Hands-on Online:

towards experiential product design education with online resources

by

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Abstract

This pilot study investigates the potential for teaching experiential, hands-on product design online. Specifically, the work is a first attempt to elucidate differences in outcomes between residential, hands-on educational experiences and online, hands-on instruction. Product design education is a subject that presents many challenges in translation to an online setting. Abstract concepts like open-ended problem solving and physical concepts like prototyping are more difficult to teach online than more codified information.

Three experimental groups were investigated. A traditional delivery group acted as a control for the study. Participants in the traditional group met at the Product Design Lab at MIT and learned the material through face-to-face lectures and demonstrations. The online group learned the material through an online resource developed specifically for this experiment. A third group, labeled the hybrid group, resembled a flipped classroom where participants learned the material on their own and then came to campus to practice what they learned. All groups took part in an opportunity identification activity in which participants identified problem solving opportunities, brainstormed solutions and developed prototypes to illustrate their most promising solution.

Participants in this study attended a 2-day workshop covering the topics of design process, sketching and prototyping with simple materials. The designs developed by participants were collected and reviewed by a panel of product design experts, who then rated the work on the realness of the identified opportunity and the effectiveness of the prototype in illustrating the solution. The assessments were compared and statistical hypothesis testing was performed. All methods employed failed to reject the null hypothesis that the groups performed equally, providing evidence that learning gains were the same for all three delivery methods. Surveys taken by the participants revealed highest instructor ratings and overall learning ratings in traditional learning and the lowest ratings of resource adequacy in online learning.

While this is an initial study with a relatively small sample size, the outcomes for early-stage product design instruction present interesting implications for both online and residential education in terms of improving education, and suggest a number of avenues for further study.

Thesis Supervisor: David R. Wallace
Title: Professor of Mechanical Engineering

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Things I learned in graduate school that are not elsewhere in my thesis:
Lindy is really good at picking out music to play during workshops,
Jeff knows a bunch and likes to talk about it,
Geoff knows a bunch and likes to teach about it,
Jim and Amy are good at judging people,
Ilan has cool stuff and is nice enough to let me use it,
Jess is popular and knows many people,
CADLAB is the best lab, but Ideation is great too,
Justin and Liza care about teaching kids,
Maria Yang, Warren Seering, and Josh Schuler are very busy and very expert,
Mathworks makes good software and employs good people,
My family really misses me when I don't talk to them for too long,
Carmen is good at putting up with me and (she made me say) I love her for it,
David likes to give me opportunities to learn new things,
I like learning new things.

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1. Introduction

Constant advances in communication technology are changing the world at a faster pace than ever. Every facet of life is changing, from what we eat to where we go and how we get there. Education is changing too. Increased data transfer speeds and advances in computing technologies allow for faster, more reliable access to content on the Internet. This change in communication technology allows academic leaders around the world to reevaluate how they teach, how they develop curriculum, and how students access information, but despite rapidly changing technology and the desire to improve education, the academic world has been slow to change.

One fairly recent edition to the educator's lexicon, the MOOC, or massively open online course, has created a buzz that is mobilizing the education world to action. While utilizing Internet technology in education is nothing new, with simple literature searches revealing online education studies dating back to the early nineties, the recent introduction of the MOOC has brought attention to a changing profession and caught media attention[1]. Renowned higher education universities like MIT and Stanford are creating resources that give free access to education, broadening the reach of high-quality education while tackling difficult distance learning challenges, such as the absence of a physical instructor and automated grading[2,3]. Even resources from sources that are not directly created by world-renowned institutions have changed the face of education and garnered public appeal, such as Khan Academy[4].

Despite the popularity of MOOCs in the media, only a small percentage of higher education institutions are participating in MOOCs, with only 2.6% of institutions currently hosting a MOOC online and 9.4% having plans to implement one[5]. Nonetheless the population of students in the United States who have taken an online course in the past year continues to grow. This past year 570,000 more students participated in online courses than the previous year, bringing the total number up to 6.7 million students that have taken at least one MOOC course. While becoming more popular and widespread, online education is not free of difficulties in both creating and implementing a course. Some academic leaders are worried about the quality of online media being produced by MOOC makers, and stress that higher production quality and honest devotion to education are necessary to move education to a higher priority in society[6]. Creating multimedia for online courses can be cumbersome and time consuming, and many institutions do not have the proper equipment, expertise or budget to create high-quality content. Professional quality video resources can take more than 150 hours per lecture unit[7], but once the initial hurdle is overcome generated content can be utilized repeatedly with no extra cost.

Another concern is the effect online education will have on real-life brick-and-mortar institutions and what unique opportunities residential education can provide. With rising tuition costs for physical universities and online education improving while remaining free, residential institutions need to demonstrate their value more than ever. Physical institutions might still have an advantage. While highly codified information might be easily transferred to an online space, physical activities tend to be more difficult to digitally translate. One main goal of this work is to investigate how physical learning experiences may or may not be supported by Internet technologies, and as such if residential institutions still have more to gain from online learning. This work aims to explore approaches for hands-on activaties that can be supported by online learning, and how Internet technologies can be utilized to support any kind of learning, residential or otherwise.

The experiments described in this work suggest that topics that are inherently both physical and abstract, namely open-ended problem solving and physical prototyping, can be supported with Internet multimedia technologies. No suggestion is made that any delivery methods described here, whether traditional, online, or both, is the most appropriate or most successful method of educating students. The goal of this work is merely to investigate the perceived boundaries and limitations of online education by attempting to put something that may not lend itself well to online delivery methods, namely early-stage product design, online and see if students can learn as well as with traditional methods. The pilot study described in this work suggests that the investigated delivery methods of traditional delivery, online delivery, and hybrid delivery are all satisfactory for transferring early-stage product design knowledge to students. This work aims to show educators that Internet technologies can be used to support even highly physical and abstract content and to suggest that current pedagogies be reevaluated to better serve future students. Non-residential institutions can gain by broadening the spectrum of studies they can support. Residential institutions can also gain from these results by shifting attention away from traditional education approaches and using physical resources, augmented by Internet technologies, to improve student-learning gains beyond what is currently possible.

This thesis begins with a description of work done in the online and experiential education space, with a specific lens on engineering education, in Chapter 1. Chapter 2 focuses on documenting the work done developing the resources used in the experimental procedure. The details of the experimental procedure are described in Chapter 3. Results from the experiment, including statistical hypothesis testing that compares the experimental groups is discussed in Chapter 4, and Chapter 5 includes a discussion of these results. Chapter 6 discusses the conclusions to be drawn from the results presented in Chapter 4, as well as suggestions for future work.

2. Background

2.1 Overview and Motivational Studies

This chapter aims to describe particular instances of prior art that have shaped the formulation of this study. Other influential works will also be discussed, as well as the fundamental pedagogies underlying the content created in this work. The first section describes the current state of knowledge about online education while the following section addresses how this work fits into the current body of similar academic studies and ventures that aim to achieve similar goals. The final section discusses recent changes and advances in online education technology.

Two early studies that have motivated this work are Wallace and Mutooni[8] and Wallace and Weiner[9]. In the first study, conducted in 1997, Wallace and Mutooni investigated the possibility of using web technology to deliver educational content about visual prototyping. The researchers began by developing a lecture that taught students how to create models that help visually explore the aesthetics and user interactions for a product idea. This material is highly physical, usually requiring face-to-face demonstrations to illustrate key concepts. Researchers concluded that not only was it possible to deliver this information via Internet technology but also that students who learned via the Internet actually had improved learning gains, as shown by their ability to demonstrate their knowledge by creating a prototype that was evaluated by experts. Besides the statistically significant evidence provided by the controlled study supporting online education, this research also shows that educators have been thinking about how Internet technologies can benefit education for years.

The experimental methods used by Wallace and Mutooni, particularly the approach of using expert panelists to evaluate student's design work, was borrowed to evaluate the prototyping efforts of students in the workshops presented in this thesis. The experiments presented in this work seek to build upon the work started by Wallace and Mutooni by attempting to broaden the scope of the material presented in the online lecture developed for that study. While the components regarding physical prototyping are still there, the content covered here is different and other parts of the design process are also included. The workshops presented in this thesis include design process elements such as observation and opportunity identification and have likewise suggested that this material can be conveyed with online delivery.

The second study, conducted by Wallace and Weiner, compared two groups of students that both learned the visual prototyping lecture material online[9]. One group then received a second presentation of the material in a traditional lecture format. This group formed the control for the study. In place of the lecture component, the second group attended a session with a physical activity where experienced product design educators mentored the students throughout the session. The researchers concluded that the students who attended the mentoring session had significantly higher learning gains, once again exhibited by their ability to demonstrate their knowledge with prototypes assessed by experts. The conclusions drawn by Wallace and Weiner included the idea that with online resources educators can better spend classroom time in ways that add value and increase learning gains. This research, conducted in 1998, shows the researchers' forethought in changing education pedagogy before the term "flipped classroom" was coined.

The work presented in this thesis does not directly build upon Wallace and Weiner, but rather calls upon it as a way to utilize the results from this thesis. Given that elements of product design were shown in this thesis to be teachable in an online and hybrid format, residential institutions should use class time with students in ways that maximize the learning gains of the students. Rather than attending lectures, students can learn on the Internet, and class time can be used to engage students in activities that utilize the physical amenities of a residential institution.

The works presented in this thesis were also influenced by the work of the educational leader Professor Woodie Flowers. Professor Flowers is well known for his part in changing MIT course 2.007 Design and Manufacturing I into the course it is today, and is probably best known for co-creating the FIRST robotics competition. Professor Flowers has published work regarding his opinions on the direction of online education and has given talks about how he envisions Internet technology-enhanced education[10]. Professor Flowers draws a distinction he believes in the difference between educating a student and training a student. In his words, "Learning calculus, for example, is training, while learning to think using calculus requires education." He stresses that delivery of easily codified materials, deemed training, is easily translated to online delivery methods, while deeper understanding of knowledge, such as the understanding required to appropriately use calculus when presented with a problem, is education. The underlying idea is that online education is well suited to support training but not to support education.

While some of the conclusions drawn from the study presented in this thesis may seem at odds with Professor Flowers' ideas, upon closer inspection they can be viewed as in agreement. Firstly, the prototyping skills portrayed in the workshops given for this thesis fit the description of training. Learning to use prototyping skills effectively in design process is education, but that content was not highly stressed in the workshops. The online component of the workshops effectively trained students in the skills necessary to prototype with simple materials, thereby upholding the ideas of Professor Flowers. Secondly, the portion of the workshop where students learn to observe the world around them and identify opportunities to solve problems more closely fits the description of education. While the workshops were successful in "educating" students in the process of identifying opportunities, no conclusions are drawn to suggest that this was the most effective approach to educating. Under the guidance of a mentor at a residential institution is likely to be a more successful approach to create deep, lasting understanding of the content. What the work in this thesis is meant to suggest is twofold. For non-residential institutions, the inclusion of hands-on activities can be used in an online delivery setting to teach early-stage product design and similar content. For residential institutions, Internet technology can be used to support learning by reallocating learning resources and creating more time to engage students on campus, as suggested in Wallace and Weiner.

2.2 Pedagogical Roots

At the heart of Professor Flowers' pedagogy is a focus on experiential learning. The idea of experiential learning date backs to John Dewey's *Experience in Education*, which stresses designing learning experiences as the most effective way to transfer knowledge[11]. Dewey renounced the traditional school system for creating the association between learning and boredom. Further, Dewey stressed that lasting, meaningful learning happens when experience assimilates knowledge into the mind of the student. It is clear that student engagement was an utmost priority for Dewey, and these principles resounded with David Kolb, who developed a framework of experiential learning that is still utilized by educators today[12]. Another educational classification that reverberates with Professor Flowers' educational doctrine is Bloom's taxonomy, created by Benjamin Bloom in 1956[13] and revised by experts in the late 1990's[14]. The revised Bloom's taxonomy, which is described in Figure 1, is seen in many forms, but basically describes a hierarchy of understanding. At the lowest level the student will remember facts, but as knowledge deepens, the student gains the ability to apply knowledge, use it in real world settings, and ultimately create something using knowledge. Using the terms described by Professor Flowers, the bottom of the hierarchy would refer to training, while the higher parts of the hierarchy require education.

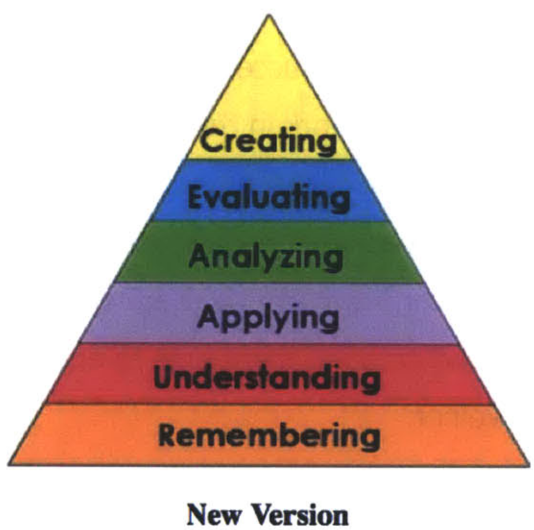

FIGURE 1: AN IMAGE DEPICTING BLOOM'S TAXONOMY

The work presented in this thesis investigates the potential of online resources in supporting experiential learning. By having physical materials associated with the content discussed in the workshops, by exhibiting their use, and by encouraging students to participate in physical activities, the online resources constructed for this study attempt to assimilate design knowledge into the students understanding. While the taxonomy presented by Bloom is not covered in it's entirety in these workshops, some sections are addressed that cover the remembering stage and touch upon aspects of the higher levels of the hierarchy.

One might think that engineering education has a wealth of opportunities to exhibit experiential learning, but in recent years researchers continue to call for more focus on learning through experience. Smith *et al.* continue to stress problem-based learning and the design of the educational experience as core fundamentals to enhance engineering education[15]. Dym *et al.* have similarly stressed project-based learning and further recommend making design pedagogy the highest priority for an engineering education institution[16]. Conclusions from this thesis support the idea that online education resources can both support design pedagogy and hopefully inspire online educators to focus more on the design of learning experiences.

2.3 The Current State of Online Education Research

In 2010 the United States Department of Education published a meta-analysis of research about online education[17]. Some interesting findings are presented here to situate this work in the current body of knowledge. It is helpful to note a few terms used in education research regarding online education. "Traditional" content delivery refers to content that is delivered in person, where the instructor and the student are physically in the same room. "Online" content delivery refers to content delivered completely through the Internet, whereas "hybrid" or "blended" content delivery mixes both traditional learning and online learning. Another distinction drawn in the literature is between "synchronous" education, where the instructor is teaching in real time to the students, and "asynchronous" education. Asynchronous education, which is the main type of digital learning discussed in this work, separates the instructor's delivery of the content with the student's consuming the content in time. For example, posting videos for students to watch on their own schedule is asynchronous learning, while broadcasting a lecture in real time is synchronous learning. Across all of the studies considered in the meta-analysis conducted by the Department of Education, online and blended learning have been shown to generally be at least as effective as traditional learning, and in some cases modestly more effective[17]. Specific instances of research comparing different delivery methods, including instances in engineering education research, are presented in the next section.

The Sloan Consortium is a group of researchers, educators and education leaders that study the potential of online education[18]. Each year they conduct a survey that evaluates the current standing of online education in the United States[5]. The survey presented in January 2013 reveals that 6.7 million students have taken at least one online course over the past year, increased by 570,000 students from the previous years results. However, this increase is also the lowest growth rate of students year-over-year that has been recorded in the survey's history. The survey also mentions the perceptions of academic leaders regarding online education. 44.6% of faculty thinks it takes more effort to educate students with online resources, and 77% of faculty believes education through Internet technology is the same or superior to traditional methods. 23% of faculty believes that online education is inferior to traditional methods. There is also disagreement as to whether online education creates lasting knowledge, as a majority of faculty believes that online education gives lower retention rates. A large majority believes that more discipline is needed on the part of online students.

Since most forms of online education have been shown to be at least equally effective as traditional learning, it then helps to focus on some of the advantages of online learning to warrant future attention. Once online content is developed, online education has the ability to reach wide audiences with no further costs. Constructivist approaches, which have students guide their own learning and help to create independent, meta-cognitive learners[19], work well online[20]. Additionally, current work is being done by artificial intelligence experts to create formative assessments techniques, which provide feedback that guides learning[21], instantly for different types of questions in online learning environments[22]. With data being recorded on every mouse click and page view time for every learner on the Internet, a wealth of data can be explored that can later improve student learning and customize the online education experience[23,24].

Many issues do still need to be addressed about the value added by online education. In 2002 researchers were calling for more controlled studies about learning gains from online learning and stressing the design of the online experience instead of just taking traditional classroom curriculum and putting it online[25]. After a decade, those requests remain unchanged. In a guest editorial for the Journal of Engineering Education, Peercy and Cramer suggested more work on hybrid delivery methods because of the potential to capture the best of traditional and online education[26]. Another guest editorial for the Advances in Engineering Education Journal call upon engineering education researchers to innovate in the realm of communication technology and to develop frameworks that move away from accommodating traditional classroom activities online[27]. Finally, in a comprehensive study of the flipped classroom, Bishop *et al.* reveal that while the results are promising and flipped classroom learning tends to outperform traditional learning when done appropriately, the actual pool of research with properly controlled studies is shallow[28].

2.4 Examples from Engineering Education

There are many different ways that engineering educators have attempted to use web technology to enhance student learning. The majority of the studies attempt to utilize some new technology and then gauge student perceptions of learning and engagement in the form of surveys. While these studies do exhibit efforts to change the current education paradigm, they do not always include quantitative evidence of the effectiveness of their efforts. This section seeks to present examples of research done that documents efforts to integrate technology and education as well as examples that perform experiments to determine the relative effectiveness of different delivery formats for educational content. This summary is meant to provide context for the experimental methods presented in this thesis.

In 2007 engineering educators at the West Point Military Academy made an effort to utilize a website, handsonmechanics.com[29], as a repository for live demonstrations that could be used by other educators[30]. The website seems to be mostly defunct today, but this effort represents an early attempt at crowdsourcing educational content for use at institutions around the world. Researchers concluded that the demonstrations enhanced student learning based on course evaluative feedback. Three other studies were conducted that explored digitized environments where students could explore professional equipment. The first used camera equipment to record physical machines that could be controlled remotely by students using National Instruments' LabView software[31]. In the scenarios described the instructor would demonstrate the equipment and then students would be allowed to run programs on the equipment to see how it would respond. This approach required an operator in the classroom to control the camera and the equipment. A similar study was conducted where students controlled remote equipment with LabView to do heat transfer experiments to learn nuclear engineering[32]. These studies were conducted in 2001 and 2008 respectively. In a third research project educators constructed a virtual representation of a physical chemical plant that students could explore[33]. This environment was supported by 2D schematics, photography and animations and would take students through a curriculum that taught them about the different chemical processes taking place in the plant. All three studies show examples of how Internet technology can allow access to professional, physical equipment, but no study commented on the effectiveness of the developed resources or how teaching with them compared to traditional learning.

Several studies document putting traditional classroom materials online for students to access. Although not many controlled experiments were performed, studies where recorded lectures, annotated screencasts and Microsoft PowerPoint slides were generally seen as effective and well received by students[34–37]. More controlled and statistically rigorous experimentation is required to actually determine the effectiveness of these methods. These approaches, where educators take content they have generated for traditional classroom learning and make them accessible online, rarely take advantage of the potential of Internet technologies.

Improper use of Internet technology can actually be detrimental to student learning. A 2009 study reported that in an environment where the technology framework did not operate properly, copyright issues prevented some materials from being viewed online, and security issues with logging on to the online system prompted researchers to return to traditional teaching[38]. No statistical comparison was made, but researchers reported lower engagement and lower average grades in the online setting. A 2011 study describes a learning scenario in which students participated in physical and virtual assembly activity of parts for a mechanical toothbrush[39]. While the researchers concluded that the activities were equally effective, the method for comparing the two groups was different based on the type of activity the students participated in. Personal experience also suggests that students who work in virtual environments with solid models can develop misconceptions for how materials behave in the physical world. More rigorous research is needed to evaluate the use of 3D assembly exercises in engineering education. Laman *et al.* describe a situation in which students were instructed to do class readings outside of class instead of learning materials during lecture. Lecture time was then used for short quizzes and class discussions[40]. Although this study is ongoing, the results currently seem to suggest that learning is at least the same and student response has been favorable. There is a missed opportunity, in this case, to utilize Internet technology to enhance learning and go above and beyond the traditional textbook. Some studies have also shown that student's current use of textbooks may not be what instructors expect and can be inadequate resources during problem solving[41].

There are more innovative examples of using recorded lectures as online education material. A recent addition to MIT and Harvard's edX, i2.002, uses recorded lecture materials to teach students about advanced mechanics and materials topics[42].

The software platform used to support the course also allows for keyword searching that can seek out a particular instance in a video and bring the user to that moment. While this approach may not be as effective as designing materials specifically for web distribution, as in an ongoing study at Northern Illinois University where researchers developed a racing game to teach Dynamics and Controls, it does show how Internet technology can be used to enhance education[43]. Please note that searchable videos and the EduTorcs racing game have not been formally studied in terms of their educational effectiveness, although the EduTorcs video game has been shown to increase student engagement and possibly increase enrollment in advanced dynamics and controls courses at Northern Illinois University.

While fewer, many studies have implemented controlled experiments in order to investigate any difference in effectiveness of different delivery methods on student learning. A study in a senior engineering design class compared students in physical teams and in geographically dispersed teams[44]. In 2002, the time the study took place, video correspondence was not reliable enough to have the teams talk via video chat, but the teams utilized audio communication and file transfer protocols. Based on task completion time and overall outcomes, the researchers concluded that the groups performed comparably. In a manufacturing class, multimedia tutors were shown to be more effective than traditional delivery in 2003[45]. At the University of Wisconsin, an engineering graphics course was taught using traditional methods, synchronous delivery, asynchronous delivery, and with hybrid methods. All were shown to be statistically the same[46]. Due to increasing student populations, researchers at Missouri University tested traditional delivery of a mechanics of materials course against online delivery, against instances where students received both traditional delivery and access to video materials, and against a flipped classroom hybrid method[47]. Researchers developed materials that included online lectures and recorded experiments using reasonably high quality production equipment. No significant difference was found between any of the groups. More recent studies have shown that educators can vary the ratio of online lectures and face-to-face meetings with weekly in-person discussions or experiential activities and learning results remain the same or better than traditional learning[48]. A study at Seattle University showed that the flipped classroom delivery method improved student learning and allowed for instructors to include an additional week's worth of material over the course of a semester[49].

A recurring theme in the literature is the improvement in student's perception of learning and learning gains that are at least as good as traditional learning, and in some cases moderately better. This is a slow but encouraging first step to changing education in engineering. If the technology can be properly utilized and content developed that harnesses the potential of Internet technology, learning gains should improve significantly over traditional learning styles.

2.5 Similar Ventures and Recent Advances

This thesis sets out to investigate the ability to teach material that is inherently open-ended and physical in order to push the boundaries of online education and to evaluate the value of residential education. Both of these pursuits, the physical and the open-ended, are embodied in study of early-stage product design. Other researchers, whether specifically using product design teaching methods or otherwise, have investigated combining physical materials with online learning and trying to teach open-ended problem solving. This section will discuss a few examples of work with similar goals and will conclude with recent advances and changes in the online learning landscape.

An interesting study was conducted in 2004 regarding learning with physical materials, in this case LEGOs, and learning in an online environment designed to teach middle and high school students mechanical reasoning[50]. Some students learned mechanical reasoning by playing with LEGOs, some learned using the web environment, and some learned with both resources. Learning was the same across all groups. Another study documented the development of physical electronics kits that were loaned to students taking an online electrical engineering course[51]. The kits seemed to facilitate learning but no controlled experiments were performed. In a non-engineering example, a course was developed to train medical employees in public health disaster response[52]. The content of the course was delivered online with differences in a pre-test and post-test used to measure learning. A follow up test was conducted where participants had to physically demonstrate the skills they learned in a face-to-face examination with a supervisor in order to determine competency. The researchers showed that higher online test scores correlated with higher scores during the physical demonstration. These last two studies were conducted in 2012 and 2011, respectively. These studies show other efforts to characterize the relationship between hands-on learning with physical objects and online course delivery, an idea that is thought of as one of the biggest challenges with online learning[20].

Other researchers are also exploring the learning of open-ended problem solving strategies in an online setting. Most notably is the Stanford Venture Labs course *A Crash Course on Creativity*, which seeks to teach students how to enhance their creative thinking and problem solving strategies[53]. This experimental course includes teamwork and weekly physical projects. While no published literature exists comparing this course to traditional creativity or design courses, it does seem to be successful in investigating new ways to educate online students.

Perhaps the most similar work done compared to the subject matter used for the experiments in this thesis is Karl Ulrich's *Design: Creation of Artifacts in Society* online course hosted on Coursea[54]. Although the production value is not particularly high, Ulrich's online course covers product design process including opportunity identification, prototyping, and assessing user needs. This course marries online content delivery with physical projects in order to teach open-ended problem solving. Although no experimental study is presented, the course seems very well received by students. A study of the relative effectiveness of teaching design online and teaching with traditional methods using this course, and investigating how this and similar courses can support residential learning, would be interesting. The study presented in this thesis seeks to investigate similar ideas.

In general, online education continues to expand and evolve in interesting ways. Researchers as MIT and Harvard's edX, including the president of edX, Anant Argawal, are currently researching ways data recorded during the first class of 6.002x, an electronics circuits class (in which the author was a participant) can be used improve future courses and to learn about the population of online students[55,56]. Interesting developments in online assessment are also underway. The difficulty in ascertaining student identities has been a major roadblock in online assessment[57], creating opportunities for physical testing centers to certify online courses such as MOOCs[58]. Other technological advances are being made to overcome this issue. For instance, popular MOOC site Cousera has recently started allowing participants to receive a certificate of completion upon taking a special edition of their courses, deemed Signature Tracks, for a small fee[59]. The software platform that supports Coursea determines the identity of the student with a webcam picture of the student, a webcam picture of the student's id, and through a typing pattern sample that is reportedly unique to the student. These recent advances are changing the face online education.

3. Work Documentation

3.1 Design of the Curriculum

The workshops developed for use in the experimental methods were designed specifically for investigating the research goals. The content in the workshop comes from several sources, and the workshop model is adapted from a workshop session designed to teach educators about design education techniques. These workshops, whose original intention is to cover entrepreneurship, product design and engineering education, were developed by Professor David Wallace[60]. These workshops originally consisted of 2-and-a-half days of activities that promoted experiential learning and team building. The workshops for the experiments in this work contain similar material, but were adapted to be less broad, only take place over the course of 2 days, and to focus on individual work. Despite preparation for an online setting, no sacrifices were made regarding the focus on working with physical materials, as this was a central part of the study.

The academic content of the workshops is based on several courses at MIT that teach similar content to undergraduates. These courses, numbered 2.009, 2.00b and 2.744, all focus on some aspect of product design at different levels of detail and to different populations of students. 2.009, or *Product Engineering Processes*, is taught to senior level students and is the main mechanical engineering capstone class at MIT[61]. 2.00b is a freshman engineering class that focuses on toy design[62]. 2.744 is a graduate level class focusing on product design skills[63]. Teaching techniques developed working with these different classes were incorporated into the design of the short product design workshops that were central to the experiments in this study.

The workshops covered content including design process, observation and opportunity identification, sketching, and prototyping with simple materials. The design process content is adapted from material taught in 2.009 and 2.744. Main topics covered include identifying problem solving opportunities in the world around you, brainstorming solutions to those problems, evaluating ideas against each other, and the role of prototyping in design process. This content constitutes the abstract, open-ended problem solving materials of the workshop. Exercises from 2.744 were adapted to provide the bulk of the activities in the second day of the workshop, described in detail in Experimental Design chapter.

The skills-based physical content covered by the workshop is also adapted from material in 2.009, 2.744, and 2.00b. This content included ideation sketching and working with simple prototyping materials. The sketching section is adapted from exercises done in 2.744 developed by Professor Wallace. Sketching topics included warm-up exercises and an introductory presentation of perspective sketching. Prototyping skills revolved around the use of cardboard, foamcore, and buoyancy billet, also commonly referred to as blue foam. The prototyping skills content is adapted from all three MIT design classes, and the techniques used to teach them were adapted from the instructors of those courses. Additionally, resources provided by Beth Sullivan, a professional model maker and owner of the model making company IC3D, were used to construct the prototyping content for the workshops[64–66]. Prototyping topics included material-specific procedures for cutting, shaping and joining. The content covered are actual procedures used during various prototyping stages in professional product design work. Content was also developed regarding the safe use of prototyping equipment during the workshop.

3.2 Design of the Website

For the online and hybrid delivery methods explored in the experimental procedures, a website was constructed to disseminate the material needed to complete the workshops. The site is viewable at http://designed.mit.edu/design-online. Several methods were explored to complete the task of disseminating the video based content, including learning management system (LMS) Moodle, popular video sharing websites YouTube and Vimeo, MIT Tech TV, and the software platform being developed for hosting MITx and edX courses. Moodle seemed to have a steep learning curve and a feature set far too rich for our desired experimental procedure. Simply hosting a channel on a video-sharing site seemed too informal and disorganized, although YouTube was used to host the video content online. YouTube was chosen because of the absence of video number or size limits and the ease with which videos can be embedded in other websites. The use of YouTube was not without its flaws, with the inability to choose a video's thumbnail, or the static image shown before the video plays, being the most notable. In the future, paying to become a member of a video sharing site would probably provide more customizability options. At the time of this work, the edX software platform was still in development and not an option. The software platform supporting MITx was available, but the content would only be viewable to MIT students, which would hinder the study. Therefore a website was developed specifically for the supporting the online portion of the workshops.

The website was constructed using a series of static HTML pages to organize the navigation of the site. Styling for the website was done with CSS. To keep the website simple no JavaScript was used. Web authoring software Coda 2 was used in the development of the code. Video content was hosted on YouTube and embedded into the HTML. The website documents were hosted in a public folder on an Internet locker given to each MIT student. This allowed for all participants, whether they were an MIT student or not, access to the website and the workshop content. Any additional content, such as PDF documents describing practice projects and workshop directions, were hosted in the public folder and linked to from the website.

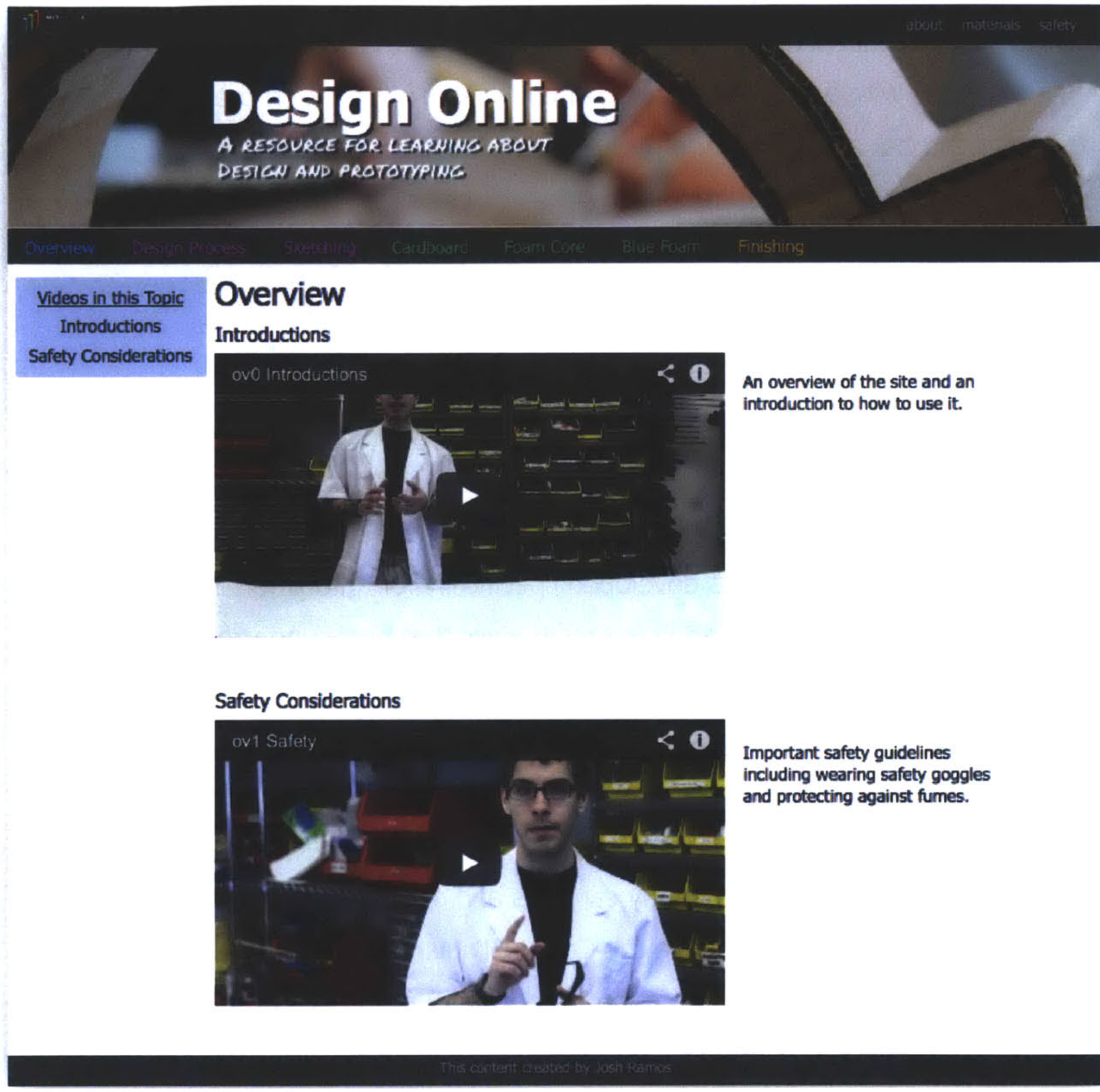

FIGURE 2: THE HOMEPAGE OF THE WEBSITE USED TO DISSEMINATE THE TUTORIALS

Figure 2 shows the homepage of the website developed to disseminate the workshop content. The name of the website, Design Online, was chosen as a way to graphically style and unify the site. All photography shown on the site was either generated for the site or associated with 2.009. Navigation around the site consists of changing pages through the colored horizontal links that display the different course topics. On each of those pages, a vertical navigation menu lists the specific videos displayed on that page. The vertical menu items are clickable links that automatically scroll the user to that specific video. Down the center of the webpage is the vertical column of videos with a short description of each video beside it on the right. The horizontal menu bar at the very top of the page links to the MIT Department of Mechanical Engineering and to important pages on the site. There were no usability complaints regarding the navigation of the website as very few usability issues occurred. Usage statistics tracking website use were not collected.

3.3 Design of the Video Content

The video content for the workshops was developed during the course of an academic semester. Content was developed specifically for an online setting. This content was broken up by topic and created in ways that best supported the material being covered. All of the content was filmed in the Product Design Laboratory at MIT. The use of animations and images were also used to illustrate concepts when necessary. Professional equipment was used throughout the entire workflow. Up to three cameras were used simultaneously during the filming of the video content, including two professional photography cameras and one professional video camera. The photography cameras used were the Canon 5D Mark III and the Canon 7D. These cameras were used because of their superb video capture abilities and the ability to use interchangeable lenses to adapt to different shooting conditions. The video camera used was a Sony PMW-100, a small, lightweight, highly portable professional video recorder. In order to obtain usable audio, a Zoom H4n audio recorder and a small, wired lavaliere microphone were used. A typical filming setup can be seen in Figure 3. All media was edited with Apple Final Cut Studio 3 software, including Apple Final Cut Pro 7, as well as Apple Motion for motion graphics and animation and Apple Final Cut Pro X. A total of 3 hours and 22 minutes of online footage was developed. See Table 1 for a detailed list of video content.

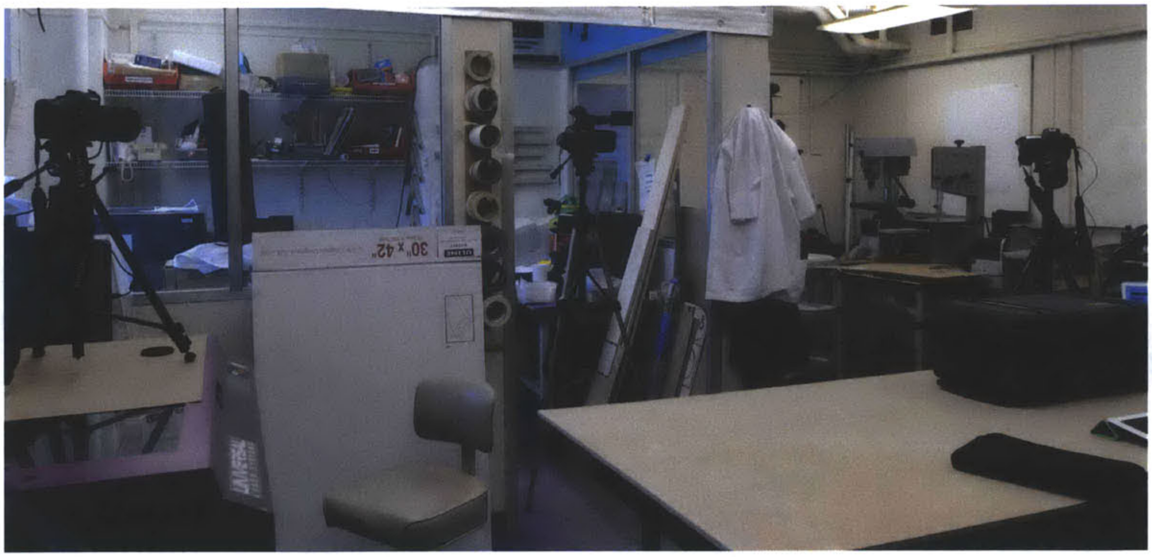

FIGURE 3: A TYPICAL FILMING SETUP WITH THREE CAMERA ANGLES

TABLE 1: LIST OF VIDEOS PRODUCED

Overview	Design Process	Sketching	Cardboard	Foamcore	Blue Foam	Finishing
Introductions	Design Introduction	Motivation	Motivation	Motivation	Motivation	When to Finish [Optional]
Safety Considerations	Observation	Warm-ups	Introduction	Introduction	Introduction	Painting Cb/Fc [Optional]
	Brainstorming	Perspective	Grain Direction	Grain Direction	Rough Cutting	Painting Blue Foam [Optional]
	Idea Selection	1 Point Perspective	Bending	Bending	How Wire Cutting	Mounting Graphics [Optional]
	When to Prototype	2 Point - Cubes	Patterns	Cutting	Patterns	
		2 Point - Cylinders	Cutting	Rabbet	Multiple Sides	
		Building up Sketches	Punching Holes	Exacto Board Cutter	Refining	
			Curved Surfaces	Other Specialty Tools	Joining	
			Joining	Curves	Putting it Together [Optional]	
			Putting it Together [Optional]	Joining		
				Putting it Together [Optional]		
				Shearing with Hotwire		

FIGURE 4: AN EXAMPLE OF A DESIGN PROCESS VIDEO WITH ANIMATED TEXT

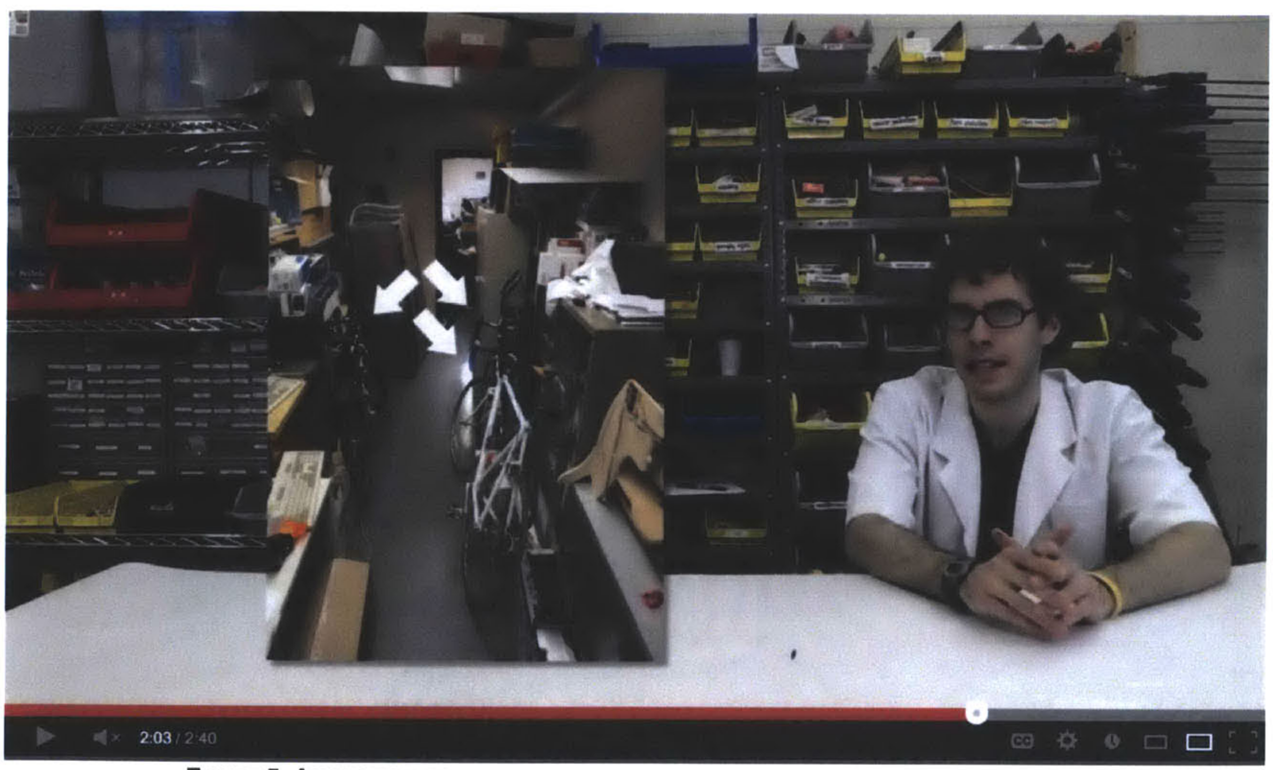

FIGURE 5: AN OBSERVATION EXAMPLE WITH AN IMAGE USED TO ILLUSTRATE A KEY CONCEPT

The design process videos were filmed for the most part with the instructor on screen and animated text to help highlight key points, as exemplified in Figure 4. Images were used when needed to illustrate a concept. Figure 5 shows the use of an image to describe an opportunity identification situation. An animation was developed to describe the use of Pugh Selection Charts to evaluate ideas. Different sections of the chart would appear when they were relevant to the discussion. An example can be seen in Figure 6.

FIGURE 6: AN ANIMATION WAS USED TO SHOW THE PROCESS OF USING A PUGH CHART

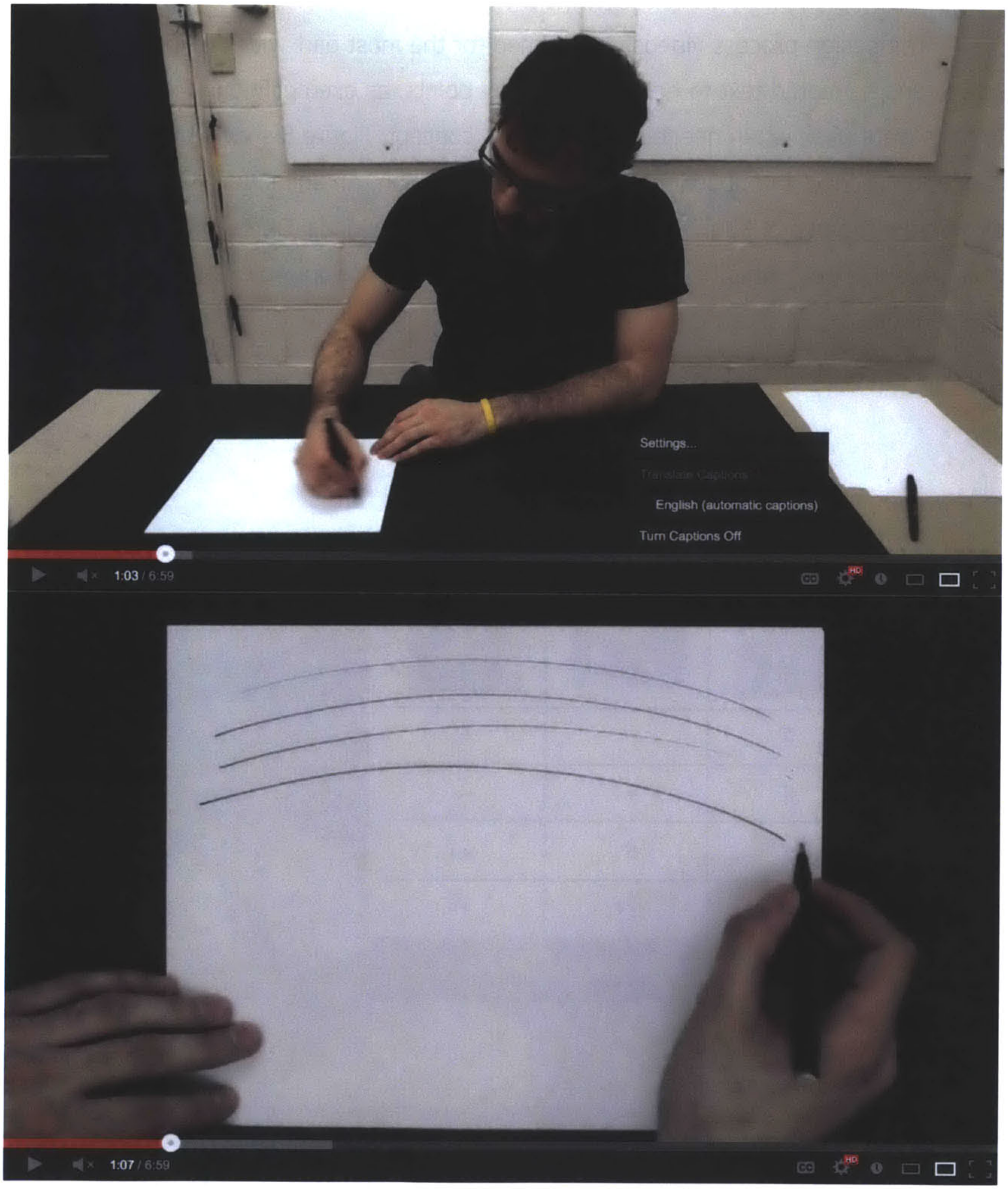

FIGURE 7: TWO CAMERA ANGLES WERE USED TO SHOW SKETCHING TECHNIQUE

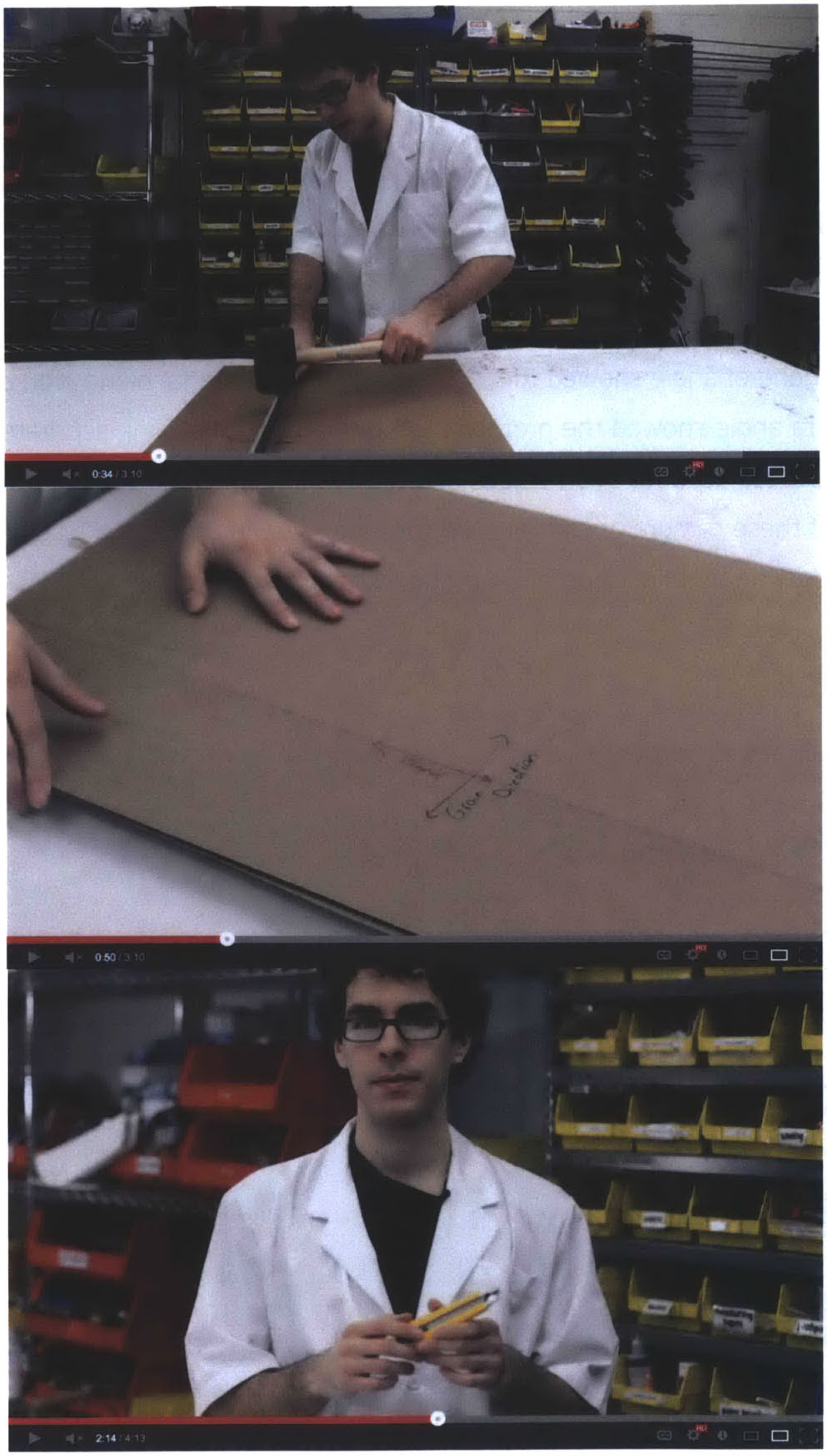

FIGURE 8: UP TO THREE CAMERA ANGLES WERE USED IN DEMONSTRATING PROTOTYPING

Multiple camera angles were utilized in video content about the topics of sketching and prototyping. During sketching exercises, camera angles would switch between showing the instructor head-on and showing a top view of the sketching procedure. This allowed for viewers to both see the techniques used to do the sketching, which involve the use of the whole arm, as well as see the resulting sketch work in detail. See Figure 7. Figure 8 shows examples of the three camera angles used during demonstrating prototyping.

One general angle showed the instructor and the material being worked on. A closer camera angle showed the prototyping work in detail. Finally a separate, medium camera angle was used for short asides and to highlight a key procedure or tool being used. Use of these camera angles allowed for better viewing then in a traditional large group demonstration, mimicking one-on-one instruction.

FIGURE 9: AN EXAMPLE PROJECT BEING PUT TOGETHER

Each video series included a motivational segment at the beginning. This segment served as an overview for the topic being discussed and as motivation, situating the work in the design process. For the prototyping sections, these videos showed an example of something constructed with the material. The prototyping sections also included optional videos about putting example projects together with the material being demonstrated. See Figure 9 for a video frame showing the assembly of an example project.

3.4 Design of the Workshop Materials

Several materials were developed in order to support the different delivery types. In each case, documents were constructed that detailed the schedule of the workshop. For the traditional delivery method, Microsoft PowerPoint slides were used to present the material. While most of these slides were developed specifically for the workshops, some slides were adapted from material presented in 2.744. The teaching techniques used for the first workshop day in the traditional delivery method, including instruction on design process and prototyping, were adapted from 2.009 and 2.00b to be suitable for the workshop. This material was taught using the video tutorials for both the online and hybrid cases. The observation exercise completed on the second workshop day was adapted from a similar exercise taught in 2.744.

Additional materials in the form of practice projects were developed for all workshop sessions. Two out of the three practice projects were designed during the development of the workshop. The third practice project was adapted from a 2.00b *Toy Design* foam-cutting exercise. Another small project, a handheld hotwire foam cutter, was adapted from a 2.009 exercise to allow online participants to cut foam without having to invest in any equipment. All four of these exercises had accompanying worksheets outlining directions for making the projects and providing cutting patterns to assist in fabrication. These worksheet were prepared for the workshops and were delivered to participants in either physical form or via a PDF file hosted on the website. Full record of these documents can be found in Appendix A.

4. Experimental Design

4.1 Overview of the Experimental Design

The goal of the research was to test the learning gains of three different delivery methods. The methods tested were traditional delivery, online delivery, and hybrid delivery, a combination of the previous two. Participants were recruited from MIT and elsewhere to participate in a 2-day product design workshop covering design process, sketching and prototyping. After conducting an observation exercise and choosing a problem to solve, participants made prototypes to illustrate the solutions they developed. After all the workshops had been conducted, all of the prototypes were collected and documented with text and photos. A survey was conducted where three product design experts rated the identified opportunities and the prototypes made to describe the solutions.

4.2 Practical Implementation of the Experimental Design

Participants were recruited to participate in the study via various methods. The target population was a varied group that might approximate the population of an online course or a college campus. To recruit on-campus students, email messages were sent through course administrators to students across MIT. Email messages were also sent out through connections obtained from previous educational events with a similar nature. For both on-campus students and the general population, flyers were put up around the Cambridge area. The workshop was open to all; student status was not required. The only firm rule was that participants had to have no experience with product design or the material presented in the workshops. Participants who were deemed to have too much experience were not allowed to participate. The majority of the participants were MIT students, both undergraduate and graduate, but people from outside of MIT participated as well. Every group has at least one non-MIT-student.

Demographic information was collected from participants. Most participants were in the age range of 20-30 years old, but participant age ranged from 18 to 52. A few students from schools besides MIT participated as well, with students participating from Harvard, Stanford, West Virginia and Notre Dame. Many fields of study were represented, including mechanical engineering, electrical engineering, urban studies, writing, biochemistry, computer science, physics and psychology. Education level was collected, and when possible, SAT or ACT scores were collected in order to gauge the equality of the groups in terms of academic performance.

Participants did not have any idea which delivery group they were participating in until a few days before the workshops. All participants knew that they were part of a study comparing different methods for teaching product design, but they did not have any knowledge of any of the other groups or even if the delivery method was being varied between groups. Flyers and emails made no indication of whether this was going to be an in-person workshop or an online one. Participants only supplied which days they could participate in. If a participant could participate in multiple workshop days, they were randomly assigned a workshop to participate in. The traditional learning workshop ended up with 9 participants, the online learning workshop group had 9 participants, and the hybrid group had 8 participants.

Each workshop took place over a weekend, with no two workshops on the same weekend over a month-long period.

4.3 Traditional Delivery Group

The traditional learning group was instructed to meet at the Product Design Laboratory on the first day of their workshop. The instructor met them in the morning and introductions were made. The morning session consisted of learning design process, observation, opportunity identification, brainstorming, idea selection, sketching and prototyping with cardboard. After a one-hour lunch break, teaching resumed with foamcore prototyping, blue foam prototyping, and practice projects where participants were instructed to complete one practice project or work on a project of their own design. The discussion of workshop topics was brief and fast-paced. Example photographs from the traditional learning workshops can be seen in Figure 10.

Figure 10: Example photographs from the workshop sessions

The second workshop day consisted of meeting in the Product Design Lab and discussing the observation exercise. Participants were then instructed to leave the lab and conduct the exercise. The observation exercise consisted of going out into the real world and taking notes about possible opportunities to solve a problem. Suggested areas to explore included public transportation areas, coffee shops, classrooms, parks, and other nearby stops. Upon coming back to the lab, participants were allowed free time to work on their ideas and prototypes. The instructor suggested taking the time to brainstorm solutions, evaluate solutions and then begin prototyping, but ultimately participants were allowed to decide how to spend their time.

The shop was once again closed for a one-hour lunch break. After the break, students were given more time to develop their prototypes. The directions were to simply construct a prototype that helps illustrate the solution to the problem you chose. All participants had to stop working at the same time. The workshop concluded with a judging ceremony by experienced product design students. Each session has a small panel of judges who rated the participant's work and a winner was chosen. The winner was given a $50 Amazon gift card, which was offered as motivation to participate in the study. After an exit survey participants were allowed to leave, leaving their prototypes behind. The instructor also collected worksheets documenting the opportunity and a description of the prototype in the participant's own words along with a descriptive image describing the opportunity either taken or selected by the participant.

4.4 Online Delivery Group

The online delivery method group participated in an equivalent workshop that was given entirely online. The major difference was that online participants were given a small budget to purchase their own materials at local art stores. A detailed list of materials was given to participants three days ahead of time to allow for time to shop. Additionally, online workshop participants needed to stop by a designated area on campus to pick up a kit with parts to make a handheld hotwire cutter. The first workshop day had the same schedule, but participants learned from the online resources instead of from an instructor face-to-face. To complete the practice projects, participants could download and follow along with PDF instructions of the same practice projects given to traditional learners. If they had access to a printer, the instructions could be printed out and then used as patterns. For those without access to a printer the physical dimensions of the patterns were displayed on a separate PDF document. It should be noted that while participants checked in with the instructor via email from time to time to confirm their participation and ensure no issues, there were no actions taken to monitor their actual work habits during the workshop. Throughout the entire workshop the instructor was available to answer questions via email, phone, text message or video chat. Participants preferred to communicate via email.

The second day for the online learners was once again the same schedule as the traditional delivery method, only without the instructor in person. Instructions for the observation exercise were given in the form of a text PDF. Afterwards, the exercise participants were given time to work on their prototypes. Once again, the instructor was available to answer any questions, was in contact with all students via email, and students were told to take a one hour lunch break. All participants were instructed to stop at a certain time and hand in the documents describing their prototypes. This time, participants were also instructed to include a short video detailing their opportunity and prototype. The panel of student judges met to review the documents and the winner of the workshop was selected. Participants then conducted an online survey to record their learning experiences. After the workshop the instructor met with participants over the course of the next few days to obtain their physical prototypes.

4.5 Hybrid Delivery Group

The hybrid delivery group participated in the workshop in the same way as the online delivery group on the first day of the workshop, and in the same way as the traditional group on the second day. This order of online and then traditional delivery was chosen in order to simulate conditions of a flipped classroom, a classroom style where students learn from video resources on their own time and then use class time to work on more engaging activities. Hybrid participants were also given a budget to collect their own prototyping materials, but were instructed to leave these materials at home and use resources in the Product Design Lab during the second workshop day. Participants left their prototypes with the instructor and could leave after filling out the exit survey.

It should be noted that wherever possible the instructor made the effort to keep all three groups consistent. They learned the same material and participated in the same activities. However, differences inherent in the different delivery methods were allowed to play out. For instance, although each participant completed individual work, in the traditional setting participants could see the work of others, talk and socialize together. Online participants ultimately decided how to spend their time and when to take breaks, while the traditional group had to leave the lab when it closed for lunch. The traditional group could ask questions to the instructor in real time, whereas the online group could pause and replay video content at will and work along with the videos.

After the collection of all the prototypes from all of the different workshop sessions, the prototypes were documented in a consistent manner to remove any bias that might come about from differences in photography equipment or language skills. A survey was generated that described the opportunities identified by the participants. A characteristic image that was taken or chosen by the participant was included. The prototype descriptions were rewritten and photographs were taken of each prototype in enough detail to adequately describe them. This survey was then sent to three product design experts who rated the prototypes. The expert panelists were asked to rate how real the opportunity described by the participant was and how effective their prototype was in illustrating their solution. These ratings formed the basis for the comparison of the learning effectiveness of the different delivery methods.

5. Results

5.1 Overview and Group Comparison

Early-stage product design topics were covered in a series of 2-day workshops in order to compare the learning effectiveness of three different delivery methods. Product design process and prototyping were chosen as topics to cover because of the relative difficulty of translating that material into online resources. Three experimental groups were formed. The first group, the traditional learning group, met in the Product Design Laboratory, a small prototyping workspace at MIT, to learn the material face-to-face. The second group, the online learning group, received the material through an online resource developed for this experiment. This group was not instructed to meet on campus. The third group, the hybrid learning group, learned in a "flipped classroom" setting, watching the online resources in order to learn the material the first day and then meeting on campus the second day. All groups submitted documents regarding opportunity identification and a prototype depicting a solution after the workshops. These materials were collected, documented, and a survey was sent to a panel of three product design experts to determine any difference in performance among the groups. The panel answered questions about whether the described opportunity was a real opportunity and whether the prototype helped illustrate the participant's solution to the identified problem. All scores were from rated from 1 to 10 on these two metrics, with 10 being the highest score.

The sizes of the groups and consequently the sample sizes for the study were small (traditional n = 9, online n = 9, hybrid n = 8). Because this was a pilot study, different statistical methods for comparing the groups were performed. The first method was the Kruskal-Wallis method of statistical comparison, which compares multiple groups to determine if the samples come from the same distribution or not. The second method was a standard bootstrap statistical method to compare the means of the online and hybrid groups to the traditional learning group to investigate any differences. The small sample sizes are within guidelines for these statistical methods, but larger samples would provide more trustworthy results[67]. The three groups – traditional, online, and hybrid – were compared in terms of opportunity realness scores, prototype effectiveness scores, and an average of the two scores representing an overall quality score for the idea. In all cases, no significant difference in performance was observed between the experimental groups. A full data set of the results from the expert panel survey can be seen in Table 2.

TABLE 2: RAW SCORES FROM THE EXPERT PANEL SURVEY

Expert Panel Results		Realness of Opportunity Rating				Effectiveness of Prototype Score				Quality
Number	Style	Judge 1	Judge 2	Judge 3	Average	Judge 1	Judge 2	Judge 3	Average	Average
1	Traditional	8	8	7	**7.7**	6	5	9	**6.7**	**7.2**
2	Traditional	8	7	8	**7.7**	8	3	7	**6.0**	**6.8**
3	Traditional	4	8	8	**6.7**	3	4	7	**4.7**	**5.7**
4	Traditional	7	6	3	**5.3**	6	5	10	**7.0**	**6.2**
5	Traditional	6	7	6	**6.3**	7	5	8	**6.7**	**6.5**
6	Traditional	8	8	2	**6.0**	7	4	8	**6.3**	**6.2**
7	Traditional	3	7	4	**4.7**	7	6	5	**6.0**	**5.3**
8	Traditional	6	8	6	**6.7**	4	8	9	**7.0**	**6.8**
9	Traditional	4	8	3	**5.0**	3	4	2	**3.0**	**4.0**
10	Online	8	5	9	**7.3**	8	8	7	**7.7**	**7.5**
11	Online	2	9	7	**6.0**	3	3	5	**3.7**	**4.8**
12	Online	8	9	5	**7.3**	6	3	4	**4.3**	**5.8**
13	Online	3	8	5	**5.3**	5	5	2	**4.0**	**4.7**
14	Online	4	8	4	**5.3**	3	3	2	**2.7**	**4.0**
15	Online	7	7	5	**6.3**	2	4	6	**4.0**	**5.2**
16	Online	6	1	6	**4.3**	7	4	7	**6.0**	**5.2**
17	Online	7	4	6	**5.7**	7	5	3	**5.0**	**5.3**
18	Online	5	7	6	**6.0**	7	7	7	**7.0**	**6.5**
19	Hybrid	4	3	2	**3.0**	5	3	4	**4.0**	**3.5**
20	Hybrid	5	8	8	**7.0**	6	3	8	**5.7**	**6.3**
21	Hybrid	7	8	4	**6.3**	7	6	7	**6.7**	**6.5**
22	Hybrid	6	7	6	**6.3**	6	8	9	**7.7**	**7.0**
23	Hybrid	7	6	2	**5.0**	7	5	4	**5.3**	**5.2**
24	Hybrid	7	6	2	**5.0**	7	6	7	**6.7**	**5.8**
25	Hybrid	7	8	4	**6.3**	2	3	4	**3.0**	**4.7**
26	Hybrid	6	8	2	**5.3**	6	5	4	**5.0**	**5.2**

5.2 Method 1: Procedure and Results of the Kruskal-Wallis Comparison

The typical procedure for analyzing data comparison between experimental groups in engineering education literature is to perform an ANOVA test, or an analysis of variance, to investigate the null hypothesis that different groups have means that are statistically the same. The ANOVA method generalizes the student t-test to more than two groups. However, the ANOVA method was determined to be unsuitable for the data presented in this study. ANOVA methods make the assumption that the data being compared are normal distributions[68]. There was not significant evidence to comfortably make the assumption that the distribution of judge scores formed a normal distribution, so more robust methods were chosen.

The Kruskal-Wallis method is a statistical comparison between two or more groups that makes no assumptions about the normality of the sample distributions. The Kruskal-Wallis method is completely agnostic to distribution type, making it a particularly useful method for non-normal distributions[69]. The only underlying assumption is that the distributions being compared are of the same shape. Testing to see if groups exhibit homoscedasticity, or testing whether the groups have the same variance, can confirm this. Variances that are statistically the same suggest distributions that are of the same shape and therefore appropriate for the Kruskal-Wallis comparison[67]. To compare the variances of the groups in this experiment the most appropriate test is the Brown-Forsythe test, which is also robust to distributions that are non-normal[70]. A Brown-Forsythe test comparing the traditional, online and hybrid groups confirmed the null hypothesis that the groups had the same variance for both the opportunity and prototyping scores ($p = 0.85$ and $p = 0.72$).

The Kruskal-Wallis method tests the null hypothesis that the samples come from populations such that making a random observation from one group has a probability of 0.5 of being greater than a random observation from another group[67]. This circumstance describes populations that are from the same distribution by essentially testing for significant differences in the median ranks of the groups in question. Therefore if the Kruskal-Wallis test provides an achieved significance level that is low enough to reject the null hypothesis at least one of the groups tested is from a different distribution from another group. The procedure for conducting a Kruskal-Wallis test involves replacing the data with rank values, with 1 as the lowest rank, and averaging ties. While the rank conversion does sacrifice some information contained in the data, it allows for robustness with non-normal distributions. The three groups – traditional, online, and hybrid – were compared in terms of opportunity realness scores, prototype effectiveness scores, and an average of the two scores representing an overall quality score for the idea. Ranked data for the different comparison groups is shown in Figure 11.

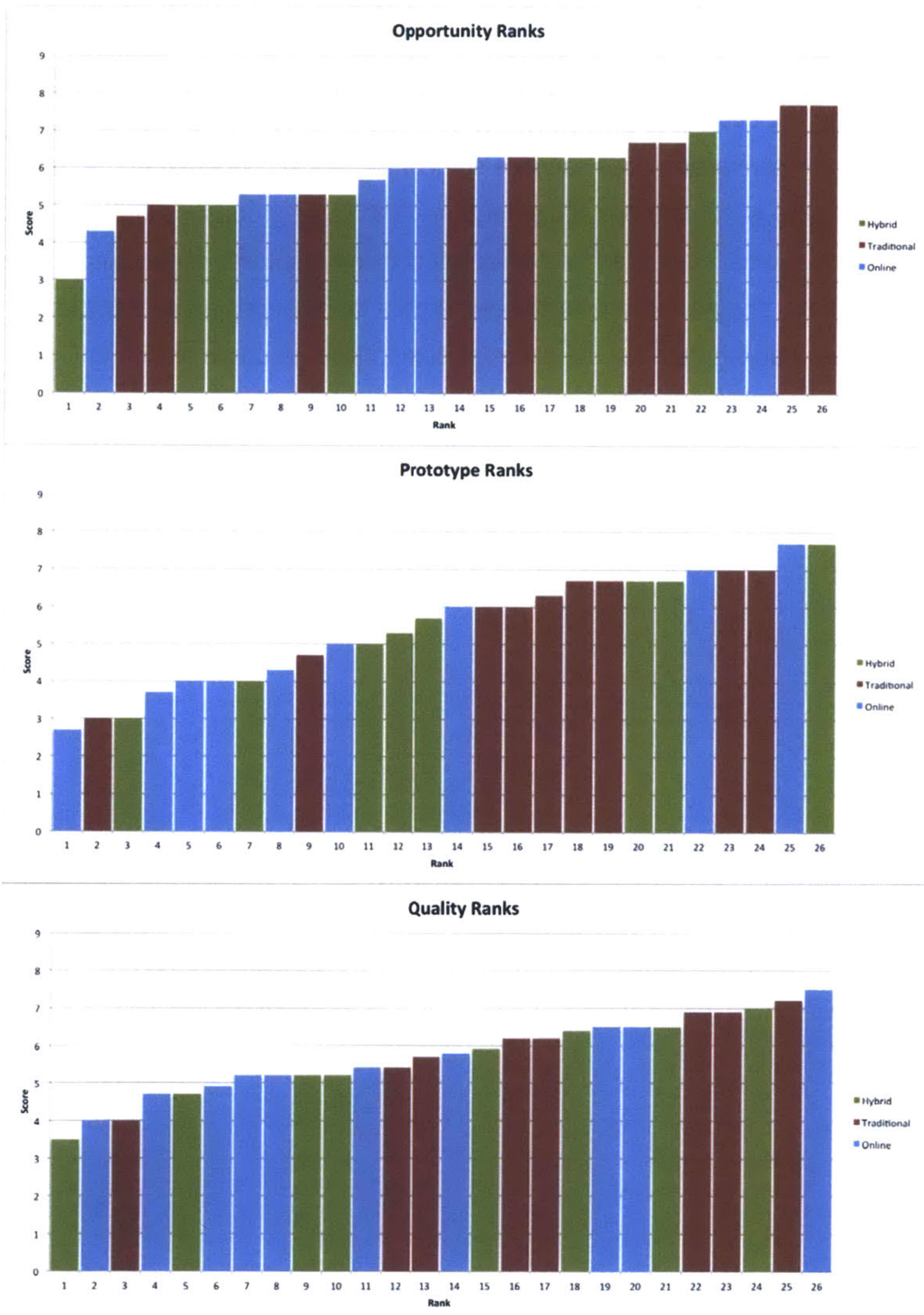

FIGURE 11: RANKED SCORES SHOWING THE PLACEMENT OF THE SCORES FOR DIFFERENT GROUPS. THE KRUSKAL-WALLIS TEST DETERMINES IF THERE IS A SIGNIFICANT DIFFERENCE BETWEEN THE GROUPS

A Kruskal-Wallis test between the three groups was conducted using Mathworks MATLAB software. Scripts detailing the procedure can be found in Appendix B. The test failed to reject the null hypothesis that the groups had statistically significant median ranks, confirming that they are from the same distribution. The achieved significance levels are displayed in Table 3. Therefore no difference was observed in the performance of the three groups.

TABLE 3: ACHIEVED SIGNIFICANCE LEVELS RESULTING FROM THE KRUSKAL-WALLIS TEST

	Kruskal-Wallis p-value
Opportunity Scores	0.58
Prototype Scores	0.38
Quality Scores	0.29

5.3 Method 2: Procedure and Results of the Bootstrap Statistical Method

In order to further investigate the difference in performance between the two groups, another statistical method was utilized. This also allowed for further exploration into statistical methods that could benefit future research. As mentioned in the previous section, usual statistical methods, such as the ANOVA comparison, are not appropriate for use with non-normal data. The Kruskal-Wallis method was used to overcome that barrier. However, while the typical guideline for the use of groups in comparison for the Kruskal-Wallis is N = 5, which is met in this study, other methods that are robust to small sample sizes were investigated[67]. The bootstrap statistical method helps expand the usefulness of small data sets in situations where attaining more data is difficult[69] and has been used in engineering education literature previously[8,9].

The bootstrap method takes a sample and then constructs other sample distributions by selecting observations from the experimental data set[71]. Observations are chosen at random and replacement is allowed. The computer-constructed data sets are of the same length as the original, experimental data set. Some meaningful statistic, such as the mean, is calculated for each computer-constructed data set and then the distribution of that calculated statistic is treated in the same way data from the overall population distribution would be. The only assumption made under the bootstrap method is that the samples taken are a good representation of the entire population, an assumption that was made in this experiment.

The meaningful statistic explored in this experiment was the difference between the means of two experimental groups, suggesting differences in performance. Comparisons were made between the traditional group and the online group as well as between the traditional group and the hybrid groups. In each of these comparisons the opportunity realness scores, the prototype effectiveness scores, and the overall quality scores were compared. Each comparison was done by combining the data sets in question together to form one larger data set. For example, to compare the traditional and online group in terms of opportunity realness, the nine traditional realness scores and the nine online realness scores were combined to for a data set with 18 values. Two computer-constructed data sets were put together by randomly choosing observations from the larger data set. Next, the means of the two computer-constructed data sets were calculated and the difference between the two sets was taken. This procedure was repeated 1000 times for each comparison. A distribution was constructed for each comparison made. See Figure 12 for the histograms representing the bootstrap samples. Confidence intervals were constructed and are summarized in Table 4. Once again, computation was done using Mathworks' MATLAB software, and scripts can be found in Appendix B.

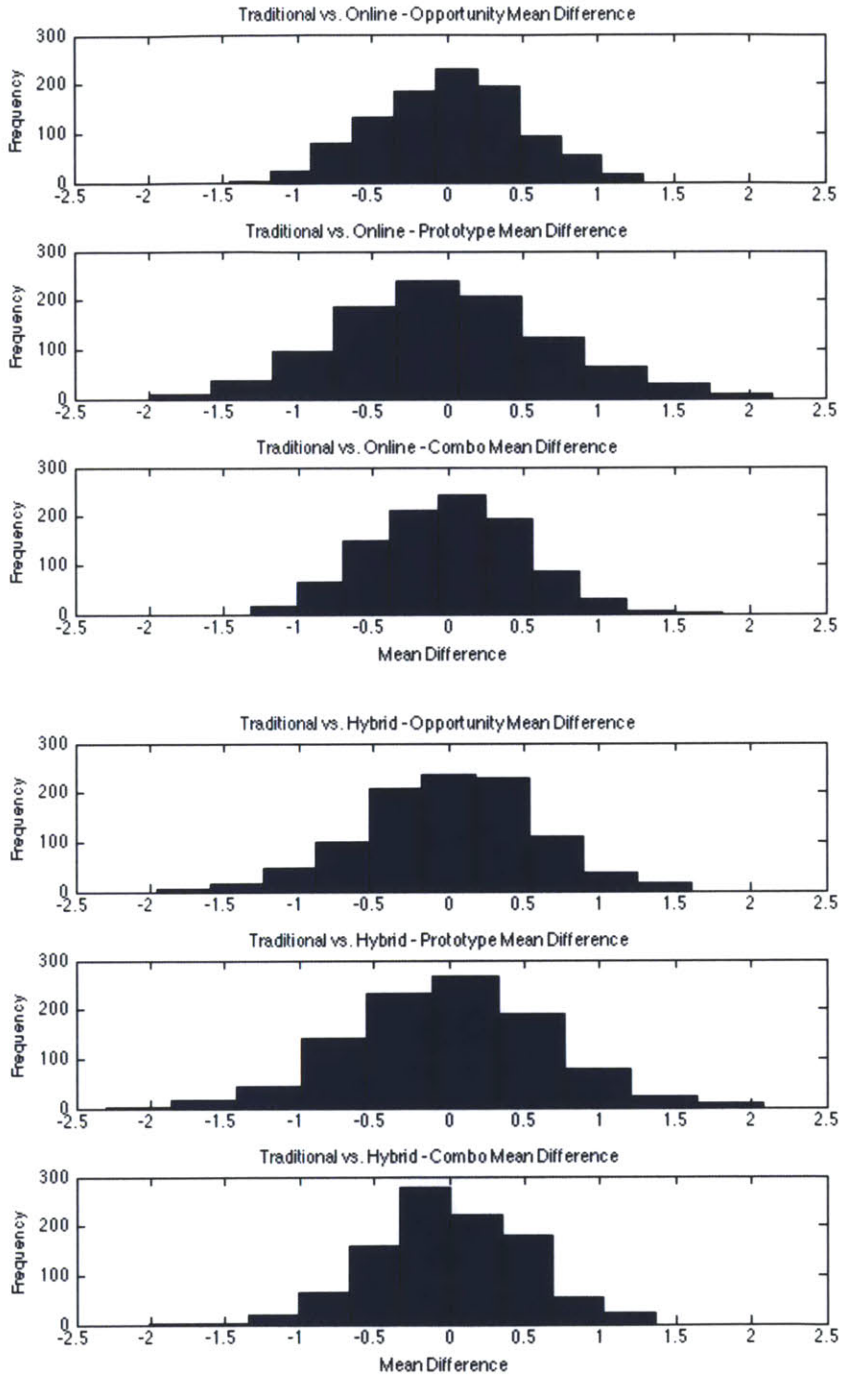

FIGURE 12: HISTOGRAMS SHOWING THE DATA FROM THE BOOTSTRAP ANALYSIS. CONFIDENCE INTERVALS WERE CONSTRUCTED TO DETERMINE ANY DIFFERENCE IN MEAN VALUES BETWEEN THE GROUPS

TABLE 4: 95% CONFIDENCE INTERVALS FOR THE MEAN DIFFERENCES CONSTRUCTED FROM THE BOOTSTRAP DATA

	Lower Bound	Mean Difference	Upper Bound	Observed Mean Difference
Traditional vs. Online				
Opportunity Scores	-0.93	0.01	0.96	0.29
Prototype Scores	-1.40	-0.01	1.38	1.00
Quality Scores	-0.98	0.00	0.98	0.64
Traditional vs. Hybrid				
Opportunity Scores	-1.13	-0.01	1.13	0.71
Prototype Scores	-1.30	0.00	1.29	0.42
Quality Scores	-0.98	0.01	1.00	0.56

The distributions created with 1000 bootstrap samples all showed confidence intervals that include a mean difference of 0, failing to reject the null hypothesis that the groups performed the same. This result shows with statistical significance that there was no difference in performance between the groups compared as measured by the scores from the product design expert panel. Therefore the traditional group, acting as the control, performed no differently than the online group. Additionally, the hybrid group also performed no differently than the traditional group.

5.4 Exit Survey Results

The exit survey tallied answers from participants about various aspects of the course. This information will be used to guide similar ventures in the ongoing expansion of this work. Some interesting results that can suggest student perceptions of learning and assess student satisfaction are presented in Figure 13, Figure 14, and Table 5.

FIGURE 13: OVERALL EXPERIENCE GRAPHS

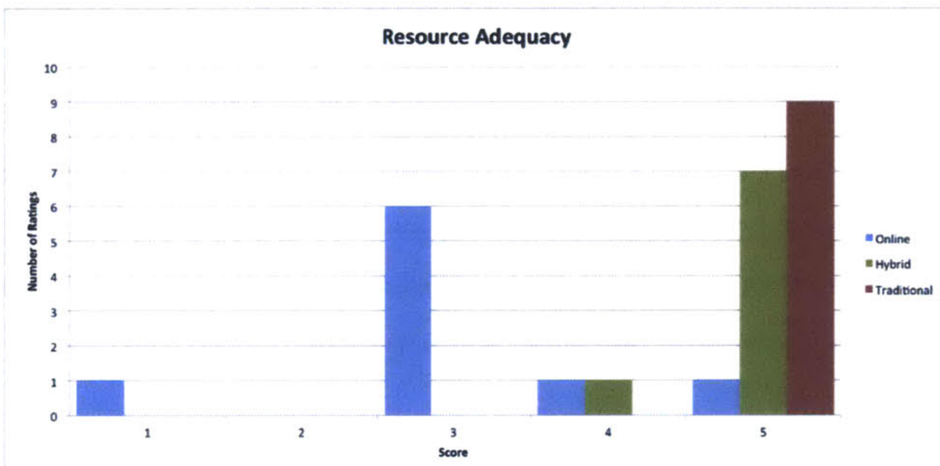

FIGURE 14: GRAPH SHOWING RESOURCE ADEQUACY

TABLE 5: SELECTED AVERAGE SURVEY RESPONSES. SCORES ARE RATED ON A SCALE OF 1 TO 5, WITH 5 BEING THE MOST POSITIVE RESPONSE

	Traditional	Online	Hybrid
Overall Experience Rating	4.4	4	4
Future interest in Product Design	4.9	4.8	4.8
Content Delivery Satisfaction	N/A	4.3	4.6
Resource Adequacy	5	3.1	4.9
Instructor Rating	5	4.6	4.9

6. Discussion

6.1 Summary of Results

Three different delivery methods of early-stage product design content were explored to see if there was any difference in learning gains. The three delivery methods tested were traditional, online, and a hybrid methods that resembled a flipped classroom. These groups were compared using scores from a panel of experts specializing in product design. These panelists rated the work on the realness of the opportunity identified and the effectiveness of the prototype developed. The three experimental groups were compared on the average value of the scores across the panelists, as well as an average of the scores across both the opportunity and the prototype scores, creating one general quality metric. Two different statistical procedures determined that there were no differences in panelist rating between the three experimental groups, suggesting that the learning gains across the groups were constant. Exit survey data was also collected from the participants in the study in order to gauge their engagement and perceived learning gains.

6.2 Comments on Experimental Design and Statistical Rigor

More work should be done to ensure the statistical robustness of this and future studies. One example is the comparison of groups before participating in the workshops. In order to ensure a consistent level of ability in the different experimental groups, SAT and ACT scores were requested from all participants. While most participants were able to provide these scores, some international students did not have scores from those standardized test so other tests or adjustments were made. In the current experiment those test scores were just used to examine if there were any "red flags," or participants who scored low enough to consider them very different in ability from an MIT student. Much of the content discussed in this particular workshop did not require exceptional reasoning skills, mathematical ability or reading comprehension, so the test scores were only used as a first estimate of ability. In order to prevent potentially biasing the expert panel reviews based on written descriptions of the opportunities identified, all of the written documentation handed in by the participants was rewritten before being presented in the expert panel survey. In a future study it would be recommended to formulate the experimental design in a way that more rigorously assesses the potential ability of each group to ensure equal potential going in to the experiment. This could be done by having participants do exercises together at first, using the same delivery method to assess their performance before changing the experimental conditions.

Another area of potential improvement could be in the use of the expert panel. In this study three experts were used and no characterization of inter-rater reliability[72] was performed. Future studies would benefit from more panelists in hope of attaining more consistent results. A training session before hand to ensure the consistency of the responses and to make sure each of the panelists properly understands the rating scale could also be beneficial in the future.

Of course, larger populations would also help make the study more statistically robust. The workshops, which consisted of two full workdays worth of time, are large commitments and it was difficult to get many participants to volunteer that amount of time. Integrating this study as part of an existing class would most likely provide more consistent results and potentially larger population sizes.

6.3 Interpretation of Survey Results

The results of the exit surveys given to the participants of each experimental group collect responses about perceptions of learning gains and satisfaction with the workshops. All feedback will be used in any future expansion of this work. The results are generally positive, and some interesting statistics are presented in an effort to understand the effectiveness of the workshop as a pedagogical venture. These scores are rated from 1 to 5, with 5 generally being the most positive result.

In terms of overall experience, the average rating across all participants was 4.1 (traditional = 4.4, online = 4, hybrid = 4). There was one instance of the lowest score, a 3, in each experimental group. When asked whether participants wanted to learn more about product design and prototyping, besides five instances of a score of 4, all participants responded with a score of 5. Participants in the digital delivery groups generally rated their delivery method as "a good fit for the material" (online = 4.25, hybrid = 4.6). An interesting trend can be gleaned from the data regarding responses to the question "Did you find you had the resources necessary to complete the design challenge?" While the overall response was satisfactory (average = 4.3), the online group responded with lowest average score (traditional = 5, online = 3.1, hybrid = 4.9). This lower result could suggest the extra value added by the dedicated prototyping space provided by the Product Design Lab in the residential cases. All groups had a positive rating of the instructor, as all instructor ratings were either scores 4 or 5 (traditional = 5, hybrid = 4.9, online = 4.6). These findings suggest positive engagement with the material and positive student perceptions of the different course delivery methods and of the workshop in general. However, in future studies it would be wise to construct surveys that lend themselves to more statistically rigorous studies and to collect usage statistics on all digital platforms.

Some quotes from text responses from other survey questions that help characterize student opinion of the workshops are provided below.

Response to "Why did you take the workshop?"

"Wanted to learn product design. Didn't know it was an online thing, but I'm glad I did it anyway." – Online learner

Response to "Would you recommend this workshop to a friend? Why or why not?"

"Yes, I definitely would because I thought it was a fun experience that taught you a lot about something you can do right from your home." – Online learner

"Yes - I learned a lot and had a lot of fun building things!" – Traditional learner

Response to "What other engineering/design topics would you like to see in this format?"

"Toy product design/kitchen product design" – Hybrid learner
"Mechanical engineering! This was awesome!" – Hybrid learner

Response to "Do you have any comments for the instructor?"
"Good videos. I would love to see more advanced stuff in the future!" -Online learner

"It's harder to do but it would be good to have the first part less lecture style - some was really boring to sit through and easy to forget when we were designing things" – Traditional learner

Response to "Would you rather learn this material in person or online? Please comment on the delivery method you chose"
"It is very subjective, cutting/designing methods are learned best from experience than canned knowledge" – Traditional learner

6.4 Interpretation of Experimental Findings

The findings in this work have potential implications for different sections of education. The work presented here provides evidence that early-stage product design and product-design-like material have the ability to be presented in online and hybrid formats without harmful repercussions. Please note that no conclusions are drawn as to which learning style is most appropriate for delivering the material, only that all three are potentially viable options. This is an important point for the underlying motivation of the study.

Product design as an academic pursuit embodies many different topics that are fundamentally different and can be pedagogically challenging to teach. Firstly, product design involves open-ended problem solving, which can be abstract and challenging for students who are used to more straightforward approaches. Secondly, product design involves highly physical activities, one of which is prototyping. Both of these concepts – open-ended problem solving and physical activities – are challenging to present in the form of online digital media such as video tutorials, but the work presented here suggests that it can be done. This has implications for online educators in that there is positive evidence that they should explore expanding the boundaries of online education. The most obvious realization of this conclusion is to continue experimenting with teaching product design and open-ended problem solving. This pilot study presented here supports justification for those efforts, and in fact researchers elsewhere have already begun those pursuits[53,54]. However, less literal conclusions can also be drawn. More physical demonstrations and activities can be presented to online learners in order to enhance their education with experiential learning.

No evidence has been presented suggesting the most appropriate delivery method for early-stage product design material, and this has important implications for residential institutions in the real, physical world. As students turn to online education as a way to battle rising tuition costs and crowded lecture halls, residential institutions need to innovate to stay relevant. Being beyond relevancy, but rather exceeding for the sake of improving education to a level of effectiveness never exhibited before is where these institutions should be aiming. The results of this study suggest that the educational content explored could be taught online, but experience suggests that there is just something to be gained by working in a dedicated space with professional equipment and professional mentors. Intuition can be formed that can enhance learning and last a lifetime. Social skills can be developed and face-to-face teamwork skills can be fostered. The work presented in this study, especially in the hybrid case, suggests that the best of both worlds can be achieved. Even in the case of learning abstract and physical concepts, the ability to use the advantages of online resources, such as giving learners more control over their learning pace, reaching a wider audience, and increasing engagement due to interactivity is possible. Combining this with the advantages of residential institutions has the potential to change higher education and the way we learn in general.

7. Conclusions

7.1 Summary

Online learning is becoming more promising as technological advances in communication happen. Internet technologies stand to improve how education happens. In this work, the challenge of taking product design, a subject embodied by abstract open-ended problem solving and physical skills, to an online setting was explored. Three delivery methods were investigated. The first, traditional learning, had participants learn material face-to-face in a workshop dedicated to prototyping. The second, online learning, had participants purchase their own materials and learn from a set of video tutorials developed for this experiment. The third, a hybrid case, combined the two in a delivery method similar to a flipped classroom, where students learned material at home and then practiced it on campus. In each case participants took a 2-day workshop that had them learn about design process, sketching, and prototyping with simple materials. They completed an observation exercise where they identified a problem solving opportunity in the real world, brainstormed and selected a solution to that problem. They developed a prototype to illustrate their solution and documented their work. The documents created by the participants were collected along with their prototypes and used to create a survey for a panel of experts that evaluated their work. Surveys were also given out to gauge student engagement.

The expert panelists rated the participant's ideas in terms of the realness of the opportunity identified and in terms of the effectiveness of the prototype fabricated. These scores formed the data used for the experimental inquiry. The opportunity scores, the prototype scores, and an average of two to form an overall quality score were compared between the three delivery methods. Two statistical methods were used to compare the groups. The Kruskal-Wallis method, which is robust to non-normality, was used to compare all three groups to determine if they were from the same distribution or different ones. A Brown-Forsythe variance comparison was done to determine suitability for the Kruskal-Wallis comparison. A bootstrap statistical method was also done to compare the online and hybrid delivery methods to the control group to determine if there were any statistical differences in mean scores. In all cases the hypothesis tests failed to reject the hypothesis that groups performed differently in opportunity identification or prototyping. Surveys showed that students of all groups were generally satisfied with their learning experiences.

7.2 Future Work

The conclusions from this pilot study warrant further exploration of teaching product design and product-design-like material online. Results suggest that abstract concepts like open-ended problem solving and physical concepts like prototyping can be taught online. For online educators this means that the boundaries of online education can expand to include abstract and physical material if the online resources are developed properly. More online resources can include physical activities to facilitate experiential learning. Residential educators can expand their options for teaching these materials on campus. Some of the material can be transferred to online resources to allow for students to have a constructivist-style control over their learning, wider audiences to be reached, and focus on experiential learning on campus. The best of both worlds holds the true potential to enhance education worldwide.

Several ideas touched on in the study can be further explored in the future. One typical criticism of MOOC-style courses is low completion rates. Incorporating physical activities into online coursework or requiring students to purchase materials for online courses could increase motivation to complete the course. An investigation could be done exploring the effect of having "skin-in-the-game" on student motivation. Changes in student self-efficacy after workshop completion with different delivery methods warrants further investigation. Using a full semester product design class with different delivery methods, especially including a hybrid case designed to take advantage of multiple delivery methods, would be a logical extension of this work. Extending the experimental procedures to include teams instead of individual work would also be worth investigating. The work presented in this thesis has revealed many possible avenues for potential future work toward enhancing both online and residential education.

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Appendices

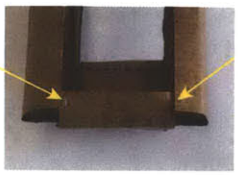
Appendix A: Workshop Materials

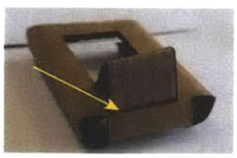
1. Measure your phone, decide the dimensions and draw the outline on the cardboard

2. Cut out the outline

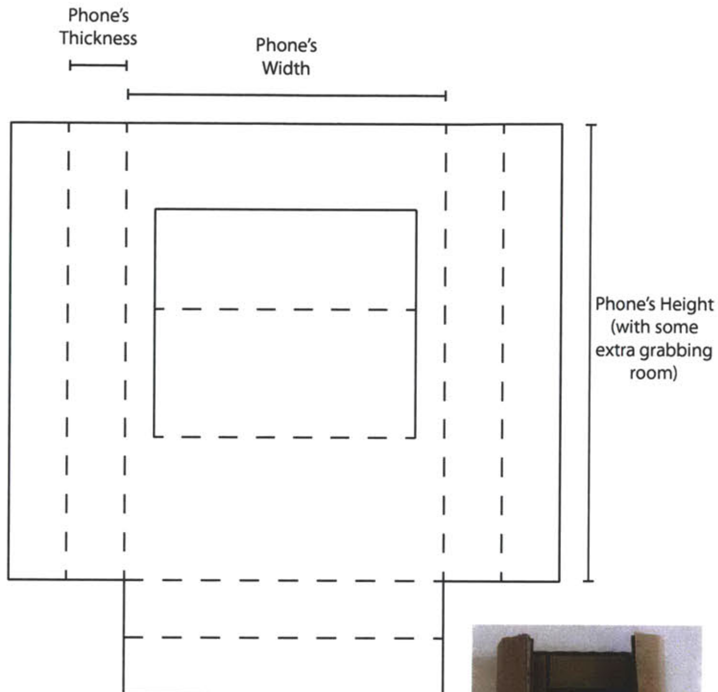
3. Fold along the dotted lines

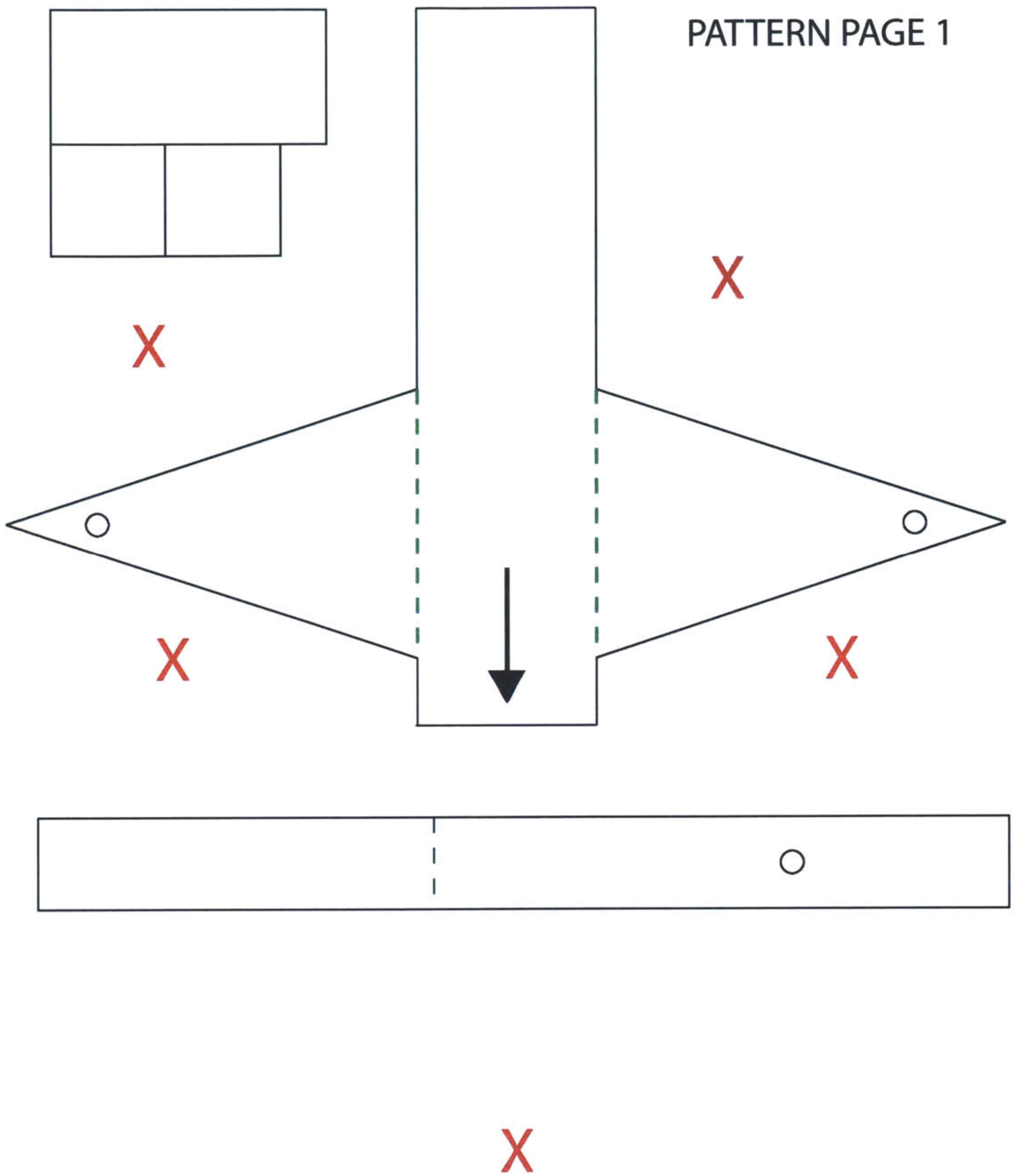
4. Put glue on all the right places





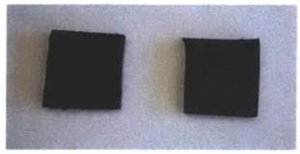
5. Insert phone!

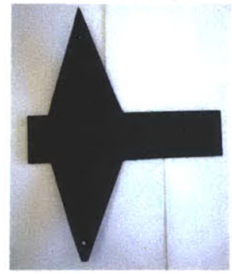


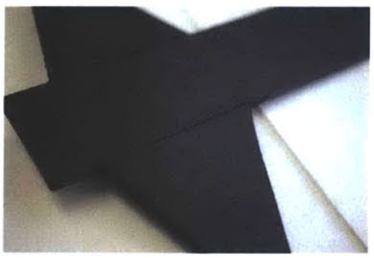


PATTERN PAGE 2

1. Cut the patterns out. You don't need the sections marked with a red X.







2. Use the patterns to cut out foamcore pieces.

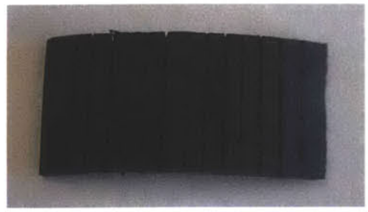
Bend along the black dotted lines

And don't cut all the way through on the green dotted lines! Leave one layer of paper!

Cut holes (with a pointy object like an awl, chopstick or pen/pencil) where there are circles.

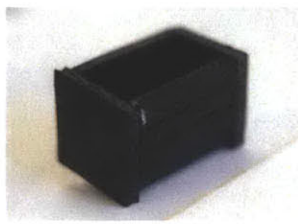
3. Bend the "wings" of the catapult up. We'll glue these in a little bit to make sure they stay in place.

4. Cut a bunch of slices into the 3" by 1.5" rectangular piece. Don't cut all the way through, leave one layer of paper untouched!

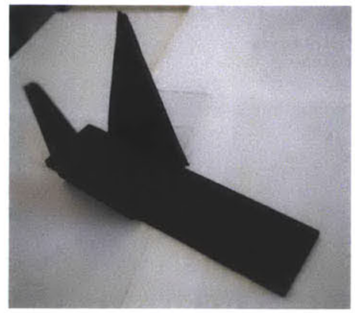


5. Bend that foamcore piece into a "U" shape to the make launch cup of the catapult.

6. Hot glue the small squares onto the ends to complete the launch cup.

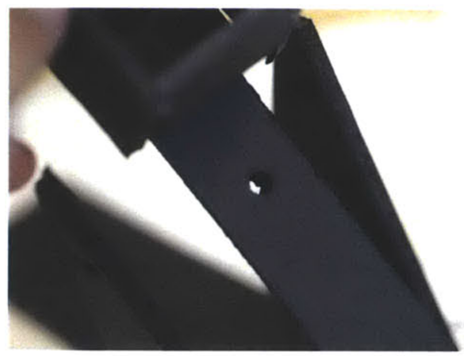


7. Hold the wings upright. You may need to put some tape on the wings to hold them while you glue.



8. Hot glue the corners of the wings on both the top and bottom of the bend. Let the hot glue dry and then apply another layer to better fill gaps underneath. The wings should stay up on their own when the glue has dried.

9. Glue the launch cup on the long, thin piece of foamcore just above the hole. Bend the long piece and glue the shoter end down onto the base of the catapult. Rememer, the shorter end of the catapult base is the front!

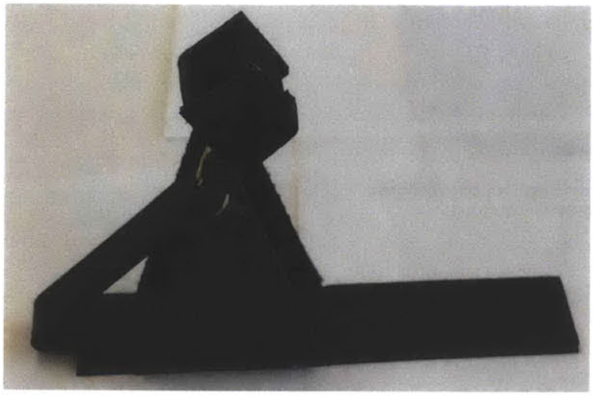


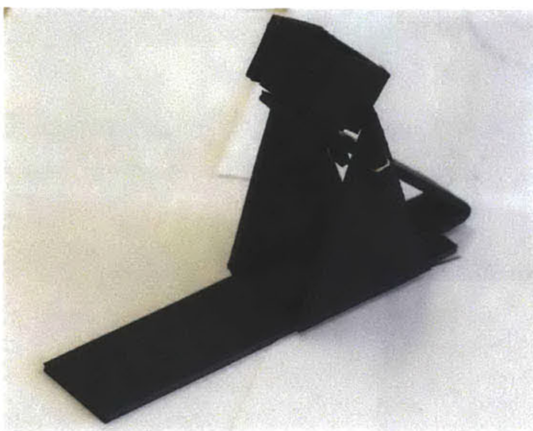
10. Double loop a rubber band and poke it through the hole on the thin piece of foamcore. This part can be a little frustrating, using a pencil might help!

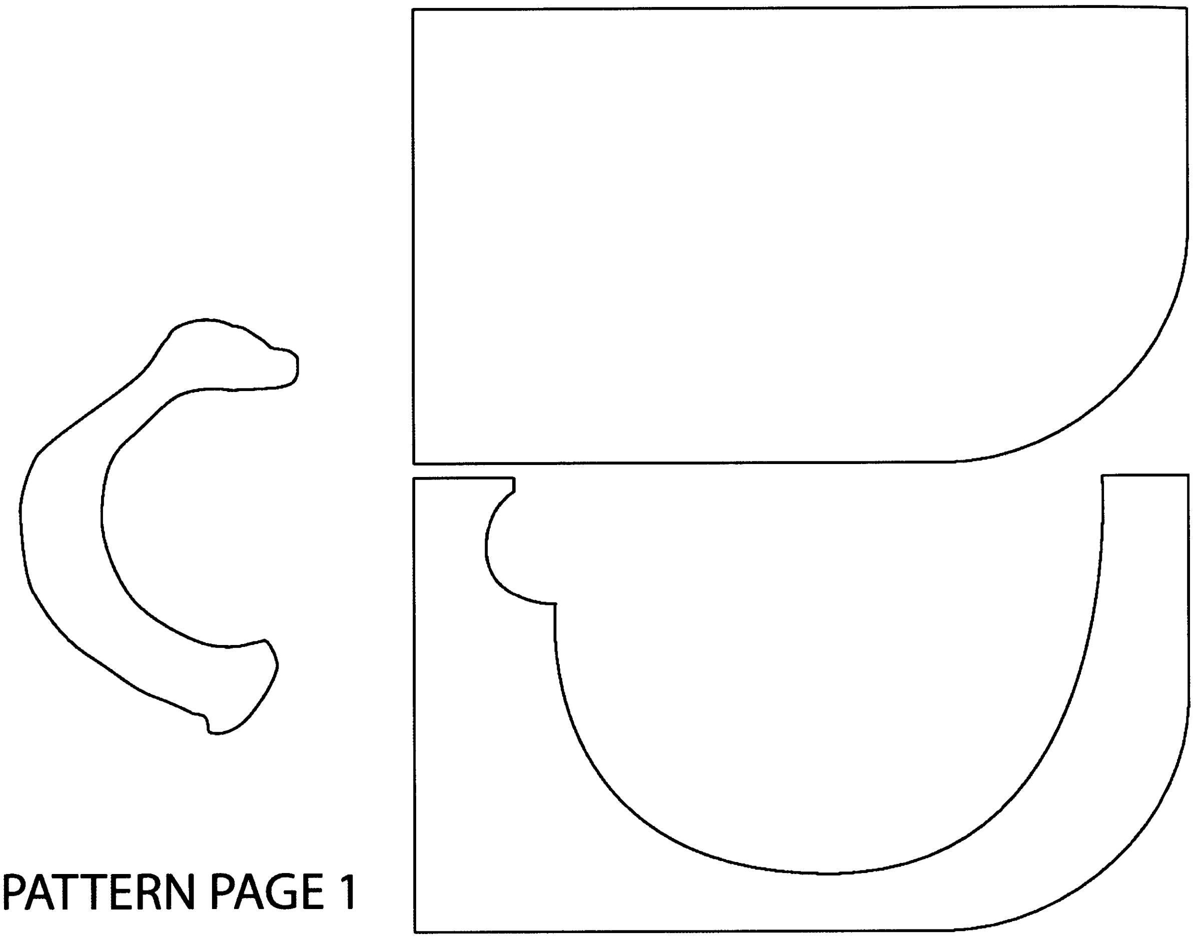
11. Cut a small length of foamcore and use that to secure the rubber band.

12. Poke one loop through the hole in one of the wings and use a small length of foamcore to secure it. Repeat for the other loop on the other side.

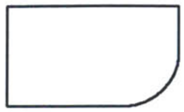
13. Admire your catapult and have some fun! Notice anything that could be improved? Remember to use your powers for good and not evil!

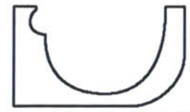


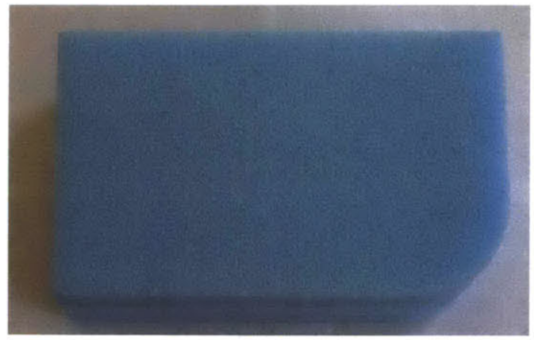




PATTERN PAGE 1

1. Use the  pattern and cut 2 foam blocks that are 1" thick. Stick the pattern to the foam using studio tac or double sided tape and cut the foam using a hot-wire.

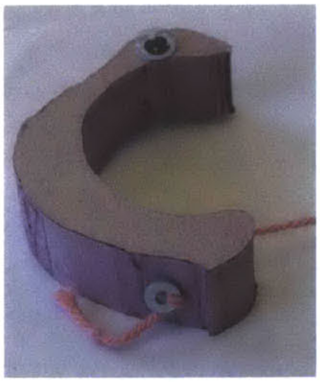
2. Use the  pattern and cut 1 foam block that is 1.25" thick.



3. Cut the snake out of 1.25" thick pink foam. Add googly eyes for more fun!

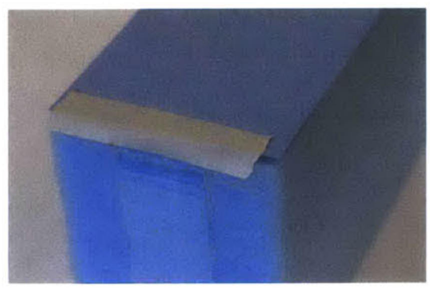
4. Dry mount the foam blocks together, using the curved corner for alignment. Make sure the glue goes on the correct side and the blocks are in the correct order!

5. Use a pointy object (a large pin, a chopstick, the back end of a plasic fork, a pencil) to make a hole in the blue foam. Push a piece of yarn through that hole.

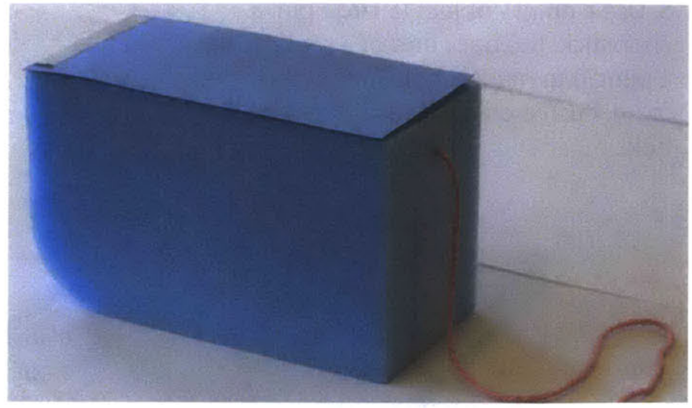


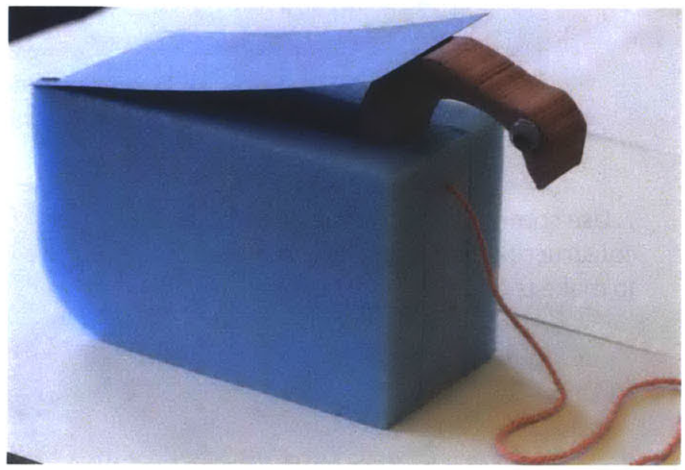
6. Poke that yarn through the bottom of the snake. Make sure you poke from the inner (concave) section of the snake out to the back! Secure the yarn with a washer, a toothpick, or a large knot to keep the yarn from going back through the snake.

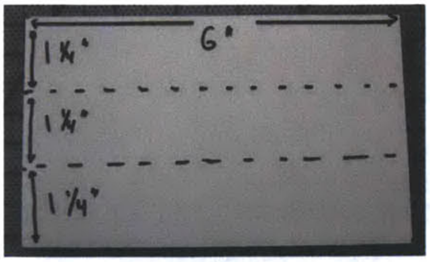
7. Use some tape and some colorful construction paper (or regular paper) to make the trap door on the top



8. Have your friends pull on the string. Boy are they in for a surprise! They are going to think you are so cool!

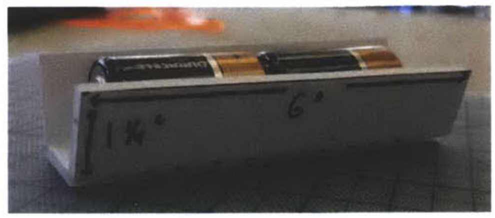


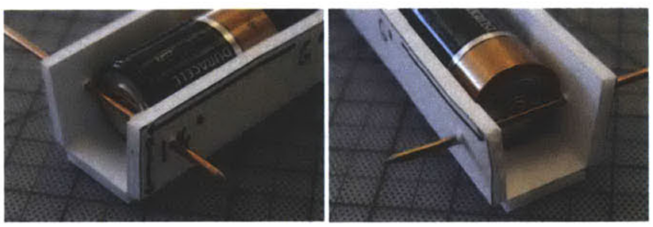




1. Read the safety notices! Then start by cutting out a piece of foamcore that is 6" by 3.75". Divide the short side into 3 even 1.25" segments

2. Cut the dotted line segments through the foam, but do not cut through the last layer of paper! Fold the ends up to make the battery holder



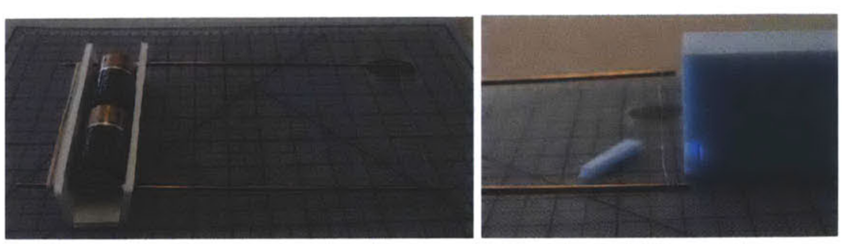


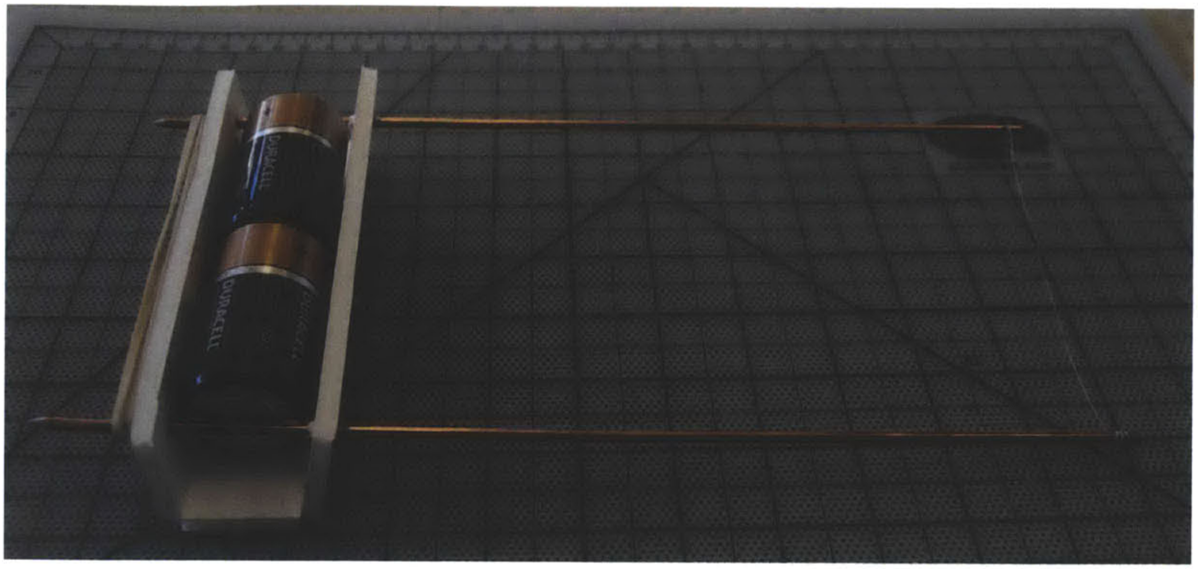
3. Take the sharp ends of the metal rods out of the protective foam. Careful, these ends are dangerous! Poke the sharp ends into the foamcore. These rods need to be in contact with the batteries, holding them snuggly together.

4. With the batteries disconnected from the metal rods (very important if you don't want to get burned!) poke the nichrome wire through the holes in the metal rods. Wrap excess wire around the rods and try not to leave too much slack.

5. Double wrap the rubber band around the ends of the metal rods on the opposite side of the battery holder. This should tighten up the nichrome wire and make the hotwire cutter more sturdy.

6. Place the batteries in to start the foam cutting! The foam cutter should last around an hour with the provided batteries. Place some tape around the shape ends to prevent injury.





Handheld Hotwire Cutter Instructions

Safety Notices:

-be careful with the sharp ends of the metal rods
-note that the battery voltages are too low to shock you
-as soon as a loop is formed connecting the batteries with the metal rods and the piece of nichrome wire, electric current will flow through the device. The nichrome wire will immediately become very hot! This wire is used to cut the foam, but it can burn you with extended contact with the skin. Rinse any minor burns with cool water and seek medical attention if necessary.
-Take the batteries out of the device to cool the nichrome wire while not operating the hotwire cutter

Appendix B: MATLAB scripts

```
% Joshua Ramos
% Aug 2009
% MIT CADLAB
% Brown-Forsythe test for homoscedasticity

clear
close all
clc

file = 'variance.xlsx' ;

%GROUPS:
%online
oo = xlsread(file,'B2:B10') ;
op = xlsread(file,'B11:B19') ;

%hybrid
ho = xlsread(file,'C2:C10') ;
hp = xlsread(file,'C11:C19') ;

%in person
io = xlsread(file,'D2:D10') ;
ip = xlsread(file,'D11:D19') ;

%construct matricies where columns represent groups to be compared
%opp compare
o_compare(:,1) = oo;
o_compare(:,2) = ho;
o_compare(:,3) = io;

%prot compare
p_compare(:,1) = op;
p_compare(:,2) = hp;
p_compare(:,3) = ip;


%Brown-Forsythe test
%compares variences-low p means different variances-high p means same

[po,stats1] = vartestn(o_compare,'TestType','BrownForsythe','Display','off') ;
[pp,stats2] = vartestn(p_compare,'TestType','BrownForsythe','Display','off') ;
```

```
% Joshua Ramos
% Special thanks to Peter Lu
% Aug 2009
% MIT CADLAB
% Kruskal-Wallis test - delivery comparisons

clear
close all
clc

file = 'kruskal_wallis.xlsx' ;
[~,styles] = xlsread(file) ;
styles = styles(3:28,3) ;

%judge scores
RO = xlsread(file,'F3:H28') ;
HP = xlsread(file,'P3:R28') ;

%averaged and combined
opp = mean(RO,2) ;
prot = mean(HP,2) ;
combo = opp+prot;

boxplot(opp,styles)
boxplot(prot,styles)
boxplot(combo,styles)

[p_o,t_o,s_o] = kruskalwallis(opp,styles) ;
[p_p,t_p,s_p] = kruskalwallis(prot,styles) ;
[p_c,t_c,s_c] = kruskalwallis(combo,styles) ;

[c_o,m_o] = multcompare(s_o) ;
[c_p,m_p] = multcompare(s_p) ;
[c_c,m_c] = multcompare(s_c) ;

display(p_o)
display(c_o)

display(p_p)
display(c_p)

display(p_c)
display(c_c)

% Joshua Ramos
```

```
% Aug 2009
% MIT CADLAB
% Bootstrap statistical method - delivery comparisons

clear
close all
clc

%% Pull in all data
file = 'bootstrap.xlsx' ;

%SAMPLES
%Opportunity
online_opp = xlsread(file,'B2:B10') ;
hybrid_opp = xlsread(file,'C2:C9') ;
inperson_opp = xlsread(file,'D2:D10') ;

%Prototype
online_prot = xlsread(file,'B11:B19') ;
hybrid_prot = xlsread(file,'C11:C18') ;
inperson_prot = xlsread(file,'D11:D19') ;

%Combo
online_combo = xlsread(file,'B20:B28') ;
hybrid_combo = xlsread(file,'C20:C27') ;
inperson_combo = xlsread(file,'D20:D28') ;

%% Method 1: Mean Distributions, generate samples - NOT USED IN THESIS
nboot = 1000 ;

[online_opp_means,online_opp_samples] = bootstrp(nboot, @mean, online_opp) ;
[hybrid_opp_means,hybrid_opp_samples] = bootstrp(nboot, @mean, hybrid_opp) ;
[inperson_opp_means,inperson_opp_samples] = bootstrp(nboot, @mean,
inperson_opp) ;

[online_prot_means,online_prot_samples] = bootstrp(nboot, @mean, online_prot) ;
[hybrid_prot_means,hybrid_prot_samples] = bootstrp(nboot, @mean, hybrid_prot)
;
[inperson_prot_means,inperson_prot_samples] = bootstrp(nboot, @mean,
inperson_prot) ;

[online_combo_means,online_combo_samples] = bootstrp(nboot, @mean,
online_combo) ;
[hybrid_combo_means,hybrid_combo_samples] = bootstrp(nboot, @mean,
hybrid_combo) ;
```

```
[inperson_combo_means,inperson_cmobo_samples] = bootstrp(nboot, @mean,
inperson_combo) ;

%% Plot Method 1 0 NOT USED IN THESIS
%
% %plot opportunity distributions
% subplot(3,1,1)
% hist(inperson_opp_means);
% subplot(3,1,2)
% hist(hybrid_opp_means);
% subplot(3,1,3)
% hist(online_opp_means);
%
% %plot prototype distributions
% figure
% subplot(3,1,1)
% hist(inperson_prot_means);
% subplot(3,1,2)
% hist(hybrid_prot_means);
% subplot(3,1,3)
% hist(online_prot_means);
%
% %plot combo distributions
% figure
% subplot(3,1,1)
% hist(inperson_combo_means);
% subplot(3,1,2)
% hist(hybrid_combo_means);
% subplot(3,1,3)
% hist(online_combo_means);

%% Calculate confidence intervals for method 1 - NOT USED IN THESIS

%get standard errors and means, output confidence interval
OPPORTUNITY = {'In Person', 'Hybrid','Online';
   mean(inperson_opp_means) - 2*std(inperson_opp_means),
mean(hybrid_opp_means) - 2*std(hybrid_opp_means), mean(online_opp_means) -
2*std(online_opp_means);
   mean(inperson_opp_means), mean(hybrid_opp_means),
mean(online_opp_means);
   mean(inperson_opp_means) + 2*std(inperson_opp_means),
mean(hybrid_opp_means) + 2*std(hybrid_opp_means), mean(online_opp_means) +
2*std(online_opp_means)};

PROTOTYPE = {'In Person', 'Hybrid','Online';
```

```
  mean(inperson_prot_means) - 2*std(inperson_prot_means),
mean(hybrid_prot_means) - 2*std(hybrid_prot_means), mean(online_prot_means) -
2*std(online_prot_means);
  mean(inperson_prot_means), mean(hybrid_prot_means),
mean(online_prot_means);
  mean(inperson_prot_means) + 2*std(inperson_prot_means),
mean(hybrid_prot_means) + 2*std(hybrid_prot_means), mean(online_prot_means)
+ 2*std(online_prot_means)};

COMBO = {'In Person', 'Hybrid','Online';
  mean(inperson_combo_means) - 2*std(inperson_combo_means),
mean(hybrid_combo_means) - 2*std(hybrid_combo_means),
mean(online_combo_means) - 2*std(online_combo_means);
  mean(inperson_combo_means), mean(hybrid_combo_means),
mean(online_combo_means);
  mean(inperson_combo_means) + 2*std(inperson_combo_means),
mean(hybrid_combo_means) + 2*std(hybrid_combo_means),
mean(online_combo_means) + 2*std(online_combo_means)};


%% Method 2: Combine observations, resample and look at mean differences
%NOTE: the bootstrp function outputs [A,B] where B is the matrix of
%indicies of the chosen observations, not the actual data itself

%METHOD 2a: In Person vs Hybrid

%Oppurtunities----------------------------------------------------
%combine observations, resample, separate, calculate mean difference
combined_ao = [inperson_opp;hybrid_opp];
[ao_means,iho_index] = bootstrp(nboot, @mean, combined_ao) ;
iho_data = zeros(size(iho_index)) ;
lengths_ao = size(iho_index);
for m_ao = drange(1:lengths_ao(2)) ;
for n_ao = drange(1:lengths_ao(1)) ;
  iho_data(n_ao,m_ao) = combined_ao(iho_index(n_ao,m_ao)) ;
end
end
top_ao = iho_data(1:size(inperson_opp),:);
bottom_ao = iho_data(size(inperson_opp)+1:size(combined_ao),:);
iho_diffs = zeros(1,m_ao);
for s_ao = drange(1:lengths_ao(2)) ;
  iho_diffs(s_ao) = mean(top_ao(:,s_ao)) - mean(bottom_ao(:,s_ao));
end

%calculate the 95% confidence interval and look at where the observed
```

```
%difference is
mean_iho_diff = mean(iho_diffs);
se_iho_diff = std(iho_diffs);

INPERSON_HYBRID_OPP_95 = {'Lower End', 'Mean','Upper End', 'Observed';
   mean_iho_diff - 2*se_iho_diff, mean_iho_diff, mean_iho_diff + 2*se_iho_diff,
mean(inperson_opp) - mean(hybrid_opp)};

%Prototypes--------------------------------------------------------
%combine observations, resample, separate, calculate mean difference
combined_ap = [inperson_prot;hybrid_prot];
[ap_means,ihp_index] = bootstrp(nboot, @mean, combined_ap) ;
ihp_data = zeros(size(ihp_index)) ;
lengths_ap = size(ihp_index);
for m_ap = drange(1:lengths_ap(2)) ;
for n_ap = drange(1:lengths_ap(1)) ;
   ihp_data(n_ap,m_ap) = combined_ap(ihp_index(n_ap,m_ap)) ;
end
end
top_ap = ihp_data(1:size(inperson_prot),:);
bottom_ap = ihp_data(size(inperson_prot)+1:size(combined_ap),:);
ihp_diffs = zeros(1,m_ap);
for s_ap = drange(1:lengths_ap(2)) ;
   ihp_diffs(s_ap) = mean(top_ap(:,s_ap)) - mean(bottom_ap(:,s_ap));
end

%calculate the 95% confidence interval and look at where the observed
%difference is
mean_ihp_diff = mean(ihp_diffs);
se_ihp_diff = std(ihp_diffs);

INPERSON_HYBRID_PROT_95 = {'Lower End', 'Mean','Upper End', 'Observed';
   mean_ihp_diff - 2*se_ihp_diff, mean_ihp_diff, mean_ihp_diff + 2*se_ihp_diff,
mean(inperson_prot) - mean(hybrid_prot)};

%Combo------------------------------------------------------------
%combine observations, resample, separate, calculate mean difference
combined_ac = [inperson_combo;hybrid_combo];
[ac_means,ihc_index] = bootstrp(nboot, @mean, combined_ac) ;
ihc_data = zeros(size(ihc_index)) ;
lengths_ac = size(ihc_index);
for m_ac = drange(1:lengths_ac(2)) ;
for n_ac = drange(1:lengths_ac(1)) ;
   ihc_data(n_ac,m_ac) = combined_ac(ihc_index(n_ac,m_ac)) ;
end
```

```
end
top_ac = ihc_data(1:size(inperson_combo),:);
bottom_ac = ihc_data(size(inperson_combo)+1:size(combined_ac),:);
ihc_diffs = zeros(1,m_ac);
for s_ac = drange(1:lengths_ac(2)) ;
  ihc_diffs(s_ac) = mean(top_ac(:,s_ac)) - mean(bottom_ac(:,s_ac));
end

%calculate the 95% confidence interval and look at where the observed
%difference is
mean_ihc_diff = mean(ihc_diffs);
se_ihc_diff = std(ihc_diffs);

INPERSON_HYBRID_COMBO_95 = {'Lower End', 'Mean','Upper End', 'Observed';
  mean_ihc_diff - 2*se_ihc_diff, mean_ihc_diff, mean_ihc_diff + 2*se_ihc_diff,
mean(inperson_combo) - mean(hybrid_combo)};
%%

%METHOD 2b: In Person vs Online

%Oppurtunities-----------------------------------------------------
%combine observations, resample, separate, calculate mean difference
combined_bo = [inperson_opp;online_opp];
[bo_means,iho_index] = bootstrp(nboot, @mean, combined_bo) ;
ioo_data = zeros(size(iho_index)) ;
lengths_bo = size(iho_index);
for m_bo = drange(1:lengths_bo(2)) ;
for n_bo = drange(1:lengths_bo(1)) ;
  ioo_data(n_bo,m_bo) = combined_bo(iho_index(n_bo,m_bo)) ;
end
end
top_bo = ioo_data(1:size(inperson_opp),:);
bottom_bo = ioo_data(size(inperson_opp)+1:size(combined_bo),:);
ioo_diffs = zeros(1,m_bo);
for s_bo = drange(1:lengths_bo(2)) ;
  ioo_diffs(s_bo) = mean(top_bo(:,s_bo)) - mean(bottom_bo(:,s_bo));
end

%calculate the 95% confidence interval and look at where the observed
%difference is
mean_ioo_diff = mean(ioo_diffs);
se_ioo_diff = std(ioo_diffs);

INPERSON_ONLINE_OPP_95 = {'Lower End', 'Mean','Upper End', 'Observed';
```

```
   mean_ioo_diff - 2*se_ioo_diff, mean_ioo_diff, mean_ioo_diff + 2*se_ioo_diff,
mean(inperson_opp) - mean(online_opp)};

%Prototypes--------------------------------------------------------
%combine observations, resample, separate, calculate mean difference
combined_bp = [inperson_prot;online_prot];
[bp_means,ihp_index] = bootstrp(nboot, @mean, combined_bp) ;
iop_data = zeros(size(ihp_index)) ;
lengths_bp = size(ihp_index);
for m_bp = drange(1:lengths_bp(2)) ;
for n_bp = drange(1:lengths_bp(1)) ;
   iop_data(n_bp,m_bp) = combined_bp(ihp_index(n_bp,m_bp)) ;
end
end
top_bp = iop_data(1:size(inperson_prot),:);
bottom_bp = iop_data(size(inperson_prot)+1:size(combined_bp),:);
iop_diffs = zeros(1,m_bp);
for s_bp = drange(1:lengths_bp(2)) ;
   iop_diffs(s_bp) = mean(top_bp(:,s_bp)) - mean(bottom_bp(:,s_bp));
end

%calculate the 95% confidence interval and look at where the observed
%difference is
mean_iop_diff = mean(iop_diffs);
se_iop_diff = std(iop_diffs);

INPERSON_ONLINE_PROT_95 = {'Lower End', 'Mean','Upper End', 'Observed';
   mean_iop_diff - 2*se_iop_diff, mean_iop_diff, mean_iop_diff + 2*se_iop_diff,
mean(inperson_prot) - mean(online_prot)};

%Combo--------------------------------------------------------------
%combine observations, resample, separate, calculate mean difference
combined_bc = [inperson_combo;online_combo];
[bc_means,ihc_index] = bootstrp(nboot, @mean, combined_bc) ;
ioc_data = zeros(size(ihc_index)) ;
lengths_bc = size(ihc_index);
for m_bc = drange(1:lengths_bc(2)) ;
for n_bc = drange(1:lengths_bc(1)) ;
   ioc_data(n_bc,m_bc) = combined_bc(ihc_index(n_bc,m_bc)) ;
end
end
top_bc = ioc_data(1:size(inperson_combo),:);
bottom_bc = ioc_data(size(inperson_combo)+1:size(combined_bc),:);
ioc_diffs = zeros(1,m_bc);
for s_bc = drange(1:lengths_bc(2)) ;
```

```
  ioc_diffs(s_bc) = mean(top_bc(:,s_bc)) - mean(bottom_bc(:,s_bc));
end

%calculate the 95% confidence interval and look at where the observed
%difference is
mean_ioc_diff = mean(ioc_diffs);
se_ioc_diff = std(ioc_diffs);

INPERSON_ONLINE_COMBO_95 = {'Lower End', 'Mean','Upper End', 'Observed';
  mean_ioc_diff - 2*se_ioc_diff, mean_ioc_diff, mean_ioc_diff + 2*se_ioc_diff,
mean(inperson_combo) - mean(online_combo)};

%%
clc

figure
a = subplot(3,1,1)
hist(ioo_diffs) ;
ylabel('Frequency')
axis([-2.5 2.5 0 300])
b = subplot(3,1,2)
hist(iop_diffs) ;
ylabel('Frequency')
axis([-2.5 2.5 0 300])
c = subplot(3,1,3)
hist(ioc_diffs) ;
ylabel('Frequency')
xlabel('Mean Difference')
axis([-2.5 2.5 0 300])

title(a,'Traditional vs. Online - Opportunity Mean Difference')
title(b,'Traditional vs. Online - Prototype Mean Difference')
title(c,'Traditional vs. Online - Combo Mean Difference')

figure
d = subplot(3,1,1)
hist(iho_diffs) ;
ylabel('Frequency')
axis([-2.5 2.5 0 300])
e = subplot(3,1,2)
hist(ihp_diffs) ;
ylabel('Frequency')
axis([-2.5 2.5 0 300])
f = subplot(3,1,3)
hist(ihc_diffs) ;
```

```
ylabel('Frequency')
xlabel('Mean Difference')
axis([-2.5 2.5 0 300])

title(d,'Traditional vs. Hybrid - Opportunity Mean Difference')
title(e,'Traditional vs. Hybrid - Prototype Mean Difference')
title(f,'Traditional vs. Hybrid - Combo Mean Difference')

display(INPERSON_ONLINE_OPP_95) ;
display(INPERSON_ONLINE_PROT_95) ;
display(INPERSON_ONLINE_COMBO_95) ;
display(INPERSON_HYBRID_OPP_95) ;
display(INPERSON_HYBRID_PROT_95) ;
display(INPERSON_HYBRID_COMBO_95) ;
```