaching again as the parent had a student who could not make the course this time but would like to participate in the future. There are more students in each grade that the researcher was not able to reach in this course, but through a positive word of mouth from students who had already taken the course, the researcher hopes to have more interest in potential future classes.

The researcher would also like to offer a more advanced engineering course to students who have already taken her introduction course. This advanced course would target high school students, and if enough sign-ups allow, primarily only 9-10th graders so they have time in their high school curriculum to take appropriate classes to pursue engineering in college. The researcher has no plans on what material this advanced course would encompass, but she would still want it to follow many of the same practices of the introduction course with interactive activities during every class and some sort of design challenge in the end.

The researcher was pleased with the results of the course and looks forward to teaching this program again to more students if the opportunity arises.

Appendix A

SCA Newsletter Advertisements

SCA May-September 2016 Newsletter Advertisements:

Introduction to Engineering and Design

January 9th-February 3rd, 2017

6th-12th Grade (different classes for different grades)

Class will meet 2 hours per day, twice per week for one month. *Day and time to be determined.*

Join me as I take your student on an engaging and highly interactive adventure to learn the basic principles of engineering and design! My name is Hannah Huynh, SCA alumni class of 2013 and Massachusetts Institute of Technology (MIT) class of 2017, and this coming January 2017, I will be teaching a class where we will brainstorm, sketch, and problem solve our way to a final toy design project! This class is open to 6-12th grade students, and my goal is that they leave this course not only with their own personalized creations, but also a physical 'toolkit' and the basic engineering design skills in order to encourage them to continue creating.

The cost of this course will be $10, a symbol of your child's commitment to attend and be active for every class. I have received funding from MIT Society of Women Engineers to teach this class*, and I am so excited about the opportunity to help guide your students to explore and think creatively. **No experience with engineering, advanced math, or science is necessary, only an open mind and a willingness to learn!** Feel free to reach out to me at hehuynh@mit.edu if you have any questions!

*Though funding is coming from MIT Society of Women Engineers, this is not an official MIT sponsored class.

Don't miss out! Sign up with Rodelle Brehm at the May faculty meeting. Days and time will be determined based on those signed up.

SCA December 2016 Newsletter Advertisement:

Introduction to Product Design

Wednesdays and Fridays, January 11th-February 3rd
Olders 9-12th: 8:30a-10:30a
Youngers 6-8th: 10:45a-12:45p

Registration has officially closed for this course, and I am thrilled to have so many interested students! Parents should have received an introduction email recently with a link to sign up to volunteer. This course will be a project-based introduction to product development and engineering design. It emphasizes key elements of the design process, including defining design problems, generating ideas, and building solutions. It presents a range of design techniques to help students think about, evaluate, and communicate designs, from sketching to physical prototyping. Students work both individually and in teams, and the course culminates in a final design challenge.

Feel free to reach out to me at hehuynh@mit.edu if there are any questions.

Appendix B

Syllabus

Syllabus v1 - 09/2016

I Intro, Why PD is important, Design Characteristics

(a) Course objectives so people know what to expect

(b) What is engineering design and product development vs art and design

(c) Why design is important

(d) Show examples of good and bad design

(e) Logistics - be on time and attend every lecture, timeline for class

(f) Activity: Draw a logo/emotion

i. Paste in back of room and talk about effective design

II Brainstorming

(a) Brainstorming exercise

i. Individual brainstorm

A. How many 'blank' can you think of/how many ways can 'blank' be used

B. What can be used to grab something off the playground

ii. Talk about techniques to use for brainstorming

A. Four creative strategies from 2.009

iii. Team brainstorm and write down on large sticky poster

A. Post papers around room and have students describe their ideas

iv. How to choose a good idea - Pugh chart?

III Sketching/Shading

(a) Visual language

    i. Draw a bicycle/lobster from memory
  (b) Warm up, how to draw straight lines, circles, ellipses
  (c) Perspective drawing
    i. Cubes
    ii. Proportions for people
  (d) Shading for enhancement
  (e) Assignment is to draw out idea pitched in last class

IV Sketch Models

  (a) Looks-like and works-like models
  (b) Preliminary estimation and feasibility
  (c) Have some sort of build activity

V Building and Quick Prototyping

  (a) Talk about rapid prototyping
    i. Pros and cons of different manufacturing processes (008)
  (b) Some building activity

VI Build and Challenge

  (a) Prep materials beforehand
  (b) Have students assemble and participate in challenge
  (c) Discuss results afterwards
    i. Practice communication skills

VII Form

  (a) Curves and contours
  (b) Structure and color
    i. Modeling clay exercise to create an emotion by only surface features
    ii. "I will always find you"
  (c) Compare the quick prototyping to "nice" design elements
  (d) Understand layouts and graphics formatting

VIII Looking Forward for the Product and You

  (a) Elevator pitch
  (b) Market feasibility
  (c) Cost estimation
  (d) Back of the envelope calculations
  (e) Potential careers in engineering

Final Syllabus

I Introduction, Importance of Engineering and Design

(a) Prep: Name tags; index card, design pouch, design notebook, and three sheets of paper at every seat
(b) 2 min: Introduction and course objectives
(c) 5 min: Mini quiz on course objectives
(d) 5 min: What is engineering and design
(e) 5 min: Why is engineering and design important
(f) 10 min: Examples of good and bad design and engineering
(g) 5 min: Design pouches
(h) 30 min: Symbol design drawing activity
(i) 5 min: Product design process
(j) 5 min: Design notebook
(k) 5 min: Class logistics
(l) 23 min: Design challenge
(m) 5 min: Homework: pictures of good/bad design and haiku about design and engineering

II Ideation: Brainstorming and Sketching

(a) Prep: Name tags, 6 sheets of paper and sketching worksheets at every seat, expo marker and eraser
(b) 10 min: Review haikus and good/bad design pictures
(c) 5 min: Mini quiz on product design process and design notebooks
(d) 5 min: Ideation: brainstorming and sketching
(e) 10 min: Brainstorming techniques and strategies
(f) 10 min: Individual brainstorming exercise
(g) 10 min: Creative brainstorming strategies
(h) 20 min: Group brainstorming exercise
(i) 15 min: Sketching
(j) 15 min: Review design challenge
(k) 5 min: Homework: brainstorm and sketch 10 ideas for device and draw a flag that represents you

III Team building and Ideas discussion

(a) Prep: Colored bandanas in envelopes, Post-it notes, tape, design challenge supplies, index card at every seat

(b) 5 min: Review individual brainstorming results
(c) 5 min: Practice sketching
(d) 5 min: Mini quiz on ideation and creative strategies for brainstorming
(e) 5 min: Qualities of a successful team
(f) 10 min: Team building activity
(g) 10 min: Team individual flag sharing activity
(h) 30 min: Team ideas sharing
(i) 5 min: Safety foamcore cutting demo
(j) 30 min: Prototyping time

IV Estimation, Prototyping, and Testing

(a) Prep: Design challenge supplies, colored table cloths, set up a couple flags on playground, index card at every seat
(b) 5 min: Safety, ideation, and creative strategies review
(c) 5 min: Mini quiz on estimation
(d) 5 min: Review design challenge
(e) 5 min: Pugh Chart
(f) 20 min: Pugh Chart Activity
(g) 70 min: Prototyping time

V Building I

(a) Prep: Design challenge supplies, colored table cloths, set up flags on playground
(b) 110 min: Open lab time

VI Building II

(a) Prep: Design challenge supplies, colored table cloths, set up flags on playground
(b) 110 min: Open lab time

VII Design Challenge

(a) Prep: Set up flags on playground, prizes
(b) 30 min: Final preparations of product
(c) 5 min: Move devices to outside
(d) 40 min: Design challenge
(e) 15 min: Review lessons learned from design challenge, hand out prizes for every student

(f) 20 min: Clean up devices

VIII Looking Forward

(a) Prep: 2 sheets of paper, post-class survey, dental floss packet, and index card at each seat; foamcore for extrusion demo, injection molded and thermoformed yo-yo, and plastic water bottle

(b) 5 min: Review product design process, ideation, brainstorming techniques

(c) 5 min: Practice sketching

(d) 5 min: Review Pugh chart and design challenge

(e) 5 min: Show design challenge recap video

(f) 5 min: Overview of mechanical engineering

(g) 5 min: Mechanicals and materials - cantilevered beam

(h) 5 min: Dynamics and controls - Disneyland's Mickey's Fun Wheel

(i) 5 min: Thermal-fluids engineering - refrigerator

(j) 10 min: Design and manufacturing - manufacturing techniques

i. Extrusion

ii. Thermoforming

iii. Injection molding

iv. Bending and punching

(k) 10 min: Dental floss teardown

(l) 5 min: Product design

(m) 5 min: Form, color, and surface

(n) 10 min: Graphics - font choice example

(o) 5 min: Form follows function

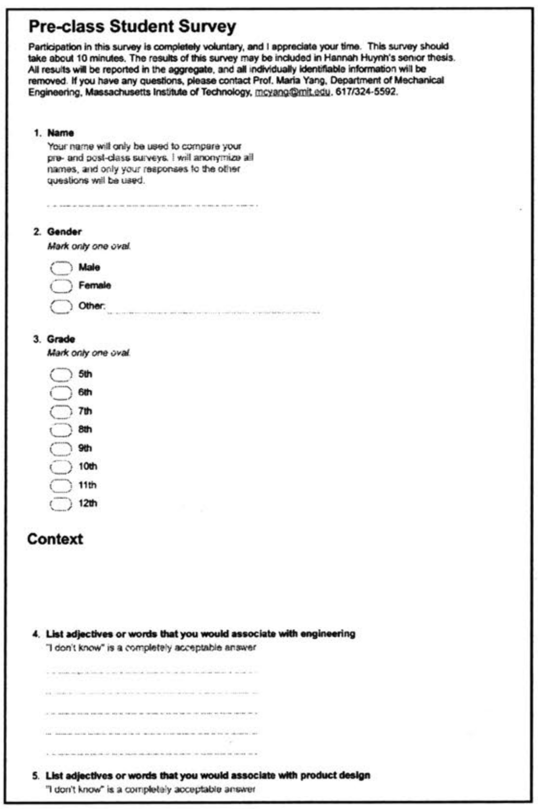
(p) 5 min: Principle of Pragnanz

(q) 5 min: Other types of engineering and thank you

(r) 10 min: Post-class survey

Appendix C

Pre-Class and Post-Class Surveys



Pre-class Student Survey

Participation in this survey is completely voluntary, and I appreciate your time. This survey should take about 10 minutes. The results of this survey may be included in Hannah Huynh's senior thesis. All results will be reported in the aggregate, and all individually identifiable information will be removed. If you have any questions, please contact Prof. Maria Yang, Department of Mechanical Engineering, Massachusetts Institute of Technology, mcyang@mit.edu, 617/324-5592.

1. **Name**
   Your name will only be used to compare your pre- and post-class surveys. I will anonymize all names, and only your responses to the other questions will be used.

2. **Gender**
   Mark only one oval.
   - Male
   - Female
   - Other:

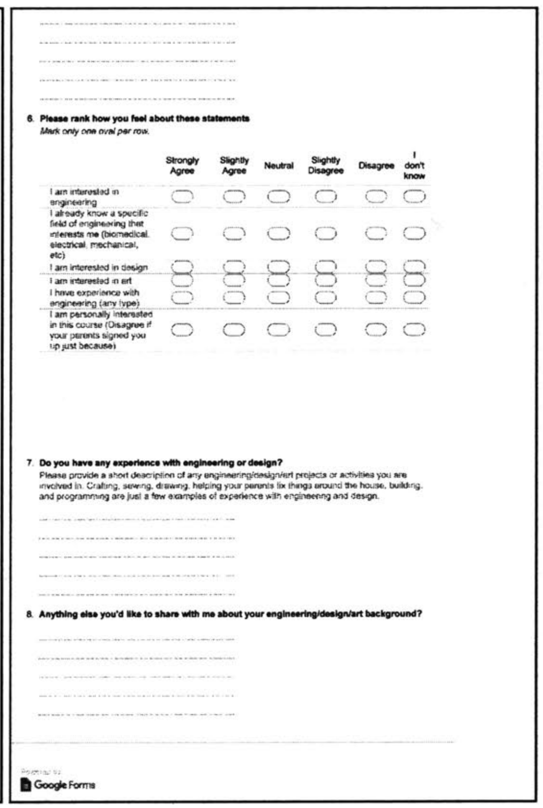
3. **Grade**
   Mark only one oval.
   - 5th
   - 6th
   - 7th
   - 8th
   - 9th
   - 10th
   - 11th
   - 12th

Context

4. **List adjectives or words that you would associate with engineering**
   "I don't know" is a completely acceptable answer

5. **List adjectives or words that you would associate with product design**
   "I don't know" is a completely acceptable answer

(a) Page 1



6. **Please rank how you feel about these statements**
   Mark only one oval per row.

	Strongly Agree	Slightly Agree	Neutral	Slightly Disagree	Disagree	I don't know
I am interested in engineering						
I already know a specific field of engineering that interests me (biomedical, electrical, mechanical, etc)						
I am interested in design						
I am interested in art						
I have experience with engineering (any type)						
I am personally interested in this course (Disagree if your parents signed you up just because)						

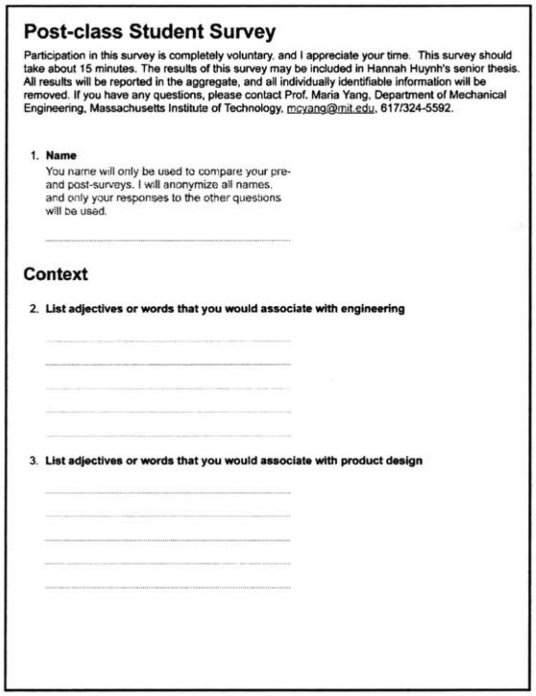
7. **Do you have any experience with engineering or design?**
   Please provide a short description of any engineering/design/art projects or activities you are involved in. Crafting, sewing, drawing, helping your parents fix things around the house, building, and programming are just a few examples of experience with engineering and design.

8. **Anything else you'd like to share with me about your engineering/design/art background?**

Google Forms

(b) Page 2

Figure C-1: PDF version of pre-class survey.



Post-class Student Survey

Participation in this survey is completely voluntary, and I appreciate your time. This survey should take about 15 minutes. The results of this survey may be included in Hannah Huynh's senior thesis. All results will be reported in the aggregate, and all individually identifiable information will be removed. If you have any questions, please contact Prof. Maria Yang, Department of Mechanical Engineering, Massachusetts Institute of Technology, mcyang@mit.edu, 617/324-5592.

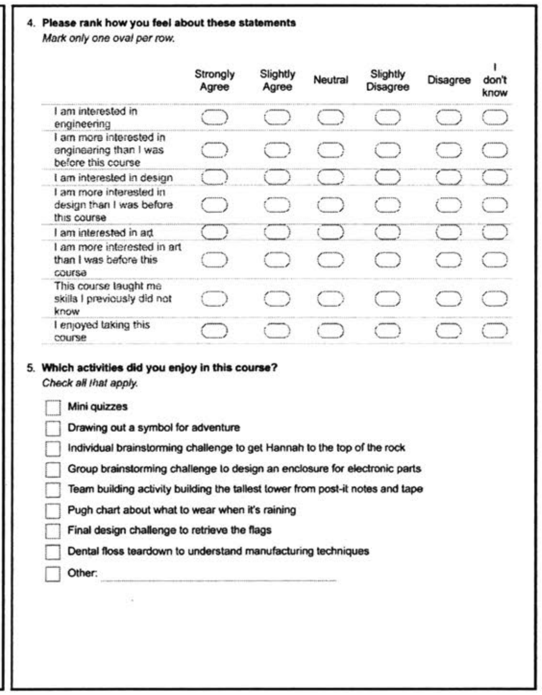
1. **Name**
   You name will only be used to compare your pre- and post-surveys. I will anonymize all names, and only your responses to the other questions will be used.

Context

2. **List adjectives or words that you would associate with engineering**

3. **List adjectives or words that you would associate with product design**

(a) Page 1

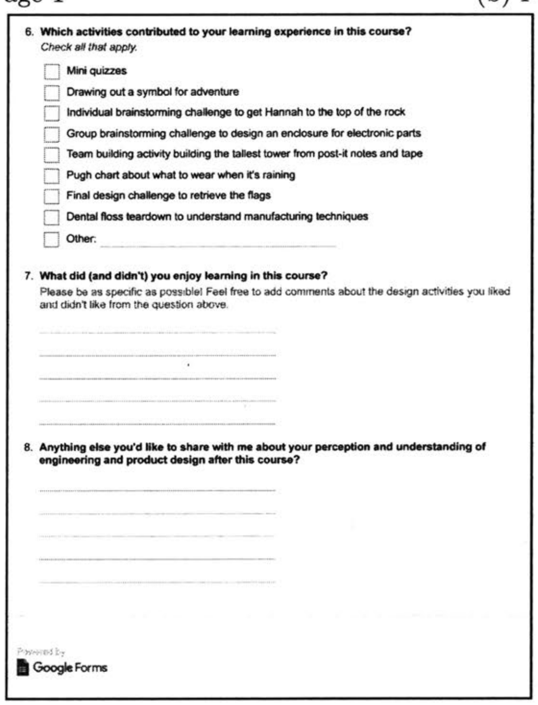


4. **Please rank how you feel about these statements**
   Mark only one oval per row.

	Strongly Agree	Slightly Agree	Neutral	Slightly Disagree	Disagree	I don't know
I am interested in engineering						
I am more interested in engineering than I was before this course						
I am interested in design						
I am more interested in design than I was before this course						
I am interested in art						
I am more interested in art than I was before this course						
This course taught me skills I previously did not know						
I enjoyed taking this course						

5. **Which activities did you enjoy in this course?**
   Check all that apply.
   - Mini quizzes
   - Drawing out a symbol for adventure
   - Individual brainstorming challenge to get Hannah to the top of the rock
   - Group brainstorming challenge to design an enclosure for electronic parts
   - Team building activity building the tallest tower from post-it notes and tape
   - Pugh chart about what to wear when it's raining
   - Final design challenge to retrieve the flags
   - Dental floss teardown to understand manufacturing techniques
   - Other:

(b) Page 2



6. **Which activities contributed to your learning experience in this course?**
   Check all that apply.
   - Mini quizzes
   - Drawing out a symbol for adventure
   - Individual brainstorming challenge to get Hannah to the top of the rock
   - Group brainstorming challenge to design an enclosure for electronic parts
   - Team building activity building the tallest tower from post-it notes and tape
   - Pugh chart about what to wear when it's raining
   - Final design challenge to retrieve the flags
   - Dental floss teardown to understand manufacturing techniques
   - Other:

7. **What did (and didn't) you enjoy learning in this course?**
   Please be as specific as possible! Feel free to add comments about the design activities you liked and didn't like from the question above.

8. **Anything else you'd like to share with me about your perception and understanding of engineering and product design after this course?**

Powered by
Google Forms

(c) Page 3

Figure C-2: PDF version of post-class survey.

Appendix D

Sketching Worksheets

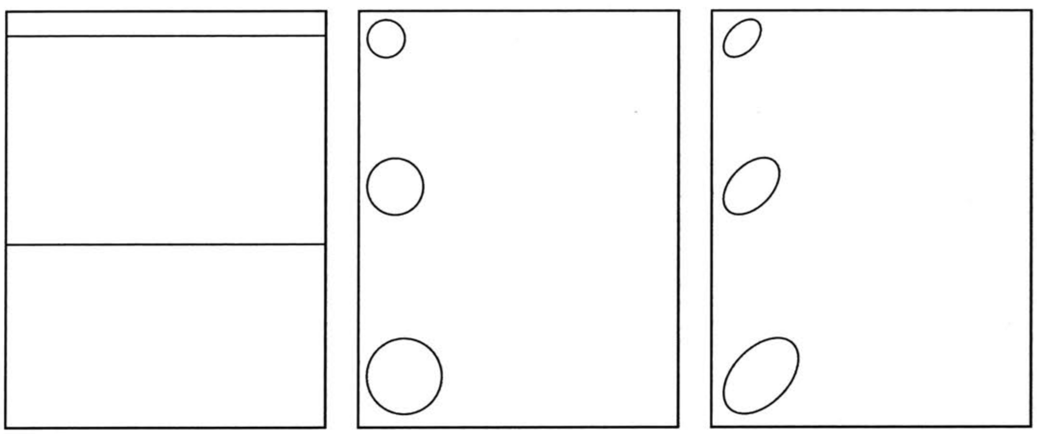


Figure D-1: One dimensional sketching worksheets.

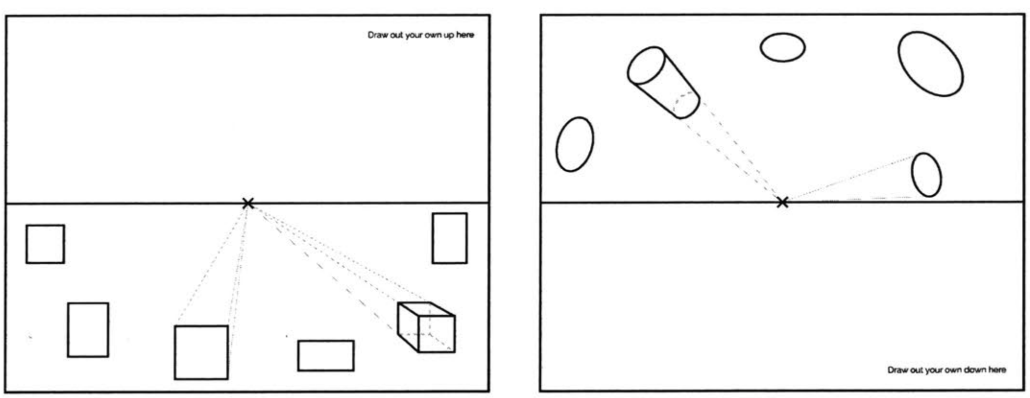


Figure D-2: Two dimensional sketching worksheets

Appendix E

Individual Brainstorming Results

Grappling hook x4	Climb x12	Hope
Ladder x10	Build elevator x6	Build a rollercoaster
Suction cups x2	Propeller hat	Anti-gravity boots
On hands and feet	Human ladder/pyramid	Scaffold
Helicopter x12	Build a skyscraper with a bridge	Throw her
Try harder	Build a ramp x3	Handglide x6
Ride an animal x4	Call for divine providence	Use two pickaxes
Trampoline x7	Belaying	Airplane x3
Parachute x3	Catapult x7	Ski lift
Springs on feet x4	Grab an eagle by the talons x2	Wait for Ice Age
Grow wings x2	Gloves from Mission Impossible	Slingshot x3
Teleport x3	Chairs stacked onto each other	On a donkey
Quadcopter	Hike a way around x7	Canon
Warp	Climb a giraffe/tree/hair x2	Teach her to hike
Ballista	Zipline x2	Rope x5
Trebuchet x3	Give her a pair of rocket shoes	Walk up
Jump x3	Have someone carry her x2	Harness seagulls
Pole vault x2	Take a tram x2	Airplane x4
Fly x7	Reverse gravity	Escalator x2
Pulley system x7	Indoor skydiving tube	Spiderman
3 Forklifts	Pretend you're already there	Give up
Hot air balloon x6	Engineer a way	Swim up
Bouldering x4	TNT+metal plate=launch	Teach a class instead
Make stairs x10	Use something in your backpack	Bike up
Bouncy ball	Monkey climbing lessons	Super jumpy shoes
Jetpack x6	Make tube a fill it with water	Run up x3
Long neck dinosaur	Make clones to climb up	Grow a tree
Drive a spy car with spiky wheels x2		Rocket x3
Stacking blocks/boxes underneath x5		Magnets

Carve a tunnel/passageway through x2	Slingshot x3
Carving/sticking holds into the rock x4	Cable car
Photoshop herself on the top of the rock	Magic beans
Flood valley and float up to top x2	Teeter totter
Carve off the top of the tock to make it lower x2	Diving board
Find a tall tree, climb it, then jump onto boulder	Sky dive x4
Anti-gravity juice from the Willy Wonka movie	Explode rocks x2
Bake a giant birthday cake and climb the candles	Really high powered fan
The Infinite Improbability Drive or the Hear of Gold	Use stilts

Table E.1: Individual brainstorming results from high school class

*A few incomprehensible responses (4) were left out. Some responses were rephrased, and similar responses were grouped together.

Elevator x6	Escalator x3	Stairs x12
Chain	Defying gravity x3	Driving a boat
Magic	Slingshot	Jump x8
Giant bean stalk	Sky diving x2	Pulley system x4
Teleportation x5	Trampoline x9	Rock climbing gear x7
Climbing claws	Jet pack x8	Fly x12
Stacking blocks x8	Fork lift	Fire engine geyser
Gravity suit	Grappling hook x7	Use a fishing pole
Climb x14	Rocket x3	Climb rope x11
Plane	Send a drone x2	Use a tool to create a path x2
Build a bridge	Lasso a tree	Someone carries her up x3
Use a superpower	Hot air balloon x2	Find the easiest way up
Ballista	Fishing pole	Pretend she is already there
Trebuchet x3	Hiking x2	Use really long arms/legs x2
Bow, arrow, and rope	Pickaxe x2	Duct tape
Run x2	Hand holds to climb up	Weave plants into a rope
Sling shot	Find another way	Take a jet/airplane x2
Dig/drill a tunnel x5	Chisel the rock so it falls	Special shoes/gloves x3
Catapult x6	Suction x2	Smash it with a wreaking ball
Pogo stick x2	Zipline	Be thrown up
Drop from a plane	Scare her	Motivation ... food at top x2
Giant friendly gopher	Walk	Wear really tall shoes
Quadcopter	Wood	Ride an animal up x8
Pole vault	Bungee cords/jump x4	Ride a vehicle x4
Parachute x2	Use lots of balloons	Wait for a landslide
Lasso a pigeon	Knock over the rock	Use the force x2
Genji wall climb	Ladder x13	Break the laws of physics
Find a secret passage	Tower	Rocket ship
Rocket cats	Rainbow wings	Helicopter x13
Thruster pack	Barrel row	Become a superhero x7
Have an alien drop you from space		Have a tractor beam you up
Pretend you're already there		Cannon x3
Dynamite the rock so the top lands near you x2		Parkour
Flood the area and swim to the top x3		Earth bending
Blow up the rock so you're already at the top		Parachute down from a plane
A giant worm picks her up and flies her to the top		Fly the Millennium Falcon

Table E.2: Individual brainstorming results from middle school class

*A few incomprehensible responses (6) were left out. Some responses were rephrased, and similar responses were grouped together.

Appendix F

Group Brainstorming Results

High School Group 1:
Do the components get hot?
How much power does it take to run it?
Does it need power? How does it get power?
Should it be weather compatible? Water/sun/fire/heat/wind/pressure proof?
How many parts?
What is the part going to be used for?
How sturdy does the part have to be?
How big are the electronic parts?
Will it burn?
Where is it used?
Is it environmentally friendly?
Is it technology compatible?
Does it need to take an external signal?
Does it attach to something else?
Do we need a specific design?
Does the case need technology?
Do you see it? Is it eye-catching? Does it need to be interesting, colorful, aesthetic?
What materials is it compatible with?
What material is it made of?
Do you hear/feel/taste/smell it?
Does it have to be user compatible?
Does it have to be compact?
Does the case have to be intelligent?
Should it be travel-sized?

High School Group 2:
What is it being used for?
What are the limiting dimensions?
How durable is it (the electronics)?
Is it water-proof?
How much materials are available?

How much are the manufacturing costs (labor, parts, rental)?
Is it dangerous (flammable, explosive, temp/burn, shock/electric, sharp)?
What is the power consumption requirement?
What material would be ideal?
Is it going to be used by multiple people (1 size fits all)?
Will it need a way to charge?
Will there be buttons/controls/ports?
Are there conditions for the shape/can it be uneven or must it be smooth?
What are the weight restrictions?
Will it need to fold up/be put away?
Mobile or fixed to foundation?
How frequently will this need to be used?
Does it need a grip (handle/surface texture)?
Will it need to be "pretty" (marketable)?
Will it need replaceable parts?
Should it come in multiple colors?
Does it need to be a structure that supports sound?
Will it be in another casing/jacket?
Cleaning?

High School Group 3:
What materials are waterproof?
Is it strong enough to survive a drop?
Are there are holes (USB, etc) to plug in?
Can we manufacture this in a third world country?
Does it require a screen or a screen protector to protect it?
How expensive are the resources?
Is it comfortable/shape efficient?
How big or small is it?
How tough is this enclosure?
What mechanics are inside of this enclosure?
Do we have a coolant?
How tightly can we squeeze into it?
Does it have a speaker or camera lens?
Do we need to create a multi-faceted enclosure?
Is it pleasing to the eye?
What color(s) would it be?
Does it have moving parts?
What temperature can it withstand?
Is it easy to use?
Is the design patentable? Able to be patented?
What pressure can it withstand?
Is it environmentally friendly?
Is it safe (kosher)?
Is it politically correct?

Is it backwards compatible?

Middle School Group 1:
How much space do we have for it?
Where are we building it (mountains, valleys, wet lands, ...)?
What is the price range we are targeting?
What type of consumer (outdoors lifestyle, elegant, ...)?
Are there risks (land slides, earthquakes, floods, animals)?
What are options for materials?
Style of home (ranch style, courtyard, ...)?
How many people and ages (family, group of students/elderly)?
Will we have electricity and water supply (sewage)?
Do we need room for guests?
How many bathrooms to each room?
Do we need a smart system for the home (computer, wifi)?
What is the size of the driveway, garage, kitchen, and bedroom?
What is the accessibility to the house and its rooms?

Middle School Group 2:
What style do you like?
Should it be stable?
What is the size of property?
What foundation is being built on?
Do you want windows?
Where is the house located?
What are we building a house?
What is the budget?
What size is the yard?
How many stories?
What materials are you using?
Will there be electrical components?
What color will it be?
Will there be AC/heater?
Do they want painted designs?
What flooring?
Do we want a pool/fountain?
Do you want a secret room?
What is the state code/regulation?
What do you want in your backyard?
Do they want furniture?
How many rooms/people/bathrooms?
What is the surrounding?
What is the temperature around the area?
Is there a highway nearby?
Is there civilization nearby?

What type of roofing?
Do we need a chimney?
Does the house have wifi?
Do we need gardeners?
Are there bugs/animals around?
Do we need a fire alarm/smoke detector/security system?
Are there pets in the house?
What type of kitchen do we need?
Do we need a basement/garage?
How much furniture?
Do we need a driveway?

Middle School Group 3:
Is it in a tornado zone?
What type of association?
Can you paint it pink?
Is there foundation?
What style house do I want? Rustic? Castle-like? Classical? Hogwarts? How many people? How much property/lot?
What size?
What type of neighborhood? Safety?
How much $$ do I have to spend?
Is it vulnerable to natural disaster?
Are there pokestops nearby?
Is it near Disneyland? Noise/traffic issues?
What materials quality is used? Brick/wood/...?
What type of people am I building for? Family gathering? Wide open space? Murders - concealed?
Color? Happy - bright? Rich - gold? Sad - grey/black?
Is a wolf going to blow your house down?
What is the temperature change of the area?
Do you need wifi in each room?
What holiday potential is needed?
Do you need more technology? Jarvis? Refridgerator?
Do you want a pool?
How big does the garage need to be? Cars? Storage?
Do you need a background? Fenced? Are you outdoorsy/sporty?
Do you need a guest room?

Middle School Group 4:
Would it be close to water? (i.e. mudslides, floods)
Would they want an open or closed concept? (i.e. rooms are connected/less walls)
How big of a garage do they want?
Would they want a garden?
Would they want an attic of a basement?

Would they want a built-in entertainment center?
Is it going to be close to a street?
How many people are going to live in it?
What style would it be?
Will it have 1 or 2 stories? What's the arrangement of the rooms? (i.e. kitchen, bedrooms)
How big would the backyard be?
Would they want a pool or playground?
What material would they want to use for the house?
Would they want an intercom system?

Middle School Group 5:
Who's living in it?
Where is the building?
How many people?
What type of soil/ground?
What is the budget/$?
Supplies?
Workers?
Supply/demand?
Interior house questions: Height of inhabitants? How many bed/bath/toilets? Style/type of appliances? Need air/water? WIFI? Close to powerlines? Electric/gas?
Building for who? Style? Size? Location? View?
Nearby needs? School? Starbucks? Market?
Do you need a barn?
Are there predators? Pests?
Weather? Need basement (tornados)? Earthquake proof?
Fence/wall/protection?
Do I need a boat?
Garden? Farming?
Yarn for animals/barn?
Warzone/crime area? Protection needed? Security system?

Bibliography

[1] Saddleback Christian Academy.

[2] Ronald Carr, Lynch Bennett IV, and Johannes Strobel. Engineering in the K-12 STEM Standards of the 50 U.S. States: An Analysis of Presence and Extent. *Journal of Engineering Education*, 101(3):539 – 564, 2012.

[3] Micheal F. Cogan. Exploring Academic Outcomes of Homeschooled Students. *Journal of College Admission*, (208):18 – 25, 2010.

[4] Siddika Selcen Guzey, Tamara J Moore, and Michael Harwell. Building up STEM: An Analysis of Teacher-developed Engineering Design-based STEM Integration Curricular Materials. *Journal of Pre-College Engineering Education Research (J-PEER)*, 6(1):2, 2016.

[5] Krisztina V.1 Jakobsen and Megan1 Knetemann. Putting Structure to Flipped Classrooms Using Team-Based Learning. *International Journal of Teaching & Learning in Higher Education*, 29(1):177 – 185, 2017.

[6] David Kastbery, Jessica Ying Chan, and Gordon Murray. Performance of US 15-Year-Old Students in Reading, Mathematics, and Science Literacy in an International Context: First Look at PISA 2015 (NCES 2017-048. *National Center for Education Statistics*, 2016.

[7] Ahlam Lee. Determining the Effects of Pre-college STEM Contexts on STEM Major Choices in 4-year Postsecondary Institutions using Multilevel Structural Equation Modeling. *Journal of Pre-College Engineering Education Research (J-PEER)*, 3(2):3, 2013.

[8] Marie-Louise Mares and Zhongdang Pan. Effects of Sesame Street: A Meta-analysis of Children's Learning in 15 Countries. *Journal of Applied Developmental Psychology*, 34(3):140–151, 2013.

[9] Muhsin1 Menekse, Glenda S.2 Stump, Stephen3 Krause, and Michelene T. H.3 Chi. Differentiated Overt Learning Activities for Effective Instruction in Engineering Classrooms. *Journal of Engineering Education*, 102(3):346 – 374, 2013.

[10] Jeremy Redford, Danielle Battle, and Stacey Bielick. Homeschooling in the United States: 2012. *National Center for Education Statistics*, 2017.

[11] MWM Van den Toorn and Rein Have. *Notebooks as didactic tool in design education.* 2012.