**Hands-On Online? An Investigation of Experiential Design Education With Online Resources**

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ABSTRACT

Online education is becoming more prevalent in every field, especially with the advent of MOOCs and initiatives such as Coursera, Edx, MITx, Khan Academy and more. Product design education involves open-ended problem solving and prototyping with physical materials, so it presents a number of interesting challenges in an online educational setting.

This paper describes an initial study to better understand the value proposition of offering hands-on product design education using different delivery methods, ranging from hands-on residential to fully online, and combinations in-between. A series of two-day workshops were used to teach students typical introductory product design coursework including opportunity identification and early-stage prototyping. Students attended one workshop session that was taught with one of three content delivery types: traditional (n = 9), online (n = 9), or hybrid (n = 8). Each student worked individually to identify a product opportunity and produce a preliminary prototype. The performance of the students was compared to elucidate any differences based on workshop delivery method.

Based on the comparison of student work, as evaluated by academic product design experts, there were no statistically significant differences in performance between groups. This result suggests that all delivery methods have potential for successfully transferring knowledge to students. Furthermore, this preliminary evidence warrants more detailed investigations of the effects of delivery method on product design education. Interesting observations regarding workshop attendance identify motivation to complete courses as a point of interest in both residential and online settings. A number of insights gained and possible directions are discussed.

1 INTRODUCTION

Communication technology advances are rapidly changing the way we live our everyday lives. The delivery of educational content, even in highly technical domains such as engineering and design, is changing to adapt to new technologies [1].

One Internet-based delivery method that has garnered recent media attention is the MOOC, or Massively Open Online Course [2]. MOOCs have a few defining characteristics that set them apart from conventional education methods in that: they can be delivered completely online; they can potentially reach massive audiences of tens of thousands of students in each offering [3]; and they have the ability to incorporate typical computer media such as photography, video and even interactive simulation elements. Well-known higher education institutions such as MIT, Harvard, and Stanford have committed themselves to producing online courses through various distribution networks [4], [5]. Other popular online course delivery companies are managed as entities separate from any particular institution [6]. Some MOOC sites use very simple means to create video tutorials, such as Khan Academy, which uses computer tablet writing software with audio recordings [7]. Despite the many different flavors of online courses, Internet-based education continues to rise in popularity. In 2012 over 6.7 million people in the United States took at least one online course, 570,000 more than the previous year [8].

It is assumed that different delivery methods will have different educational weaknesses and strengths, and the goal of this work is to try to compare and understand characteristics of residential delivery and Internet delivery methods in the context of product design education. This initial study focuses on early-stage product design, addressing open-ended product...
opportunity identification and early stage concept modeling, often referred to as sketch modeling. The purpose of this initial study is to evaluate the potential of online product design coursework for future research. The main goal is to try to understand what educational strength different delivery methods offer so that we might be more deliberate in crafting high-value educational experiences. This paper outlines an experiment to compare the performance of three groups instructed using different delivery methods, from fully in-person and residential, to fully online and remote. The paper begins with a description of motivational work and founding pedagogy. A detailed description of the workshop sessions is presented, followed by a description of the experimental methods. Results comparing the performance of the different experimental groups as characterized by a panel of expert product designers are presented. Finally, there is a discussion regarding the direction of future work.

2 BACKGROUND

2.1 Motivation for Work

This work builds directly upon similar work regarding product design education with online resources. In a pair of studies, Wallace and Mutooni, and later Wallace and Weiner, investigated teaching later-stage product design prototyping either in a traditional lecture or via a set of computer tutorials given online [9], [10]. The first study showed that students using online tutorials performed better than students who learned via lecture style delivery. Their follow up study investigated replacing lecture time with mentor-style prototyping instruction, what is now referred to as the “flipped classroom.” The experiment conducted compared two groups that both used online tutorials. The control group received a second covering of the material in a lecture format, whereas the experimental group received a mentoring session instead. The research found that the group receiving mentor instruction performed better than their counterparts. This work aims to build upon the previous studies by focusing on early stage design opportunity identification, ideation, sketching, and early prototyping/sketch modeling.

2.2 Pedagogical Roots

In a discussion about the future of education in the midst of changing technologies, Woodie Flowers suggests classifying different components of teaching as training and education [11]. Training is the part of teaching where skills are transferred to the student whereas education includes higher order knowledge that can be applied to thinking about and solving problems using the transferred skills. He uses the example that teaching the mechanics of calculus is training, while teaching to think using calculus to solve problems is education. The conclusion is that training may be more appropriate for online delivery formats and education for residential formats with in-person mentoring. An analogy can be drawn to the well-known teaching tool Bloom’s taxonomy, which segments education into different stages (Figure 1) [12], [13]. Training, which represents the base of the pyramid, is the more codified information that Flowers suggests should be taught online, while the higher parts of the pyramid, which represent education, may be better left for in-person teaching.

Figure 1: A depiction of the revised Bloom’s Taxonomy [13]

Subject content in the engineering domain has great potential for being taught through experience. Educators have stressed experiential learning for decades as a way to make learning engaging and to increase learning gains [14], [15]. Despite the physical nature of engineering education, various works still call for an increase in experiential learning via problem- and project-based curricula [16], [17].

The training versus education distinction, Bloom’s taxonomy, and a focus on experiential learning all provide different perspectives for evaluating the relative strengths and weaknesses of different educational delivery methods. In this study, teaching skills for sketch modeling with physical materials resembles training. Open-ended problem solving represented by opportunity identification in early-stage product design more closely resembles education. Both utilize experiential learning techniques. Online education, being remote, presents challenges when trying to teach these components of product design. By utilizing a controlled experiment comparing residential learning experiences with online experiences, one aim of this study is to see if product design coursework can readily transfer physical and open-ended knowledge to students and thereby serve as a platform for further characterizing learning differences in future studies.

2.3 Examples from Engineering Education

Meta-studies conducted by the U.S. Department of Education have shown that fully and partially online courses have generally been at least as effective as traditional education delivery methods [18]. Online courses have advantages that can make them desirable alternatives to traditional delivery. Although developing high production value coursework for online delivery can be time consuming, with production times reaching 150 hours per lecture [19], once online materials are prepared they can reach wide audiences. Constructivist approaches, which stress creating metacognitive learners who can direct their own learning [20], tend to work well online [21]. Certain online course companies have also been
attempting to create software that can utilize formative assessment to automatically tailor learning to the individual [22].

For these reasons and more, engineering educators have been calling for more education that is enhanced by Internet technologies [23]. Lindsay and Madhavan stress moving away from just adapting traditional teaching materials for an online setting, and call for developing frameworks that aid developing material optimized for online delivery [24]. In a comprehensive study on flipped classroom approaches in engineering education settings, Bishop concludes that learning gains are usually at least as good as traditional teaching, although more controlled studies comparing approaches are needed [25].

2.4 Similar Ventures and Recent Advances

Education in the online space is continuously evolving and research in many different areas is ongoing. Some new courses being offered over the past few years are particularly relevant to this study. Tina Seelig’s course presented in Stanford’s network for distributing online coursework is titled “A Crash Course on Creativity” and involves creative problem solving, prototyping, and teamwork [26]. Another similar offering is Karl Ulrich’s online course “Creation of Artifacts in Society,” presented through Coursera [27]. Ulrich’s course also includes design process and early-stage prototyping. While no formal studies are presented regarding these online design courses, evaluations show that they are generally well received by students. The work presented here aims to begin characterizing the effectiveness of online product design coursework by using controlled studies to compare content presented in a similar way to these other ventures.

3 TWO-DAY WORKSHOPS DEVELOPED FOR THIS STUDY

3.1 Curriculum and Materials

Two-day educational workshops were designed specifically for this research study. They are adaptations of workshops that were initially developed to teach educators about design education and entrepreneurship. The content presented in the workshops also draws upon several undergraduate and graduate classes that are taught at MIT [28]–[30]. The workshops cover coursework including opportunity identification, creativity, brainstorming, idea evaluation, ideation sketching, and the merits and craft of early-stage prototyping/sketch modeling. Workshop Day 1 consisted of topical instruction, whereas Day 2 was reserved for completing a product opportunity identification and sketch modeling exercise. Day 2 gave participants a chance to demonstrate the skills they learned in Day 1 with a design exercise. The Day 2 exercise was then used to form the basis of comparison for the experiment conducted in this study.

3.1.1 Workshop Day 1

The workshop curriculum began with an overview of product design and how to use observation to identify potential areas of interest for developing new products. The coursework specifically referred to user-centered design [31]. Strategies for field observation, documentation, and how to identify problem areas were presented to the students. Next, creative strategies for brainstorming solutions were covered. Idea comparison techniques, including the Pugh Selection Matrix, were presented as a way for students to compare both potential opportunities for further investigation and to compare potential solutions to problems. Ideation sketching, or fast, rough sketching that illustrates key concepts during idea formation was also covered. Students practiced sketching during instruction with materials they were given or purchased, based on experimental group.

After the sketching material was covered, the rest of Day 1 was devoted to teaching early-stage prototyping with simple materials. The tools and materials used in this section of the workshop consisted of things you can find at a local arts and crafts store. The tools included straightedges, utility knives, hot-glue guns, hotwire foam cutters, and various other cutting and adhesive instruments. The materials used to create prototypes mainly consisted of cardboard, foamcore, and buoyancy foam. All of these materials are used in professional product design work because they are readily available, inexpensive and easily workable [32]. The material presented included general shaping and joining techniques such as bending, cutting, sanding, and gluing of different materials. Safe use of tools was always stressed. How to create prototypes that answer key questions in the design process was also covered.

After learning the different techniques for constructing prototypes, students were given time at the end of the first workshop day to practice the skills that they learned. For this purpose several practice projects were developed, allowing students a chance to practice the material they just learned (Figures 2,3). Students were encouraged to complete at least one practice project or come up with their own projects. Several students decided to complete more than one practice project.

![Figure 2: A smartphone stand project for practicing cardboard working skills](image-url)
3.1.2 Workshop Day 2

The second day of the workshop consisted of completing a product opportunity identification and prototyping activity. The students were instructed to go make observations out in their community and document instances of potential problems that could be solved by applying the techniques from Day 1. Afterwards the students were instructed to brainstorm and compare ideas for solving the problems they encountered and to choose a problem to focus on. Finally, students constructed a prototype to illustrate their solutions. Student performance was characterized and compared based on how successfully they identified opportunities and constructed prototypes that illustrated their chosen solutions.

3.2 Website and Video Content

Some of the groups in the experiment received instruction from a website in lieu of in-person instruction (http://designed.mit.edu/design-online/). The curriculum for all groups was the same, as described in Section 3.1, just delivered in different ways to different groups. The website and the materials contained within it were constructed specifically for this study. The website was created as a tool to organize and disseminate a series of video tutorials that cover the content for the two-day workshops. A sample page of the website layout can be seen in Figure 4.

The web page is constructed as a simple HTML document that is styled with CSS. Various other methods were explored including several learning management sites, which typically help educators organize class content and provide forums for discussion, and online course-hosting sites. Due to steep learning curves, the feature-rich learning management sites were not used. A suitable online course-hosting platform was not found, but future work will revisit this issue.

In addition to disseminating video tutorials, the website also allowed for distribution of instructions for the workshops and the various projects. Navigation of the website was structured through a navigation bar that organized the content by the design process stage or the prototyping material to be used. Each page had a series of video tutorials embedded within it and a video list that also served as links to scroll down the page. There were also links that went to pages that had general instructions, safety procedures, and material downloads. No complaints about website navigation were reported throughout the workshops.

The video tutorials produced for these workshops were filmed and edited with professional equipment and software. Several camera angles were used to mimic, or in some cases improve upon, in-person instruction. For the design process sections, a frontal camera angle was used with supporting text and animations to illustrate key points. During the prototyping sections of the video tutorials three camera angles were used to show different aspects of the physical demonstrations on screen, including close-ups. For sketching, a frontal and a top view were used to show both the sketching technique using the full arm and the resulting image on the paper.
4 EXPERIMENTAL METHOD

The experimental procedure consisted of testing three groups of students receiving different content delivery methods to determine if there was any performance difference in a design exercise. The control group (n = 9) was taught with conventional in-person teaching. The two experimental groups—the online group (n = 9) and the hybrid group (n = 8)—each received some form of online instruction and were given a budget to purchase practice materials. Each group participated in a design task where they were asked to identify a problem in their nearby community and prototype a solution for the identified problem. All sketchmodels/prototypes were collected and an expert panel of judges rated the performance of the students in terms of the quality of the opportunity identified and the quality of the prototype. Participants worked individually.

The only strict requirement for the participants in the study was that they had no prior knowledge of product design. This was done to ensure that the performance demonstrated by the participants was due to their learning gains during the tutorials. Student status was not required. Since online course users are not necessarily students of any particular institution, non-university students were allowed to attend as well and were represented in each group. Participants were recruited by the use of emails sent through different email lists including undergraduate and graduate groups from universities in the nearby area. Flyers advertising the workshops and their affiliation with a research study were also posted to the general public in the surrounding area. Even though the population for the study consisted of mostly university students, one study of course hosting website edX showed that many participants in online courses match the demographics that describe university students [32].

Participants were not told ahead of time that there would be different groups with varied delivery methods. They were informed that a two-day workshop would be held that would cover early-stage product design and that this workshop was part of an ongoing research study. This was done to avoid biasing the research groups with participants selecting workshops corresponding to specific delivery methods, and to prevent a feeling of competition between groups. When participants were available to attend multiple workshop offerings they were randomly assigned a session. Each experimental group was taught in a different session offered over the period of one month. At the conclusion of the study participants were informed of the research goals of the work.

4.1 Research Groups

The control group for the study received traditional, in-person instruction. The traditional group was instructed to meet at a typical prototyping lab on both days of the workshops. The participants were told where to meet a few days prior to the study to have time to arrange proper transportation. There was no communication about any other groups being tested or how the workshop would be taught. During Day 1, participants received instruction in early stage product design using slideshow presentations, live demonstrations, and practice with physical materials. Day 2 consisted of meeting in the prototyping space, leaving to conduct an observation exercise, and then spending the rest of the day back in the lab completing the opportunity identification and prototyping activity.

The online group received Day 1 instruction through a series of video tutorials organized on the website constructed for this experiment. The participants were told three days ahead of the workshop that they would be participating in the workshop in an online format. This was done so that participants had two days to purchase materials with a provided budget. The materials purchased would be used for practicing prototyping and for producing the model that was later used for comparison between groups. The instructor, who the participants did not meet face to face until after the workshop was completed, was available for online communication. Participants preferred to communicate via email. Instructions were provided each day and were available for download on the website. On the second day of the workshop, participants completed the same opportunity identification exercise as the control group. After the workshop the prototypes and descriptions were collected from the participants.

The second experimental group, the hybrid group, received instruction on the first workshop day from the online tutorials and then met in the prototyping shop on the second day in order to complete the opportunity identification exercise. This delivery method was chosen to mimic the flipped classroom teaching approach, with the idea that if online resources could be used to teach students then classroom time can be used to do more valuable activities like in-person mentoring.

4.2 Evaluation Method

Upon completion of the workshops, a description of the product opportunity identified and physical prototypes were collected from each participant. In order to account for differences in language ability, these descriptions were rewritten in a consistent manner. Each prototype was photographed consistently to produce a form that was given to a panel of three academic product design experts to evaluate. Each expert had experience in practicing, teaching, and researching product design for more than ten years. The experts had no other involvement with the study and their judging responses form the quantitative basis upon which inferences about the performance of the different groups of participants were compared.

The three judges rated the student work based on two metrics. One score characterized the quality of the opportunity identified by the participants. Opportunities identified that exhibited actual potential for significant improvement from typical product design processes were rated higher. The second metric characterized the quality of the prototype. Prototypes that added more value to the description of the proposed solution to the identified problem scored higher. Judges were given the context that the prototypes were constructed during a
two-day workshop, which is a very rapid timespan for students with no product design experience. All scores were on a scale of 1 to 10, with 10 being the highest score. From the two separate scores an overall quality score was constructed as the average of the two scores. The two metrics and the overall quality score were each tested for any significant difference.

In addition to the quality scores, an exit survey was given to each participant. Although the survey given was not structured enough to perform any strict comparison between experimental subjects, it was still possible to obtain a qualitative sense for some student perceptions of the course. Survey questions allowed for either an answer on a scale of 1 to 5, with 5 being the most positive score, or written comments. Participants were asked to rate their learning experience, to rate their instructor, and to comment on different aspects of their delivery method.

5 RESULTS

Three experimental groups were compared to assess the effect of content delivery method on student performance in a product design exercise. The groups tested included the traditional delivery group (n=9), the online delivery group (n=9), and the hybrid delivery group (n=8). The null hypothesis for this experiment is that all groups performed equally, with no measured statistical differences in groups with different delivery methods. This section describes the quantitative results provided by the ratings of a panel of academic product design experts and a qualitative section based on exit survey results.

5.1 Quantitative Results

The panel of judges evaluated the students work based on two metrics, which described the quality of the opportunity identified by the participant and the quality of the prototype produced by the participant. These individual scores, and an average of the two, were tested for any statically significant differences between the experimental groups.

Usually a test of variance, or ANOVA, is used to test for any significant differences between groups. However, in this case we cannot make any assumptions about the normality of the scores provided by the judges, and therefore the ANOVA test was inappropriate. In order to test for any differences in the evaluations the Kruskal-Wallis one-way analysis of variance was used, which is agnostic to distribution type [33]. A Brown-Forsythe test was used to confirm that the distributions were of the same shape [34][35].

The Kruskal-Wallis test allows for comparison between multiple groups at once, meaning all three experimental groups were evaluated with a single test. Since the groups were being tested on three different metrics, a total of three tests were run. For each test, a sufficiently low p-value would indicate that at least one group of the three had significantly different performance than at least one other group. The p-values resulting from the test, shown in Table 1, show that there is no evidence to reject the null hypothesis that all of the groups performed equally. Therefore there is no evidence of different performance among the traditional, online, or hybrid delivery groups tested in this study. Figure 5 shows the scores from the different groups rank ordered. The figure shows no patterns that suggest a significant difference between the experimental groups, which would be suggested if bars of the same color were clearly grouped together.

| Table 1: P-values associated with the Kruskal-Wallis test showing no evidence for performance differences |
|--------------------------------------------------|--------|
| Opportunity Scores | 0.58   |
| Prototype Scores   | 0.38   |
| Quality Scores     | 0.29   |

![Opportunity Ranks](image1)

![Prototype Ranks](image2)
5.2 Survey Results

Upon completing the workshop participants were given an exit survey. These surveys were used to qualitatively describe student perceptions of learning. Questions either had a numerical answer ranging from 1 to 5, with 5 being the most positive result, or a section for a written response. Some of the results that imply interesting student perceptions are described in Figure 6, Figure 7 and Table 2. Due to the informal nature of the survey, statistical analysis was not performed on the surveys. While not statistical, it seems like the residential students liked their experience more than the other groups. Something for more study.

6 DISCUSSION

The statistical tests performed showed no significant differences between the tested groups in terms of performance. Survey results suggest students in different groups each had a positive learning experience. Together, the results from this study suggest that there is potential for teaching product design curriculum with online resources. The main goal of this study was to determine if more detailed work regarding product design education taught with different delivery methods is warranted and what direction the work should take. The results from this work provide encouraging results, but limitations of the pilot study should also be noted.

Although the populations of the three experimental groups are within the minimum number required for the statistical tests used here, larger populations would provide more robust results. A more substantial improvement could have been gained from increasing the number of expert judges who provided the scores used for comparison between the groups to more than three. The inter-rater reliability metrics for the judges were very low (Krippendorff’s Alpha values ranging from 0.33 to -0.07, [36]), which demonstrates that the quality of ideas and preliminary prototypes were difficult to measure, even for experts. However, an analysis of the “Overall Quality” ratings given by each of the three judges individually using the Kruskal-Wallis method did not reveal any statistically significant differences ($p = 0.86$, $p = 0.77$, $p = 0.45$), meaning that none of the judges individually detected a difference in performance based on delivery method.
There are several differences between an actual MOOC and the online setting presented in this study. The fact that participants were given a budget for purchasing materials provides a different motivation structure for participants in this study versus MOOC students. Additionally, the online setting used here does not contain common MOOC components such as discussion forums, interactive simulation elements, or automatic grading. Instructor availability during the study was higher than might typically be observed during a MOOC. Due to these differences, tests in a full MOOC environment would provide conclusions that could better assess performance during an actual online class and hence improve the generalizability of the results.

Finally, for each delivery method every effort was made to ensure that instruction was adequate and balanced across groups. With that in mind, inherent differences in the course structures were allowed to play out. For instance, while each participant worked on an individual project, groups receiving in-person instruction in the prototyping lab were able to see and interact with other participants. Groups who worked from home were instructed on when to complete tasks, but no monitoring of actual work time was done, whereas participants in the prototyping lab had to leave when the lab was closed. Mentored groups could ask the instructor questions in real time, but Internet education groups could pause and replay video tutorials as many times as necessary. In future experiments, the effects of the disparities in learning environments could be compared to investigate any advantages or disadvantages for different content delivery methods.

6.1 Judge Results

Based on the results from the expert judges there was no evidence to suggest that any of the experimental groups performed differently. Therefore, as each participant came into the study with no prior design experience, no difference in performance in relation to delivery method was observed. As this study was conducted as a pilot for future research, the results are encouraging.

Product design education has several aspects that are difficult to translate into an online setting. Among those aspects are the concepts of open-ended problem solving and prototyping with physical materials. The results of this work provide reasonable evidence to suggest that the learning of both of these aspects of product design coursework can be supported with online resources. No inferences are drawn as to which delivery method may be better given the nature of the content to be taught, and this is a point of future work. However, we conclude that there is potential for product design courses to be supported or taught with online resources. The results justify more study regarding how delivery method effects product design education and possibly to investigate other areas of engineering education as well.

6.2 Survey Results

The exit surveys conducted during the workshop point to a few interesting outcomes. First, all students who participated in the course rated it positively except for one neutral response from each delivery method. Similarly the average instructor ratings were high despite the fact that some groups learned the content without meeting the instructor face to face. Most of the students in the online delivery groups were satisfied with their delivery methods even though the material was highly physical and open-ended. All of these results seem to support product design learning with online resources. More information can be gleaned from the survey questions regarding resource adequacy. Ratings were high in the traditional and hybrid delivery groups, and appear to be lower for the online group. One reason for the discrepancy may be that the online groups were the only group to never use the prototyping space. It is possible that the traditional group was satisfied with the resources provided in the prototyping lab, the hybrid group was satisfied with purchasing their own materials and then using the prototyping lab for the activity, and the online group was neutral or dissatisfied with only having the option of purchasing their own materials. This finding may suggest the value of having space, equipment, and materials dedicated to coursework that are typically found in residential education settings. Alternatively students may be expressing value of having in-person mentoring during the traditional workshops. More study is needed to determine the causes of the discrepancy in student responses.

7 CONCLUSION

Translating product design educational content into an online setting provides several challenges. Among these challenges are teaching abstract content like open-ended problem solving and teaching physical content like prototyping. Both of these issues were contained in the early stage prototyping curriculum presented in the two-day workshops described in this study.

Participants from the three different delivery methods investigated – traditional, online and hybrid – were all shown to have similar performance on a design task despite the use of different content delivery methods. Additionally, students participating in each of the experimental groups rated their learning experiences highly. This has implications for future studies as the results suggest the material covered in the workshops can be transferred via online delivery methods, specifically in a product design educational context. This motivates more detailed research regarding the effect delivery method has on product design education with the goal of utilizing different methods to craft high-value learning experiences.

8 FUTURE WORK

The encouraging results from the pilot study motivate several aspects of future work. One area of future work would be to investigate which delivery methods might be more appropriate, or yield higher learning gains, for different subject content. This would allow educators to improve teaching by utilizing different delivery methods to improve learning gains.
overall. Another potential improvement would be a workshop pretest to better characterize incoming skillsets of the participants, followed by a post-test to evaluate learning gains. Structuring the surveys given at the end of each workshop to provide more quantitative results would also be beneficial to future studies.

A common issue with online courses is completion rates, as high levels of attrition can be observed [3]. There is a possibility of improving retention rates in online courses if students need to contribute something of value to participate. In other words, having more “skin in the game” could lead to increased retention rates, and this is another area where future work could be beneficial. During the course of this study, one instance of a traditional workshop had a high attrition rate from one day to the next. For the next group, participants were instructed to commit to the full workshop beforehand or not to participate at all. Attendance improved. Interestingly, attendance was not an issue for the online or hybrid course settings, possibly due to the provision of a budget that may have motivated students to take the workshop sessions seriously. These observations present interesting opportunities for studying motivation for course completion both online and offline.

Team-based courses could also be investigated with regard to support with online content. Workshops similar to the ones described in this work could be redone to allow for teamwork, which would then be evaluated by comparing different course delivery methods. Of course, having a full semester course augmented or taught with some online resources could provide useful and robust results for drawing stronger conclusions.

In future work, several metrics could be used to characterize learning gains from courses taught with online resources. A few suggested metrics describing learning gains that could be useful to characterize in future work are changes in motivation, skills, and attitudes of students. By assessing learning gains through the comparison of these metrics useful information that can guide future education can be determined. In any case, more work can be done to provide future educators with information that can allow them to be more efficient, more effective, and more engaging to students across the globe.

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REFERENCES


