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Converting a First-Year Engineering, Makerspace Course into COVID-Necessitated Fully-Online Synchronous Delivery and Related Student Perceptions

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Abstract

This complete Evidence-based Practice paper will describe efforts and outcomes in redesigning and implementing a makerspace-based course during a time of COVID-necessitated fully online synchronous learning. This course is an introductory engineering course that all first-year engineering students at the J. B. Speed School of Engineering (SSoE) at the University of Louisville (UofL) are required to take. The course, titled *Engineering Methods, Tools, & Practice II* (ENGR 111), is primarily focused on application and integration of fundamental engineering skills introduced in a prerequisite course ENGR 110. ENGR 111 houses SSoE's Cornerstone Project, and is extensively based in active learning pedagogy taking place in a large university makerspace, with the vast majority of class activities typically taught pre-COVID through extensive hands-on pedagogical approaches.

Although the ENGR 111 structure is the antithesis of an online pedagogical setting, course administrators were forced to redesign the ENGR 111 experience during the Spring and Summer 2021 semesters to online delivery due to the reality of the COVID-19 pandemic. The use of the university makerspace was not feasible due to the close-proximity nature of numerous aforementioned hands-on activities for as many as 96 students per class, and the provision of multiple shared tools amongst six different classes. Therefore, the online format challenged instructors to retain a heavy focus on teamwork (an institutionally identified key element of the ENGR 111 experience), in addition to the active learning environment of the conventional course. Prior to the pandemic, ENGR 111 was an innovative course in its formal utilization of the makerspace setting and extensive integration of active learning, while the ENGR 111 redesign is innovative in maintaining course learning objectives despite the online format. The details provided in this paper for how to implement an active, hands-on, makerspace engineering course in an online format are conducive to adaptation for course instructors throughout the United States, as all software, platforms, and/or websites discussed are typically free for faculty and students alike. Details within this paper will be particularly focused on a handful of course curriculum features that were the most challenging to accommodate in the online format, including teamwork, experimentation, the ENGR 111 design challenge, programming and circuitry, and the Cornerstone Project.

Qualitative and quantitative measures of student perceptions during the online ENGR 111 experience were collected at the culmination of both semesters. Over 400 students shared their perceptions and reasoning of course features and topics that they found to be effective despite the online setting. They also shared perceptions and reasoning of course features and topics that they thought would have been more effective under normal face-to-face instruction. Additionally, at the end of the course for the past several years, students have completed validated, quantitative surveys grounded in value-expectancy theory, including the Perceived Belonging Uncertainty (PBU) and Interest in Engineering (IIE) scales. The qualitative responses were analyzed using grounded theory methodologies to extract emergent themes. Finally, a comparative analysis between the quantitative, belonging and interest, responses from students of the 2019 cohort that took ENGR 111 prior to the pandemic versus the 2021 cohort that experienced the online iteration of the ENGR 111 course was analyzed with independent samples t-test to explore if

there were significant differences in these key constructs that could be ascribed to the online makerspace format vs. normal face-to-face.

1. Course Description

In the fall of 2014, the J. B. Speed School of Engineering (SSoE) at the University of Louisville (UofL) commenced an endeavor to overhaul the institution's existing course(s) focused on introducing students to the fundamentals and profession of engineering. After a nearly two-year period of development, the resultant two-course sequence, required for all first-year engineering students, was inaugurated in the Fall 2016 semester [1-3]. The first component of this sequence, *Engineering Methods, Tools, & Practice I* (ENGR 110), is predominantly classroom-based and focused on introduction to and practice with fundamental engineering skills. The second course, *Engineering Methods, Tools, and Practice II* (ENGR 111), is a course primarily focused on application and integration of the fundamentals learned in ENGR 110.

One of the more unique features of ENGR 111 is that the course is conducted in a makerspace; more specifically, a 15,000 ft^2 makerspace called the Engineering Garage (EG). While makerspaces have drastically risen in popularity in numerous colleges over the past several years, the vast majority of these facilities are established as *informal* settings [4]. Utilizing a makerspace for housing an introductory course in engineering, such as ENGR 111, creates a *formal* setting for the use of these facilities. Course instruction, activities, and deliverables have been designed to augment student practice of essential engineering skills while at the same time scaffolding progression towards Cornerstone Project(s) that all students physically present at the end of the semester. ENGR 111 features a high level of faculty interaction with students during class time, with a minimum of six personnel (combination of faculty and teaching assistants) manning each class of up to 96 students per class.

It is pertinent to note that the fundamental topic of teamwork received great attention during the developmental stages of ENGR 111. The significance of effective teamwork is obvious when considering the abundance of interdisciplinary, team-based undertakings within the modern-day engineering profession [5-7]**.** Furthermore, for the past several years, when employers, including those partnered with SSoE's cooperative (co-op) education program and those hiring graduating students, are asked what abilities they are looking for in potential engineering employees, the top answer has consistently been effective teamwork skills. Given that conveying teamwork capabilities may prove difficult, the school recognizes the need to establish itself amongst prospective employers as an effective team-building institution. This begins early on for each J. B. Speed School of Engineering student with the ENGR 110 – ENGR 111 sequence. ENGR 111 is predominantly focused on the team experience, and the vast majority of class activities and deliverables are team-based. In-class lesson plans, especially those associated with building towards the Cornerstone Project, are scaffolded in a manner such that resolution becomes more dependent on team dynamics as the semester progresses. ENGR 111 student feedback pertaining to the teamwork experience had been overwhelmingly positive prior to the pandemic [3].

ENGR 111 also employs various forms of active learning, including collaborative, cooperative, problem-based, project-based, and discovery-based learning [8-16]. Cooperative learning takes place when students pursue common goals as a team while being assessed individually and has been shown to increase students' sense of belonging, which, in turn, can play a supplementary role in increasing interest in engineering [9]. Throughout the course, students are presented with design challenges, an example of problem-based learning, where a problem is used to provide the motivation and context for the learning that follows. ENGR 111 also includes project-based learning, where students work toward completion of a fully realized project, in the form of the Cornerstone Project. An example of a recent Cornerstone Project involved the construction, optimization, and mechanical design of a windmill system, which includes the integration of a windmill, student-built AC motors, DC motors, circuitry, and data acquisition systems, as well as the programming of an LCD screen that displays five different, real-time windmill system parameters upon toggling of a pushbutton. Finally, discovery-based learning is employed throughout ENGR 111 course lesson plans. In discovery-based learning, students are given tasks, such as explaining observations or answering a question, with the educational objective of discovering the underlying engineering phenomenon.

Although the ENGR 111 structure is the antithesis of a remote pedagogical setting, course administrators decided to redesign the ENGR 111 experience for Spring 2021 as a remote delivery due to the reality of the COVID-19 pandemic. The use of the makerspace was not feasible due to the close-proximity nature of numerous hands-on activities for as many as 96 students per class, and the provision of multiple shared tools amongst six different classes. Therefore, the remote designation challenged instructors in retaining a heavy focus on teamwork, in addition to the active learning environment of the conventional course iteration. Prior to the pandemic, ENGR 111 was an innovative course in its formal utilization of the makerspace setting and exclusive integration of active learning; while the ENGR 111 remote iteration redesign is innovative in maintaining course objectives in conjunction with the aforementioned pedagogical practices, in addition to the implementation of Classroom Response Systems (CRS) amongst the majority of class activities.

The details provided in the section that follows are conducive to adaptation for course instructors throughout the U.S., as all software, platforms, and/or websites discussed are (typically) free to faculty and students alike. Although there are numerous institutionally-identified fundamental engineering skills and employed pedagogical features within the ENGR 111 course structure, the following section is specifically focused on course curriculum and/or features that were the most challenging to accommodate, including fundamental skills associated with teamwork, experimentation, the ENGR 111 design challenges, programming and circuitry, and the Cornerstone Project. The addition of CRS pedagogy is also discussed in this (next) section.

2. Modifications in Delivery of Select Course Learning Objectives

2.1 Teamwork Structures Established

The Microsoft (MS) videoconferencing Teams application (freely available to all university faculty and staff) served as the backbone for ENGR 111 remote iteration delivery. A separate Teams channel was created for each of the six ENGR 111 classes – in addition to a channel created exclusively for instructor and TA use (Figure 1). Prior to the start of the semester, class rosters were used to add individual students as members of respective classes.

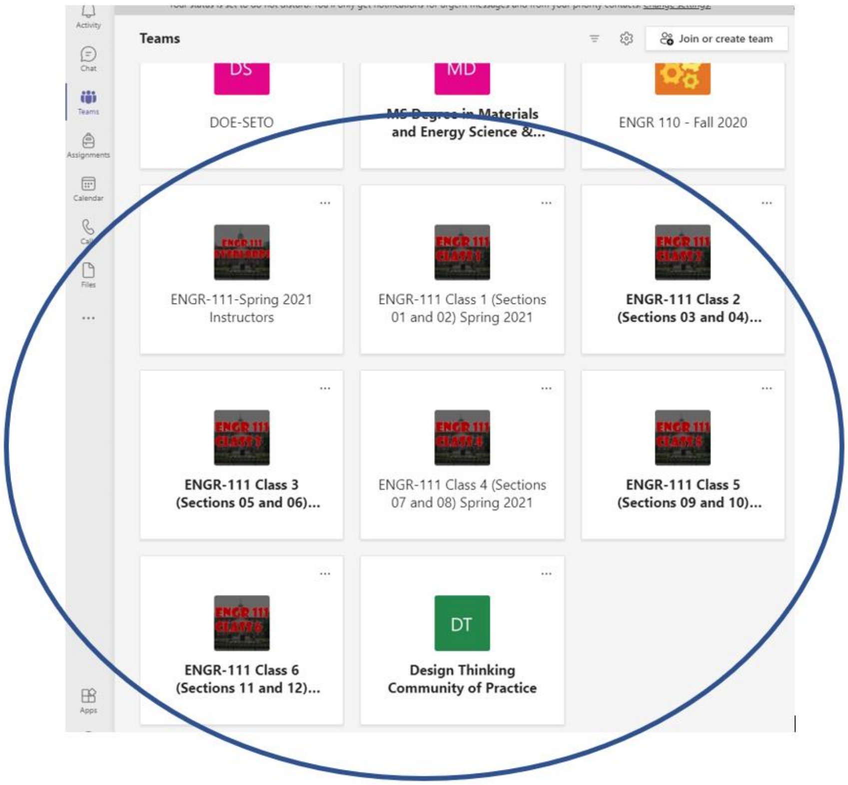

Figure 1. MS Teams utilized for ENGR 111.

Several additional subchannels were further created within each class channel (Figure 2). The *Class Lectures and Recordings* channel is the channel all students joined at the beginning of each scheduled class; and students remained in this channel while the instructor shared his/her screen and facilitated discussion for the primary topic of the day. Facilitation most often included topic-related CRS (see below) in addition to pertinent demonstrations, previews for upcoming content, etc. All sessions were recorded for future student reference and students were welcome, at any point, to ask questions via voice or chat. Once student teams were created after the first week of classes, new subchannels within each class were created for exclusive use by each respective team; only course TAs/instructors and team-specific members had access to respective team channels. Students often joined their respective teams to work on assigned activities following conclusion of initial instructional session. Figure 2 also shows two additional created channels, including the *Demo* channel in which student teams informed when they were ready for assigned project demonstration. This *Demo* channel shown in Figure 2 further demonstrates TA/instructor communication when they would join that team channel to assess the demonstration. The second channel titled *Q and A* provided an outlet for students to post course-related queries – typically utilized once students broke into their team groups. Instructors have enthusiastically noted zero drop-off in desired *team* objectives using this interface.

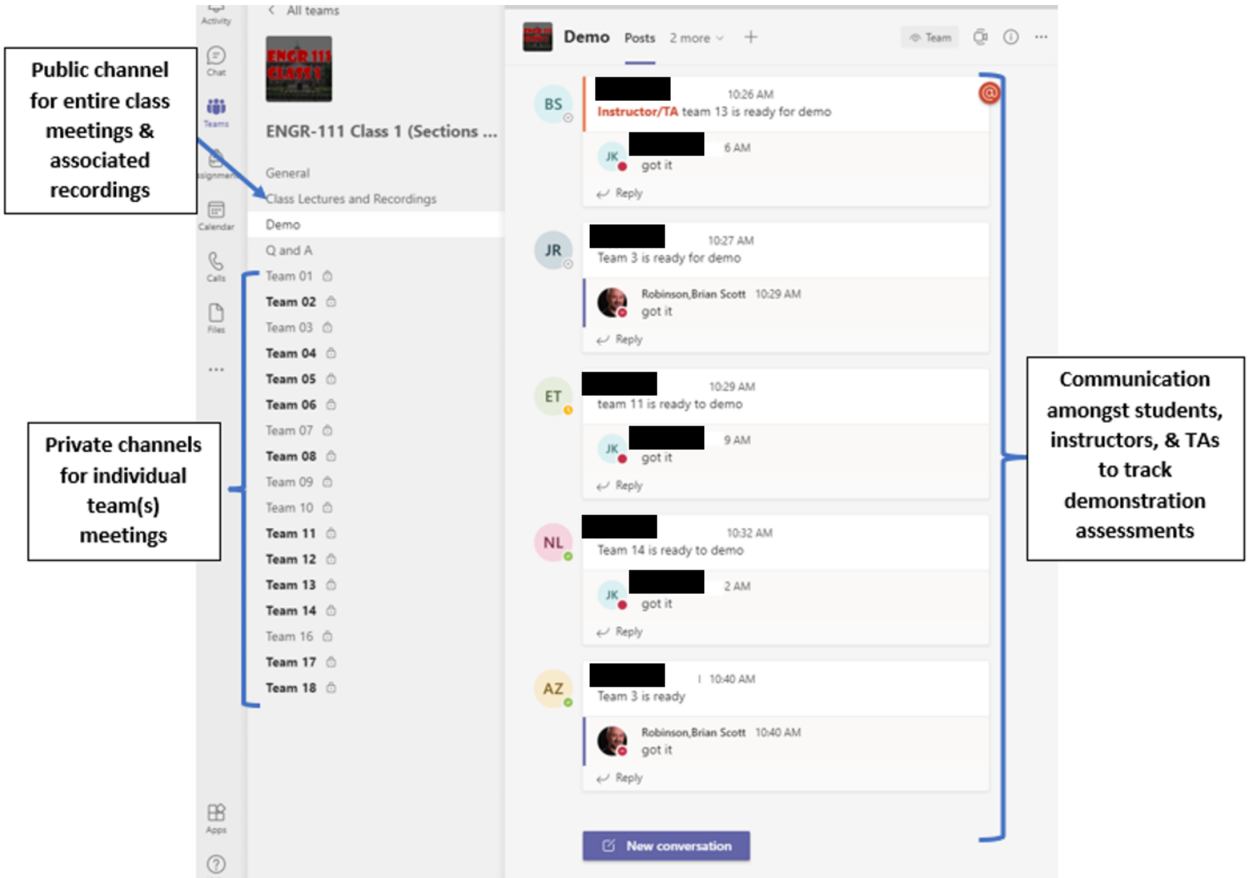

Figure 2. MS Teams subchannels utilized for ENGR 111.

2.2 Active Experimentation under Remote Instruction Conditions

For the conventional ENGR 111 iteration, the Cornerstone Project consisted of a bench-scale windmill system that students continued to build upon as the course progressed. One associated component early in the semester was practice in experimentation that also provided students exposure in the additional fundamental skills of technical writing and practice with MS Excel. Since students under the remote course iteration did not have physical access to their own constructed windmill systems, course administrators had to be creative in accommodating desired, related objectives. Thus a demonstrative windmill was built by the instructors, followed by the creation of 200 different mini-videos with a systematic variation in experimental conditions so that students could view experimental trial runs remotely while still collecting needed data. The high number of videos were created to facilitate various blade materials, pitch settings, and weight loading configurations – in addition to ensuring various groupings of unique experimental condition parameters were assigned to respective teams within each class. A sample screenshot of the page for videos containing 6-blade balsa wood is shown in Figure 3.

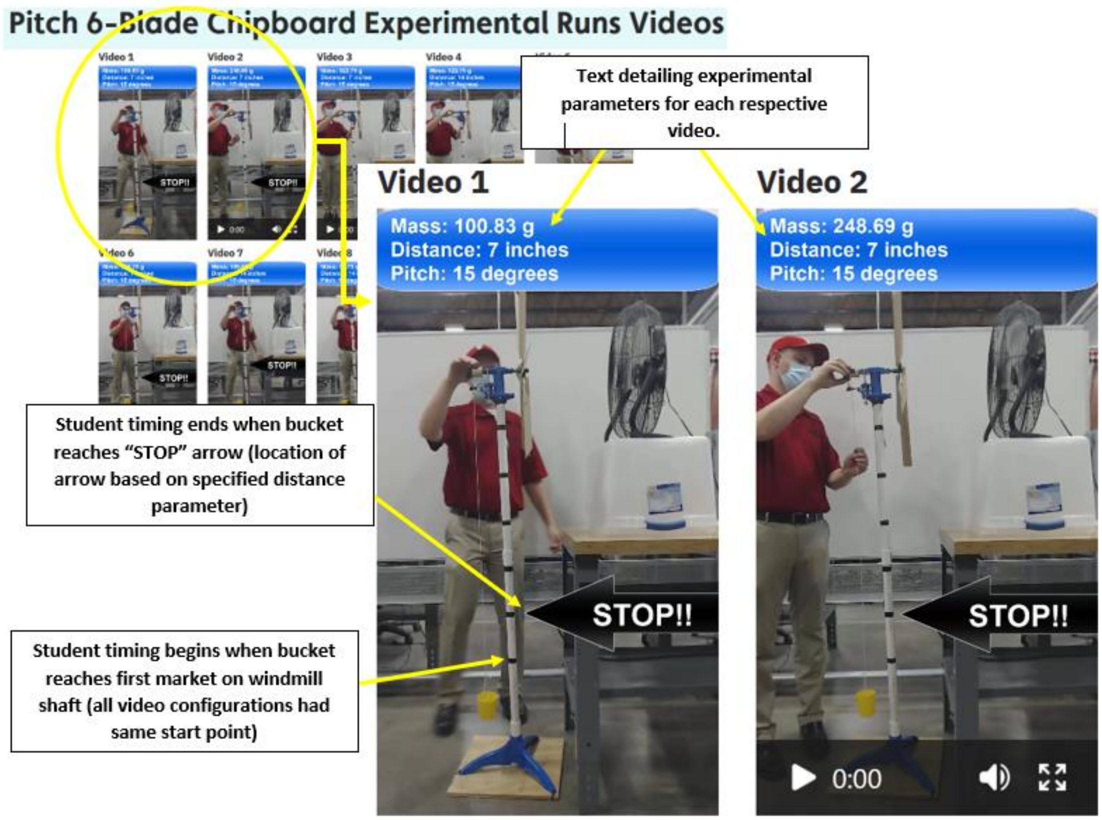

Figure 3. Sample page for students to experience remote delivery of experimental practice.

2.3 Classroom Response Systems

Classroom Response Systems (CRS) represent yet another form of active learning education, and the positive impacts of active learning methodologies that utilize CRS have also been well-documented [e.g. 17-19]. Many experimental studies state that classes using CRS significantly outperform those based in traditional lecture. CRS allow students to respond to questions displayed on a screen. Once students input their responses using remote devices, the results are instantly collected, summarized and displayed to the class in a visual format. Using CRS augments the feedback process by ensuring anonymity, rapidly and efficiently gathering and summarizing student responses, and averting students from copying answers from their peers. Due to real-time classroom feedback, the instructor has an opportunity to reinforce classroom discussion about concepts being covered. CRS have been used to improve student attention, engagement, and interaction, improve attendance, stimulate peer and class discussion, provide feedback for both students and instructors, and improve learning performance. Considerable evidence (both quantitative and qualitative) indicates that students have overall positive attitudes about the use of CRS in higher education. Numerous studies have shown that collegiate students are more attentive when CRS is employed within the classroom, that CRS increase student participation compared to classes that don't use them, and that students have reported higher levels of interest and engagement when concepts are presented and discussed via CRS. Learning benefits that have been reported include greater student articulation of thinking, deeper analytical questions, an increased instructor focus on student needs, and more effective peer-to-peer deliberations.

Accordingly, CRS methodology was identified as the ideal mechanism for remote ENGR 111 course implementation. More specifically, course administrators utilized the Mentimeter (www.mentimeter.com) site to facilitate the vast majority of class CRS sessions. The base package in Mentimeter is free, and the interface also facilitates the addition of multimedia, PPT-analogous place holders for discussion, and even friendly student-based competitions. The vast majority of class sessions during the remote iteration of ENGR 111 were commenced with a CRS session to introduce the topic of the day.

2.4 Engineering Design Challenge

For many first-year engineering students, ENGR 111 represents the first exposure to the engineering design process. Conventional iterations of the course design challenge involved designing, modelling, and 3D-printing a motor mount that would facilitate attaching student-built AC motors to their windmills. Printed designs were then tested to ensure that mounted motors were turned by the windmill (via dimensioned gearing) in turn generating electricity that could be sent to student team circuitry breadboards.

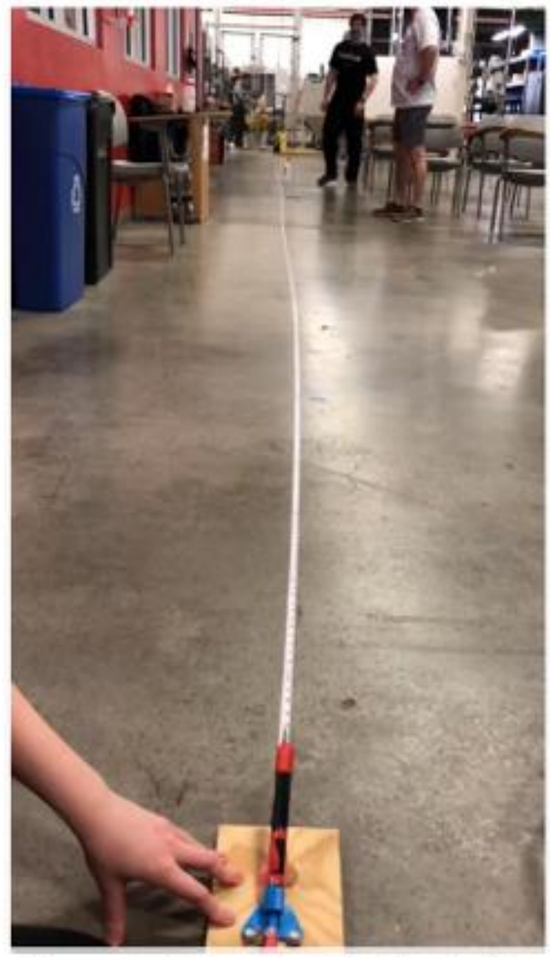

Figure 4. Visual test feedback for student-designed rocket launcher(s).

Due to the aforementioned fact that remote students have no physical access to these components, an entirely new design challenge had to be created. Design, modelling, and 3D printing are critical related course objectives that had to be maintained with the new design activity. Consequently, course administrators developed and introduced remote students to the new project, focused on the fundamental physics concept of projectile motion. Students were tasked with designing a rocket launcher with a required landing range and specified air pressure (correlated to associated initial velocity) that would be used to launch their respective rocket(s) (in addition to several additionally provided criteria and constraints). Over the next several weeks (following project introduction), students had multiple attempts (iterations) to submit design files which were then printed and tested in the university (EG) makerspace by TAs/instructors. Feedback, including videos of test launches, were then provided to students via their specific team channels (MS Teams also houses accommodations for file sharing). A screenshot of a sample launch video is shown in Figure 4.

2.5 Programming & Circuitry

A large part of conventional ENGR 111 course curriculum is focused on the essential fundamental engineering skills of programming and circuitry. Conversion of related class activities to remote instruction was exponentially simplified due to the existence of another free, online platform known as Tinkercad (www.Tinkercad.com). The entire Tinkercad site includes powerful simulation software for a variety of purposes, such as 3D modeling and Arduino programming. The circuit environment allows for design, programming, and simulation. Tinkercad has a simulation workspace and a component library that is based on existing Arduino kits. This allows for the creation of a variety of circuits that range from simple to complex. In most respects, Tinkercad operates identically to a breadboard circuit. Opening discussion for select classes focused on these topics included instructor demonstration (instead of or in addition to CRS) within Tinkercad. Figure 5 shows a sample of an in-class circuitry and programming activity.

2.6 The Cornerstone Project

Finally, conventional course delivery culminates in final realization of the Cornerstone Project, which included an associated technical report and physical demonstrations. A key obstacle as it relates to remote course delivery was the demonstrations; not only were in-person demonstrations not possible in a remote setting, but the actual demonstrations were related to the physical windmill system that students would typically be building and testing as the semester progressed. Thus, similar to the design challenge, course administrators decided to completely redesign the Cornerstone objective for remote iteration.

The associated Cornerstone Project prompt for the remote iteration of ENGR 111 tasked student teams to develop, design, and propose an alternate Cornerstone Project (potentially) applicable to future conventional iteration ENGR 111 students. Instead of an associated written technical report (aligned with the fundamental engineering skill of communication), students were alternately required to *orally* present their proposed alternate Cornerstone, while practice in *written* communication was still present in technical documentation of experiments and design process. Students were presented with the full prompt (much more detailed than that discussed here) early in the semester, and a handful of periodic meetings were held with respective teams throughout the semester to further assist students in development of their ideas.

3. Methodology

3.1 Participants

The 2021 remote iteration of ENGR 111 consisted of a total of 456 students that completed the course. All qualitative and quantitative surveys and accompanying data (discussed in the following sections) were conducted near the end of the semester and archived at the conclusion of the semester. Quantitative surveys related to Perceived Belonging Uncertainty (PBU) and Interest in Engineering (IIE) are regular features that have been built into ENGR 111 since its inauguration. Furthermore, PBU and IIE responses from the 2019 pre-COVID cohort, which consisted of a total of 443 students, were assessed alongside 2021 responses as a comparison group.

3.2 Quantitative Data

3.2.1 Quantitative Measures

As previously mentioned, quantitative surveys related to PBU and IIE student perceptions are permanent components of the ENGR 111 experience; thus we have historical data on ENGR 111 students going back several years. PBU (often referred to as “Sense of Belonging”), as defined by Strayhorn [20], was administered as an existing four-item scale that was measured on a 5-point Likert-type scale ranging from 1 (*not true at all*) to 5 (*completely true*). Negatively worded items (#1, 2, 4 in Table 1) were recoded so that higher scores indicated greater sense of belonging in engineering. Sense of belonging is an empirically-documented forecaster of student success [21-22]. See Table 1 for the belong survey items.

Table 1. Perceived Belonging Uncertainty Survey Items.

Item
1. Sometimes I worry I do not belong in engineering.
2. I am anxious about whether I fit in the engineering profession.
3. I feel confident that I belong in engineering.
4. When I face difficulties in engineering, I wonder if I really fit in.

To measure interest in engineering, an 8-item interest survey, used and validated by Linnenbrink-Garcia et al. [23] in a study of middle and high school students, was adapted by modifying the item wordings to engineering rather than mathematics as was done in the original study. The interest items were measured on a 5-point Likert-type scale ranging from 1 (*not true at all*) to 5 (*completely true*) in which higher scores indicate greater interest in engineering. Linnenbrink-Garcia and colleagues based their survey on Pintrick’s [24] 3-part characterization of interest. The authors investigated the potential factor structure of the interest construct based on three potential factors from Pintrick’s characterization of interest: useful, important, enjoyable. Moreover, the first two factors (useful, important) relate to *pragmatic* features of the engineering profession whereas the third factor (enjoyable) captures an *affective* feature of engineering interest. Table 2 displays specific wording for each interest survey item, and additionally attaches one of each of these 3 factors to each of the specific items on the survey. Results from a study of the 2019 cohort suggest that a stronger measurement model for these IIE measures would retain all three latent factors [25].

Table 2. Interest in Engineering Survey Items and Hypothesized Factor Structure.

Item code	**Item**	**Hypothesized Factor Structure**	
use1	Engineering is practical for me to know.	useful	
use2	Engineering helps me in my daily life outside of school.	useful	pragmatic
imp1	It is important to me to be a person who reasons as an engineer.	important	
imp2	Thinking as an engineer is an important part of who I am.	important	
enj1	I enjoy the subject of Engineering.	enjoyable	
enj2	I like Engineering.	enjoyable	affective
enj3	I enjoy doing Engineering.	enjoyable	
enj4	Engineering is exciting to me.	enjoyable	

3.2.2 Quantitative Analyses

In order to measure the internal consistency of both belonging and interest scales, the Cronbach's alpha (α) for each scale was calculated for the 2019 (in-person instruction) and 2021 (remote instruction) cohorts separately (see Table 3). Next, four independent samples t-tests were conducted to compare the 2019 and 2021 cohorts on their perceived belonging and interest in engineering.

3.3 Qualitative Data

3.3.1 Qualitative Measures

Two additional qualitative questions were included with the 2021 cohort surveys in an attempt to collect open-ended student perceptions related to the remote ENGR 111 experience. Specifically, the questions were 1) "*Due to the COVID-19 pandemic, the Spring 2021 ENGR 111 experience was converted to remote delivery and instruction. As a student, which ENGR 111 course features and/or topics do you think was still effective (and why)*", and 2) "*Which course features and/or topics do you think would have been more effective if your ENGR 111 experience could have been the normal, hands-on, makerspace-based delivery and instruction (and why)?*". It is pertinent to note that the second question asks students to compare against a (normal iteration) reality that they did not personally experience. Yet the authors anticipated that extensive prior student experiences with in-person classes pre-COVID – in addition to elaboration from instructors throughout the semester on key differences between the two iterations – would suffice as a meaningful point of comparison.

3.3.2 Qualitative Analyses

An inductive, grounded-theory approach [26], which permitted potential unanticipated themes to emerge from student responses, combined with a framework informed by the key remote course modifications, was used to explore student responses to these two questions. This qualitative analyses was done by the 3 core engineering faculty (co-authors of this paper) for ENGR 111 because of their deep knowledge of course details. The analyses included a structured series of both consensual coding as well as independent coding with follow-up reconciliation. One faculty member generated initial codes based on a set of 25 student responses, shared and discussed those codes with the other two faculty who then independently coded the same set of responses. Discussion of codes led to consensual agreement on the most appropriate final coding, resulting in a stronger alignment between instructors on interpretations of student responses into codes. After an additional iteration of discussion and consensual agreement on the coding specifics, one course instructor coded the remainder of the qualitative data, identifying any problematic responses for additional consultation with the 3-member faculty coding team to arrive at a consensus coding.

4. Results & Discussion

4.1 Quantitative

An initial statistical comparison between the pre-COVID in-person student group and the during-COVID remote instruction group compared interest survey data in three ways: (1 and 2) comparing the two interest factors (pragmatic, affective – see Table 2) separately for each group, and (3) comparing the entire 8-item scale as one construct. Additional, the 4-item belonging scale was compared as a single construct between the two student groups. Table 3 reports on the internal consistency reliability (Cronbach's alpha – α), the statistical significance (*p*-value) of the comparison using independent samples t-tests, and the effect size Cohen's *d*. All constructs were computed by summing the Likert-scale responses to items in that construct.

Table 3. Differences Between In-Person Instruction Cohort and Remote Instruction Cohort on Interest and Belonging Scales

	In-Person Instruction			Remote Instruction						
	M	*SD*	α	*M*	*SD*	α	*df*	*t*	*p*	Cohen's *d*
Interest (pragmatic)[a]	15.05	3.61	.80	14.37	3.19	.67	872	2.95	.003	0.20
Interest (affective)	15.93	3.68	.89	15.77	3.59	.89	896	0.65	.52	0.04
Interest[a]	30.91	6.71	.89	30.14	5.91	.84	875	1.81	.07	0.12
Belonging[a]	13.83	3.15	.57	13.00	3.81	.80	875	3.53	<.001	0.24

M=mean, SD=standard deviation
[a] Welch test is reported because Levene's test indicated that the homogeneity of variance assumption was not met for this variable.

Exploring the three-factor structure of the interest scale showed poor internal consistency (α = .42-.64). Thus, the two-factor interest scale and the overall 8-item interest scale were used as both structures showed good internal consistency (see Table 3), with the exception of the 2021 cohort pragmatic interest factor (α = .67). For the belonging scale, the 2019 cohort showed weak internal consistency (α = .57), whereas the 2021 cohort showed good internal consistency (α = .80).

Results of the independent samples t-tests showed that there is (1) no statistically significant difference in overall interest scores for the 2019 (M = 30.91, SD = 6.71) and 2021 (M = 30.14, SD = 5.91) cohorts; $t(875) = 1.81$, p =.071, d = .12, (2) statistically significant difference in pragmatic-factor IIE scores for the 2019 (M = 15.05, SD = 3.61) and 2021 (M = 14.37, SD = 3.18) cohorts; $t(872) = 2.95$, p = .003, d = .20, (3) no statistically significant difference in affective-factor IIE scores for the 2019 (M = 15.93, SD = 3.68) and 2021 (M = 15.77, SD = 3.58) cohorts; $t(896) = .651$, p = .515, d = .04, and (4) statistically significant difference in the PBU scores for the 2019 (M = 13.83, SD = 3.15) and 2021 (M = 13.00, SD = 3.81); $t(875) = 3.53$, p = <.001, d = .24. These results suggest that the mode of instruction does not have an effect on students' overall interest in and enjoyment of engineering. However, students' perceived belonging in engineering and perceived practicality of engineering were statistically, significantly lower when remote instruction of the ENGR111 course was employed in comparison to the students who experienced in-person instruction. It is noteworthy to mention that although the pragmatic factor of IIE and PBU scores showed statistical significance between the two cohorts, the effect sizes indicated small practical significance.

These results suggest that we were overall effective in retaining similar student interest in the engineering profession in spite of the COVID-necessitated need to shift to an online remote format for our makerspace course. In particular, since the affective component of interest showed no difference whereas the pragmatic component did show a weaker response in the remote group, the remote makerspace instruction seemed to have succeeded in maintaining student enjoyment of engineering. Our results also suggested that the remote makerspace instruction was less effective than the in-person modality in terms of supporting students' sense of belonging as a first-year engineering student. However, although both belonging and pragmatic interest in engineering were statistically lower in the remote group, the Cohen's *d* effect sizes do show that those differences were small [27]. These small differences, in combination with no difference in overall or affective interest in engineering, are encouraging results given the complexity and challenge of transforming an inherently intense hands-on engineering design course in a makerspace into a remote, online delivery format**.**

4.2 Qualitative

After the qualitative survey responses were coded, clear trends appeared regarding the aspects of the course that students chose to point out as effective or ineffective in the remote delivery format. The core, explicitly stated course objectives (programming, design, circuitry, 3D modeling) were among the most mentioned, whereas other topics that constitute less class time (such as technical writing) were less commonly stated in these responses.

The coded results for both qualitative questions are shown in Figure 5.

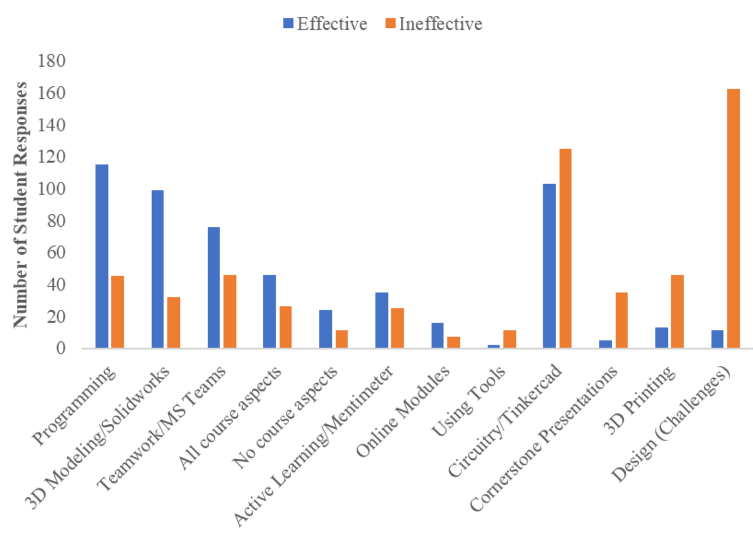

Figure 5: Coded responses to qualitative survey questions regarding effective and ineffective course aspects.

The results shown in Figure 5 illustrate a few key opinions that students held regarding course aspects that were effective and ineffective. While the number of students mentioning a topic is informative, the most important quality is the ratio of students who found that topic effective versus ineffective. As seen in Figure 5, programming and 3D modeling have the highest difference between effective and ineffective mentions; of the students who mentioned programming and 3D modeling, 72% and 76% resepectively said it was effective.This demonstrates that these topics were very well-received in a remote setting. Circuitry was widely mentioned, and about as many students found it effective as 3D modeling, but even more found it to be ineffective. With the difference between these results being so small, though, it is difficult to determine the overall student opinion on this topic.

Conversely, the topic of engineering design was demonstrably the most ineffective course aspect in the remote iteration of this course, with 94% of students who mentioned this topic saying that it was ineffective. This make sense as it is a course topic that is traditionally taught with an emphesis on hands-on learning, which was impossible to achieve in a remote setting. It is worth noting that this cateogry includes mentions of student design challenges such as the rocket launcher.

Combining the set of course features in Figure 6 into one of two broad categories, tasks that are typically software-intensive (or software-based) vs. tasks that were substitutes for physical material interactions ("build replacements") illustrate a clear trend (Figure 6). The former category includes any mention of topics that were easily adaptable to a remote setting due to the heavy use of software tools, such as programming, circuitry, and 3D modeling. The latter includes any mention of course aspects that had to be largely altered due to the inability to use hands-on methods with physical materials, such as design (building/testing/modifying prototypes), 3D printing (actually printing the part, as opposed to generating the software model which was labeled "3D modeling"), and tool usage.

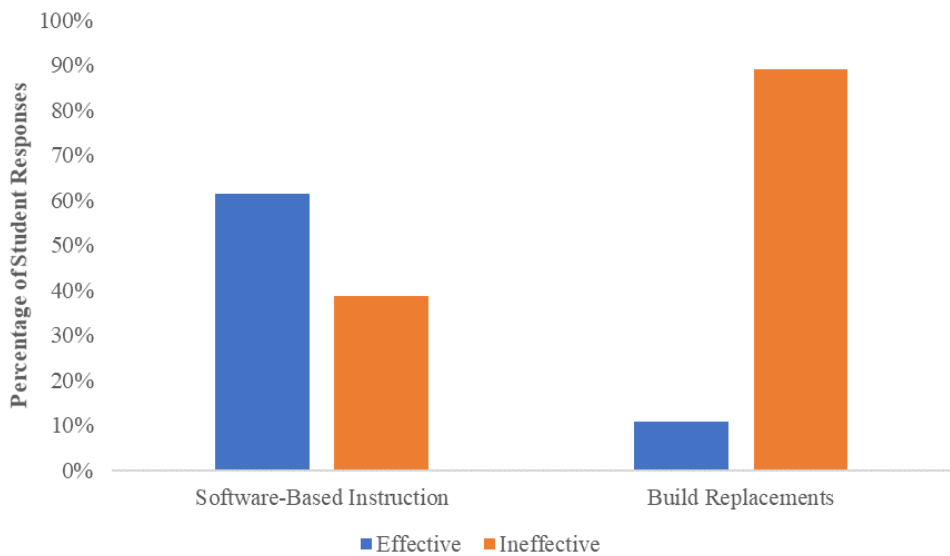

Figure 6: Consolidated responses to qualitative survey questions regarding effective and ineffective course aspects.

When consolidated in this fashion, it becomes clear that students primarily found the software instructions to be effective, with only 39% of student responses saying that they were not. This is very different from the build replacements category, in which 89% of students found these topics to be ineffective. While this is a consolidation of multiple coding categories from Figure 5, the majority of these negative build replacements responses pertain to engineering design.

Ultimately, these results show that while students appear to have found many course aspects effective, they largely judged the lack of hands-on instruction with physical materials to be less effective than they anticipate it would have otherwise been if not forced to be delivered remotely. Engineering students, especially first-year students trying to determine their future in the field, appear to have a strong desire to physically see and touch the results of their labors. This result affirms our faculty's collective decision to incorporate substantial physical tasks into the ENGR 111 makerspace course as an important central feature. Given that our engineering school's goals for this first-year exposure to engineering is intended in part to develop and maintain student interest in the engineering profession so that they persist in the engineering program beyond the first year, this result strengthens our commitment to return to using physically interactive tasks in future iterations not impacted by the pandemic.

5. Conclusions: Features of Online Iteration Retained for In-Person Iteration

Efforts focused on converting the conventionally hands-on, makerspace-based ENGR 111 course was consistently challenging and often-times daunting. Effective achievement in successful development of many features of a fully-remote iteration of the course that still served course objectives certainly yielded a high sense of satisfaction for course instructors. An unanticipated, and in many cases pleasantly surprising, outcome(s) of the course redesign for remote instruction came via realization that numerous modifications and/or features, if retained, could *further* augment the normal iteration of course delivery (ENGR 111 returned to in-person format for the Spring 2022 semester). We conclude this paper by providing a summary of new course features we intend to retain or slightly modify, with a specific focus on the fundamental engineering skills and/or features highlighted in Section 2.

Prior to the COVID pandemic, the vast majority of daily class sessions (each class for students was approximately 2 hours, twice/week) involved ENGR 111 students reporting directly to the makerspace (versus the adjoining classroom in the same facility) and students were expected to immediately begin doing planned activities for the day. Guiding prompts for tasks were provided via printed hard copies or more recently via online instructions developed by the ENGR 111 team. Any associated instruction helpful to supplement the day's activities were provided to students by faculty-created videos, and students were expected to view (and sometimes complete a follow-up quiz) prior to coming to class. Upon reimplementation of the normal (hands-on) iteration of ENGR 111 in Spring 2022, course instructors made the decision to replace many of the preparatory self-view videos with equivalent, in-class CRS sessions conducted at the beginning of class in the adjoining classroom. Results from this study reported in this paper suggested that it may have been incorporation of the CRS methodology that was one key factor for the COVID cohort to report equally strong "enjoyment" component of interest compared to prior in-person peers. In addition to the CRS benefit of active engagement of students with the ideas and information they need to be successful in the upcoming class period, during the remote instruction delivery the instructors noted additional benefits from in-class CRS instruction compared to the prior self-view videos. These additional benefits included the ability to immediately address student questions, and also offered stronger opportunities for instructors to ensure student understanding of *why* they would be doing certain activities.

Due to the clear benefits for students to be able to work directly with their own physical Cornerstone project (see Figures 6 and 7), the online series of numerous *Experimentation* videos (see Figure 3) were not employed for the in-person iteration. However, the CRS session established for the remote iteration to explain the scientific theory and associated engineering thinking behind experimental methodology was retained for the redesigned in-person course in Spring 2022. Prior to COVID, the in-person ENGR111 course used an instructor-created video for the same purpose.

The new rocket launcher design challenge was also retained, incorporated into the in-person course iteration alongside the preexisting motor mount engineering design task, thereby providing a more robust variety of engineering design experiences. This additional engineering design task also provided further opportunity for students to practice creativity, critical thinking, and problem solving – essential skills for successful engineering design. Furthermore, addition of the extra design challenge mandated expansion of class time focused on design, in turn providing students more opportunity for practicing *iterative* design.

MS Teams videoconferencing software, although no longer utilized as the primary course hub as it was during the remote iteration, remained a course feature for in-person instruction that still provided student teams their own private channel for file sharing and off-campus communication. MS Teams also provided a platform for recording and archiving the aforementioned CRS sessions, and students quarantined at home due to COVID or other illness also now have an opportunity to remotely join live during the CRS sessions, or if unavailable at the scheduled class time they could later access via MS Teams what they may have missed. For programming and circuitry, the Tinkercad software suite was retained as a course feature. Students will utilize Tinkercad for initial practice during introductory instruction, followed by using physical hardware for more advanced circuitry and/or programming challenges in the makerspace.

Finally, physical demonstration(s) of the final course (Cornerstone) project were added back into course curriculum upon return to in-person classes, but the pre-COVID required final technical report has been permanently replaced by the revised Cornerstone proposal (as discussed in Section 2.6). Practice in graphical communication has always been present in ENGR 111 via instruction in 3D modeling and MS Excel and, even with the replacement of the previously-required Cornerstone final technical report, written communication is still a course feature due to two different required midterm technical reports during the semester. The element of engineering communication most lacking prior to the pandemic-caused redesign was oral communication, but the Cornerstone proposal assignment directly requires strong oral communication skills. Furthermore, the Cornerstone proposal requirement represents a much more desirable means of culminating the ENGR 111 experience with one final holistic application of the numerous fundamental engineering skills that students have been practicing all semester long.

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