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Article

Virtual versus In-Person Presentation as a Project Deliverable Differentially Impacts Student Engaged-Learning Outcomes in a Chemical Engineering Core Course

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ABSTRACT: Over the past decade, the increasingly globalized society has continually redefined the qualities and skills of an ideal engineering graduate for industry and academic careers, and, more recently, in light of a global pandemic in 2020, the pedagogical environment has shifted toward a virtual classroom setting. Because the engineering and social challenges of the modern world are rapidly evolving, it is important to adapt teaching methods that reflect these changing times. An increasingly attractive teaching method in the engineering classroom is project-based learning (PBL), which is known to improve engaged-learning outcomes, such as creativity, risk taking, social responsibility, teamwork, self-confidence, and communication. However, it is still unclear how various PBL practices differentially impact these engaged-learning outcomes. Toward the goal of elucidating this, the impact of two different project formats, a virtual presentation versus an in-person presentation, was evaluated for a junior-level chemical engineering core course, Mass and Heat Transfer, over 2 years (248 students total). In surveys conducted after the projects were completed, students were asked to what degree the project improved each of the learning outcomes on a scale of 0 (no impact) to 10 (great impact). Data from these postproject surveys showed no statistically significant differences in impact on teamwork, self-confidence, and communication skills between the two groups. However, the virtual presentation had statistically significant greater positive impacts on student creativity [mean score: 8.9/10 (virtual) vs 7.7/10 (in-person); $p < 0.001$] and risk taking [mean score: 7.7/10 (virtual) vs 6.1/10 (in-person); $p < 0.001$], whereas the in-person presentation had a significantly more positive impact on social responsibility [mean score: 6.5/10 (in-person) vs 5.5/10 (virtual); $p < 0.05$]. Qualitative insights into these results were gathered from discussions with students in focus groups. The results of this study underscore the unique advantages associated with different presentation formats. From the perspective of the current transitions to online learning, the results suggest that changing project deliverables from an in-person to a virtual format may actually yield net gains in engaged-learning outcomes.

KEYWORDS: *Multimedia-Based Learning, Demonstrations, Inquiry-Based/Discovery Learning, Public Understanding/Outreach, Upper-Division Undergraduate, Chemical Engineering, Transport Properties*

Over the past decade, society has progressed toward a more globalized and technologically advanced future.[1,2] With this transition, aligning desired skills of an ideal engineer and those possessed by university graduates has become a point of emphasis in industry and academia.[3−6] Whereas traditional pedagogies tend to focus on improving academic performance based on standardized test scores and grades,[7,8] the challenges of the modern world call for students who possess not only technical expertise but also global skills, such as creativity, communication, and critical thinking.[1,2,4] In addition to the necessity of global skills, the more recent issue of a global pandemic has transformed the pedagogical environment from an in-person to a virtual classroom setting.[9] Because the engineering and social challenges of society are constantly evolving, it is important to adapt teaching methods that reflect these changing times.

In particular, universities are increasingly implementing project-based learning (PBL) approaches in STEM classrooms. With PBL, students are placed in situations that closely resemble what they may encounter in their careers, such as a collaborative work environment and open-ended, real-world problems.[10,11] PBL not only enhances students' understanding of concepts[12] but also produces positive engaged-learning outcomes: (1) **creativity** in the areas of imagination, curiosity, and adventureness;[13] (2) **innovation and risk taking**, attributed to the open-ended nature of projects that enable an entrepreneurial mindset;[13,14] (3) **social responsibility** for addressing social and ethical issues and for public outreach;[6,15] (4) **teamwork**, encompassing trust, responsibility, leadership, and an open mind for new ideas;[16−18] (5) **confidence** in the

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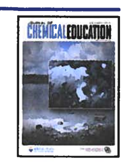

ability to apply engineering concepts and to tackle future challenges;[17,18] (6) **communication** for written and oral presentations.[18] More importantly, many studies have demonstrated the possibility of PBL to go virtual, which is not only consistent with current trends toward digital technology but also compatible with online learning in the time of a pandemic.[19−21] While the advantages of PBL are well-studied, it is still unclear how specific PBL practices promote various engaged-learning outcomes differently. One such PBL practice is the presentation format for project deliverables, which can occur in-person or virtually. In-person presentations of a poster, product prototype, or live demonstration are commonly employed for PBL,[11,13,22,23] but virtual presentation formats, including video broadcasts, are increasingly gaining popularity.[24,15,25] Understanding the differences between presentation formats on engaged-learning outcomes becomes critical when in-person presentation formats no longer become available.

We found an opportunity to shed light on the relationship between different PBL formats and various engaged-learning outcomes using a junior-level chemical engineering core course (ChE 342 Mass and Heat Transfer) at the University of Michigan as a case study. In this course, students complete a PBL assignment that consists of two stages: *Identify*, in which students choose an open-ended problem in mass and heat transfer, and *Solve*, in which students design an experiment to tackle the problem and perform a live demonstration as an in-person presentation to high school students. More recently, a third stage, *Broadcast*, in which students produce a YouTube video as a virtual presentation of the demonstration, was introduced to add an exciting and engaging media component that could be disseminated to a much broader audience.[24] With the implementation of this new *Broadcast* stage, several unique examples of creativity, including a rap musical inspired by the opening theme of a popular sitcom, and other engaged-learning outcomes became more evident. Moreover, introduction of the YouTube video as a virtual presentation format also correlated with higher final exam and control problem scores compared to the previous cohort without the video requirement,[24] suggesting the modified project format improves not only global skills like creativity but also course skills such as material comprehension.

The pilot run of the *Identify–Solve–Broadcast* PBL assignment required both a virtual YouTube video and an in-person live demonstration as project deliverables, and we hypothesized that each presentation format has different contributions to specific engaged-learning outcomes. In the present work, to elucidate the differences between these two presentation formats, a similar three-stage PBL approach was implemented, but students were given the choice between a virtual or an in-person presentation for the *Broadcast* stage. Surveys and focus groups were then conducted to acquire quantitative and qualitative measurements of the degree of impact each presentation format had on specific engaged-learning outcomes.

■ STUDY DESIGN (METHODS)

Project Description

Students were tasked with designing an original experiment or a computer simulation in mass and heat transfer that would be suitable for a high school audience. More details regarding the specific design constraints, implementation strategies, and examples of student work can be found in the pilot study.[24] To determine the impact of the presentation format on engaged-learning outcomes, students were given two options for project deliverables: an in-person 10−15 min live presentation or a virtual 3−5 min YouTube video presentation (Figure 1A). In

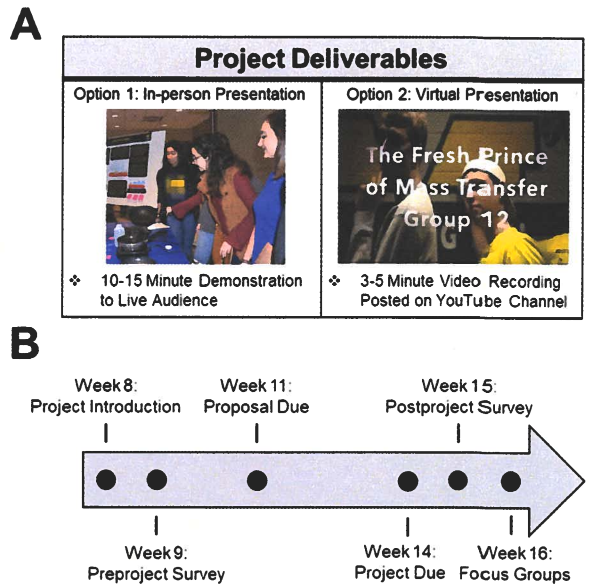

Figure 1. Project deliverables and timeline. (A) Students were given the choice between an in-person presentation or virtual presentation for their demonstration. (B) Project timeline developed for a 16-week course. Student milestones and assessment activities indicated by week.

addition, each project required a technical writing submission: a poster to be displayed during the in-person presentation or a 5-page written report to accompany the virtual presentation. Several strategies detailed in the pilot study were employed to ensure that both Option 1 and Option 2 were designed to give students in each cohort an equal amount of work.[24] For example, the writing submission for both options contained the same section requirements: background on the selected topic, experimental design, problem statement, solution, and experimental analysis. With respect to the presentation component, examples of submissions from previous years were shown in class to give students consistent expectations for each presentation format. Because some students did not have prior experience in making a virtual presentation, a workshop on video editing was held during one class period to give all students the same baseline level of skills and best practices. Moreover, survey data later showed that each team of students in the virtual presentation cohort actually included at least one student who had prior video editing experience, likely a result of the self-selection process of the project presentation format. To ensure that projects covered a wide range of mass and heat transfer concepts, student teams could choose from a total of 20 different topics (Figure S1). The experiment and combination of topic and presentation format were required to be unique for each team (Figure S1).

Participants

A total of 248 undergraduate junior-level students participated and completed the project during the Fall 2017 and Fall 2018

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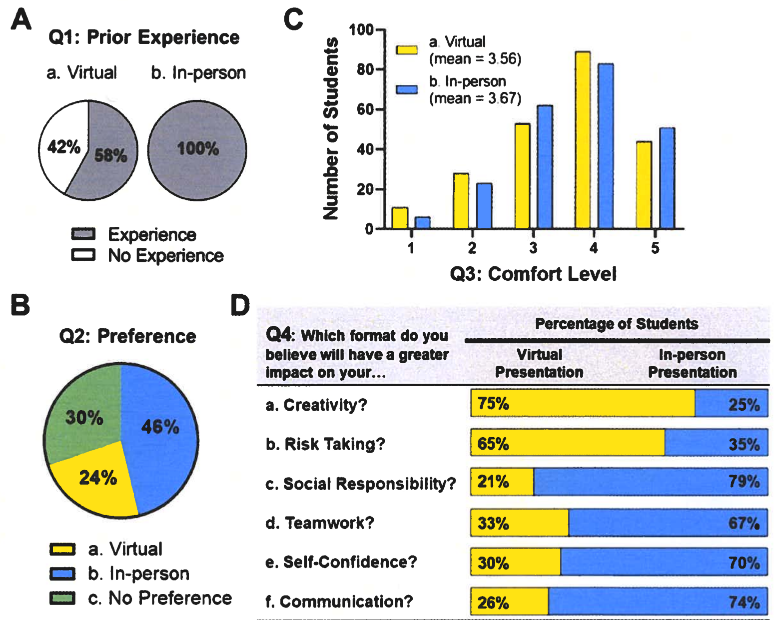

Figure 2. Preproject survey results. (A) Student prior experience delivering a virtual or in-person presentation as part of their coursework. (B) Student preference for presentation formats. (C) Student comfort levels with each presentation format. (D) Percentage of students who perceived each format would have a greater impact on improving each learning outcome. Preproject survey response rate: n = 225/248.

semesters. Students were able to choose their teams of 4 or 5 students based on their interests and schedule compatibility.[24] In <10% of the cases, students were instead assigned to a team because of either scheduling conflicts or an insufficient number of students on a given team. During the Fall 2017 semester, there was a slight imbalance in the total number of teams for each option (19 in-person presentations vs 13 virtual presentation). Therefore, to ensure similarly sized cohorts for the study, assessment data were combined with those from the following year when the distribution was more even (15 in person presentations vs 14 virtual presentations). Of the 248 students, 137 students (34 teams) chose the in-person presentation format, while 111 students (27 teams) chose the virtual presentation format, resulting in similarly sized cohorts for this study.

Assessment

Project assessment was completed over a ~9-week period, starting at Week 8 of the semester when the project was introduced (Figure 1B). At Week 9, students completed the preproject survey to evaluate their preconceptions and prior experiences with different presentation formats heading into the project. After students submitted and received approval for their project proposals at Week 11, 16 students (8 from the in-person and 8 from the virtual presentation) were recruited during Weeks 12 and 13 for participation in focus groups. Recruitment was conducted using the University of Michigan Human Subjects Incentives Program in accordance with IRB HUM#0008003. A diverse panel of students was recruited by selecting only one student from a given team and recruiting students with a range of performances in the class (A−C letter grade). A total of 32 students participated in focus groups over the two-year evaluation period. After completion of the projects in Week 14, the postproject survey was conducted with all students at Week 15 to determine the impact of project formats on specific engaged-learning outcomes. To obtain further feedback on students' experiences, focus groups were held in Week 16 or within the first few weeks of the following semester if scheduling conflicts occurred.

■ RESULTS

Student Preferences and Preconceptions: Different Engaged-Learning Outcomes Associated with Certain Presentation Formats

To evaluate student perceptions heading into the project, a preproject survey (Figure S2) was administered to students in Week 9 of the course, 1 week after the project was introduced. Preproject survey questions were divided into two categories aimed at understanding the (1) preference for different presentation formats and (2) perceived impact of presentation formats on engaged-learning outcomes. First, students were asked if they had any prior experience with either the in-person or virtual YouTube video presentation (Question 1 in Figure S2). All of the students had experience delivering a poster presentation in a sophomore-level chemical engineering course the year prior, but just over half (58%) had ever created a video as part of any high school or college course project (Figure 2A). Moreover, when asked which project format they preferred (Question 2 in Figure S2), nearly twice as many students preferred the in-person presentation (46%) compared to the virtual presentation (24%), and a significant proportion (30%) of students indicated no preference between the two (Figure 2B). Despite this imbalance, when asked on the preproject survey about how comfortable they would feel with each format (Question 3 in Figure S2), the average comfort score for the virtual presentation (3.56/5) was only slightly lower than that of the in-person presentation (3.67/5) (Figure 2C). While the mean comfort level for the virtual presentation was slightly lower, consistent with the lack of experience

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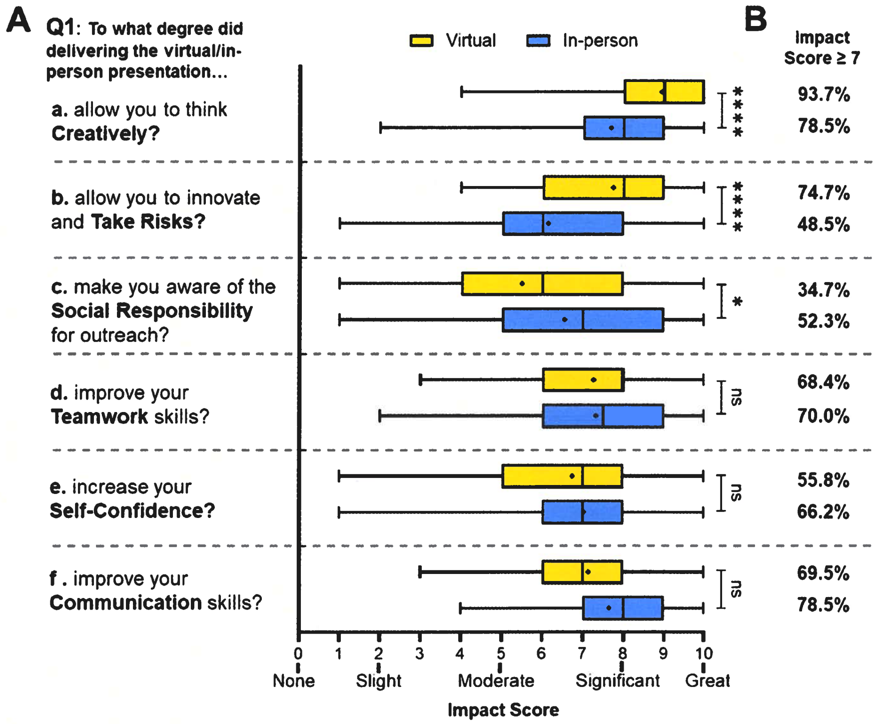

Figure 3. Postproject survey results. (A) Box-and-whisker plots of the impact score on each learning outcome for the in-person and virtual presentation formats. Whiskers indicate maximum and minimum impact scores given for each learning outcome. The mean impact scores are indicated with black dots (unpaired student's *t* test: *, $p < 0.05$; ****, $p < 0.001$). (B) Percentage of students who gave each format an impact score of ≥7. Postproject survey response rate: virtual, $n = 95/111$; in-person, $n = 130/137$.

(Figure 2A), >80% of students indicated a comfort level of at least 3 (moderate comfortability) for either format. This perceived comfortability with the virtual presentation format, even without prior experience in a course project, can be attributed to current students' everyday exposure to and "informal" training with video producing and uploading to sites such as YouTube.[15,26−29] While some students may still prefer a more traditional project format, students' propensity for social media and new technologies generally instills a high level of confidence when tasked with communicating via a video presentation in a new setting.

In the second part of the preproject survey, students were asked whether the virtual or in-person presentation would have a greater impact on each of the six engaged-learning outcomes (Question 4 in Figure S2). More students perceived that the virtual presentation format would afford greater opportunities for improvement in creativity (75% vs 25%) and risk taking (65% vs 35%) compared to the in-person format (Figure 2D). In contrast, a greater percentage of students perceived that the in-person presentation would have a larger impact on social responsibility (79% vs 21%), teamwork (67% vs 33%), self-confidence (70% vs 30%), and communication (74% vs 26%). The fact that students thought the in-person presentation would have a greater impact for 4 out of 6 engaged-learning outcomes may be due to the greater familiarity and comfort level associated with this format compared to the virtual presentation. Taken together, the in-person presentation was associated with greater familiarity, comfort level, and perceived impact on engaged-learning outcomes, resulting in a slightly larger fraction of students who chose this format (n = 137, 55%) compared to the virtual presentation (n = 111, 45%).

Virtual Presentation Shows Significantly Greater Impacts on Creativity and Risk Taking than the In-Person Format

To evaluate the impact of each presentation format on the six learning outcomes, a postproject survey (Figure S3) was conducted with the students 1 week after project completion (Figure 1B). The students from each project group were asked to what extent their project format improved each learning outcome (Figure 3A, Question 1). Descriptors for the numerical values (none = 0, slight = 2, moderate = 5, significant = 8, and great = 10) were provided to normalize students' internal scale for measuring the degree of impact. In addition to the postproject survey, two focus groups, one for each project format, were conducted each semester to collect qualitative feedback about the project experience. In the focus groups, students were shown both their own survey responses and the overall class response and asked to provide personal insight on the project impact for each learning outcome. Student responses transcribed during the focus groups are shown in quotations in the discussions below.

Students who delivered a virtual presentation experienced significantly greater impact on creativity (mean score: 8.9/10) compared to those who delivered an in-person presentation (mean score: 7.7/10) (Figure 3A). Supported by the virtual presentation focus group study, students enjoyed better opportunities to create a storyline with scenes and footage taken at multiple locations augmented by animations and special effects. For example, one group took a relatively slow and stationary thermal conduction experiment—using materials with different thermal conductivities to melt butter—and turned it into an exciting race with commentary in the style of a sporting event. Opportunities like this one were a key contributing factor to the high impact on creativity, as 93.7% of students in the virtual presentation cohort gave an impact score of ≥7 for this learning outcome (Figure 3B). In contrast, students who delivered in-person presentations noted that many of the creative opportunities offered by the virtual presentation were less conducive to the fixed setting and time constraints of an in-person presentation. To address these limitations, many students adapted their in-person presentations into carnival-like games, allowing the audience to take a more active role in discovering mass and heat transfer phenomena. One student noted, "Presenting in a game format led to a more fun environment and atmosphere compared to the poster presentations I had done in the past". Even with these endeavors, however, only 78.5% of the in-person presenters gave impact scores of ≥7 for creativity, illustrating the unique advantage the virtual presentation provides in improving student creativity.

In addition to greater opportunities for creativity, students who delivered a virtual presentation also experienced a higher impact on risk taking (mean score: 7.7/10) compared to that for the in-person presentation cohort (mean score: 6.1/10). One student in the virtual presentation focus group noted that "this was my first time making a video which felt like more of a risk in and of itself compared to a live presentation", likely because of the lack of experience and slightly lower comfort level associated with the virtual presentation, as described in Figure 2A. However, the most notable factor in determining the impact on risk taking was the ability to control the experimental conditions, particularly time. With a limit of 10–15 min for the in-person presentation, many students took a more conservative approach. As one student described, "our group felt like we had to choose a shorter demonstration that could be finished in a few minutes, otherwise we would have run out of time". A few groups delivering in-person presentations cleverly bypassed this time constraint by completing longer parts of the experiment at home and showing only the final product or using the final results of an experiment in the context of a game show. Despite these examples of innovation, only 48.5% of in-person presenters gave an impact score of ≥7 for risk taking (Figure 3B), which was also the lowest of any engaged-learning outcome for the in-person presentation format (Figure 3A).

While many of the in-person presenters were limited in their ability to take risks, 74.7% of the virtual presenters gave an impact score of ≥7 for risk taking (Figure 3B). Students used the virtual format to their advantage by slowing down, speeding up, or stitching together footage of experiments recorded over multiple time scales into a 3–5 min video. For example, to demonstrate the everyday phenomenon of soda losing its carbonation, one group measured the total flux of CO_2 produced after a yeast fermentation reaction in a plastic 2 L bottle by capturing the CO_2 in a balloon over a 3-day period. While certain aspects of this experiment (e.g., the balloons filling up with CO_2) would look incredibly slow in real time, the students sped up the frame rate in order to efficiently show several minutes to hours of footage in just several seconds. With more control over the time factor, multiple groups were able to attempt longer, more intricate experiments that would not have been feasible for a 10–15 min in-person presentation. In addition, students using the virtual presentation format could take risks and attempt more challenging experiments because they could repeat them multiple times until they captured the perfect shot for the final production. Taken together, students who delivered the virtual presentation experienced significantly greater impact on both creativity and risk taking compared to those who completed an in-person presentation, largely because of the unique opportunities afforded by video making to create a story centered on a more complex experimental design.

Virtual Presentation Shows a Lesser Impact on Social Responsibility for Outreach Compared to the In-Person Format

In contrast to creativity and risk taking, data from the postproject survey revealed that the virtual presentation had a lower impact (mean score: 5.5/10) on social responsibility for outreach compared to that of the in-person presentation (mean score: 6.5/10) (Figure 3A). Undergraduates in both groups emphasized the importance of direct interaction with their audience to appreciate the social outreach aspect of the project. One student in the in-person focus group commented, "I found that delivering the poster presentation was really helpful in furthering the understanding of the people I was teaching". In-person presenters also noted that "several [high school] students asked us questions about engineering and our studies", giving them the opportunity to share their insights and experiences with students just a few years younger than them and witness firsthand the impact of their presentations on the high school audience.

On the other hand, students who delivered a virtual presentation felt a much lower impact on social responsibility, with only 34.7% assigning an impact score of ≥7, compared to 52.3% for the in-person cohort (Figure 3B). This lower impact was attributed to the lack of in-person communication with their audience. As one of the virtual presenters summarized, "We didn't receive any feedback on our videos except from the instructors, and missed out on any face-to-face interactions with the high school students". To address this shortcoming of the virtual presentation in the future, some students in the focus group recommended that high school students leave comments and questions on the YouTube video page, which has been previously shown to inspire virtual presenters as global educators.[15] Furthermore, a virtual meeting could be arranged between the presenters and high school students to provide the presenters with an opportunity to directly interact with the high school students, hear feedback about the videos, and answer questions. Although this could, to some extent, better increase their awareness of social responsibility, other students in our focus group noted that virtual feedback from their audience could never fully replace in-person interactions.

Overall Impact on Several Engaged-Learning Outcomes Is Not Sensitive to the Presentation Format

While creativity, risk taking, and social responsibility were all differentially impacted by the two presentation formats, there was no significant difference between the levels of impact of the virtual versus in-person format on teamwork (mean score: 7.3/10 vs 7.2/10), self-confidence (mean score: 7.0/10 vs 6.7/10), and communication (mean score: 7.6/10 vs 7.1/10) (Figure 3A). For teamwork and self-confidence, the impact primarily stems from the *Identify* and *Solve* stages of the project rather than the *Broadcast* stage via either presentation format. In particular, students in both focus groups explained that their teamwork skills mainly improved by interacting with group

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members to make decisions when researching project topics, designing experiments, and developing the story for their in-person or virtual presentation. In the focus groups, many students explained that their teams performed certain tasks together, such as selecting a topic and designing the experiment, while other tasks, including executing the experiment, editing the video, designing the poster, and writing the report, were divided among team members. These interactions were common to both presentation formats, which likely explains why a nearly equal fraction of students gave an impact score of ≥7 for teamwork in the virtual (68.4%) and in-person (70.0%) cohorts (Figure 3B). Similarly, students primarily attributed self-confidence to successfully designing and performing an experiment, which was required in both presentation formats. During the focus group, a student from the in-person cohort did point out that "once I saw the high school students engaging with our demonstration that really boosted my self-confidence", which was affirmed by several other in-person presenters. Even though there was no statistically significant difference between the mean impact score for either format (Figure 3A), this boost is reflected by the slightly higher fraction of students (66.2%) assigning an impact score of ≥7 for increasing self-confidence compared to those delivering virtual presentations (55.8%) (Figure 3B).

With regard to communication skills, a combination of both shared and unique aspects of each format contributed to a similar level of impact on this learning outcome. Students primarily viewed communication from the perspective of communicating ideas to their audience. In particular, the process of communicating advanced chemical engineering concepts to high school students forced the undergraduates to carefully consider the technical design of the project, which led to a deeper understanding of the content. As noted by one of the students, engaging the general public in technical material is an important communication skill not emphasized in a traditional chemical engineering education: "I don't feel that we have enough practice vocalizing what we know as engineers, so this really allowed us to do that." Although this was a common sentiment from members of both focus groups, each presentation format offered unique ways to improve on communication skills. Students delivering in-person presentations had to answer questions on the spot, which improved their oral improvisation skills as well as the ability to think under pressure. These challenges likely contributed to both the high average impact score (7.1/10) and the large fraction (78.5%) of in-person presenters who felt a great impact of this presentation format on their communication skills (Figure 3B). A similarly large percentage (69.5%) of virtual presenters felt this degree of impact (Figure 3B), although their experience was different in that virtual presenters were not able to answer live questions. Instead, they had to anticipate audience questions and address them proactively in their videos through both verbal and visual forms. Taken together, while each presentation format offered different ways to improve communication skills, both groups experienced similar levels of improvement on this engaged-learning outcome.

■ DISCUSSION

With the great scientific and technical challenges of the modern world, it has become increasingly important for graduates to possess global skills that are applicable in broad contexts and transferable to their future careers. While the incorporation of engaged-learning methods, particularly PBL, has demonstrated great promise in engineering education, a deeper understanding of how PBL affects students is required to fully unlock its potential. Here, we investigated the impact of the presentation format as a PBL practice on six engaged-learning outcomes: creativity, risk taking, social responsibility, teamwork, self-confidence, and communication.

Overall, both presentation formats resulted in moderate-to-great perceived improvements of all six learning outcomes, indicating that students saw both formats as beneficial (Figure 3). These results were supported qualitatively by student comments in each of the focus groups. A student from the virtual presentation cohort explained that they "had a lot of fun coming up with the idea, writing the script, filming, and editing the video", while a student who chose the in-person presentation claimed that "the freedom to be creative allowed us to really make the project our own". These sentiments were echoed by their peers and are consistent with previous findings that PBL increases student engagement through entertainment and project ownership.[30−32] Regardless of the presentation format, students also expressed concerns that generally apply to PBL assignments,[32−34] most notably the time commitment required to schedule meeting times with group members, design and perform experiments, and rehearse or film presentations. These concerns were partially alleviated by allowing students the flexibility to choose a presentation format that both aligned with their interests and was more conducive to showcasing their particular demonstration.

Going into the project, students perceived that the virtual presentation would allow more opportunities for creativity and risk taking, while the in-person presentation would have greater impact on social responsibility, teamwork, self-confidence, and communication (Figure 2D). Coming out of the project, students indeed felt the virtual presentation had a greater impact on creativity and risk taking and a lower impact on social responsibility compared to the in-person format (Figure 3A), consistent with their earlier perceptions in the preproject survey. To our surprise, there was no significant difference in the impact on teamwork, self-confidence, and communication by the end of the project (Figure 3A) even though significant majorities (67−74%) of students in the preproject survey perceived that the in-person presentation would have had a greater impact on these three learning outcomes (Figure 2D). There are several important factors that may have led to this perception shift. First, not all students had experience making a video before and thus had to rely solely on their experience with in-person presentation formats when answering the preproject survey questions. Because all of the students presented in-person posters the year prior as sophomores, it is very likely that they associated the positive impacts of teamwork, self-confidence, and communication with that experience before completing the current project. Second, based on the focus group discussion, the impact on certain engaged-learning outcomes, including teamwork and self-confidence, was associated more with the *Identify* and *Solve* stages of the project rather than the presentation format. One possible way to identify learning outcomes that students perceive to be less sensitive to the presentation format heading into the project would be to include a "Neither Format" option in the response to the preproject survey Q4 on learning outcomes. Nevertheless, the changes in student perception that occurred between the pre- and postproject surveys illustrate that the impacts on learning outcomes are not always predictable, and it is critical to compare project formats side-

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by-side with a quantitative survey both before and after the project.

In light of the current pandemic, virtual PBL formats and online learning have already replaced in-person presentations, and it is likely to remain this way for some time. Therefore, it is critically important to ensure that virtual formats positively impact engaged-learning outcomes. In this study, the virtual presentation format resulted in moderate-to-great improvements of all six learning outcomes and outperformed the in-person presentation format with respect to creativity and risk taking (Figure 3). Only the impact on social responsibility was lower for the virtual presentation, although the recommendations of allowing audience feedback on student videos and having virtual meetings between the undergraduate and high school students are likely to improve this learning outcome substantially. Taken together, net improvements for engaged-learning outcomes can be achieved using virtual formats.

■ CONCLUSIONS AND FUTURE WORK

Moving forward, more studies are needed to better understand the impact of switching to partially or entirely virtual PBL. In the current study, it is important to note that while students could choose between an in-person or virtual presentation, the design and execution stages of the project were all performed with students meeting in-person. Because in-person meetups may continue to be more restricted in the near future because of the COVID-19 pandemic, it is equally important to investigate the impact of going virtual for the earlier stages of the project. Additionally, while the impact of the presentation format was evaluated from the perspective of the presenter, further investigations between in-person and virtual presentations should also be made from the perspective of the audience. Because the high school student audience also plays the role of learner, this could reveal additional valuable insights about virtual learning.

This study has demonstrated the versatility of PBL to reflect not only the demands of industry and academia for engineers with global skills but also the changes to the pedagogical environment. The results indicate that videos as a virtual presentation format are suitable for improving engaged-learning outcomes. However, future investigations of other PBL practices are needed to fully maximize the potential of PBL. Elucidating the impact of virtual formats on learning outcomes through the use of surveys and focus groups will allow educators to identify limitations of switching to virtual learning and address deficiencies perceived by students. With a greater understanding of the relationship between PBL practices and engaged-learning outcomes, PBL could be tailored not only to target specific learning outcomes but also to adapt to global technological and social transitions.

■ ASSOCIATED CONTENT

Supporting Information

The Supporting Information is available at https://pubs.acs.org/doi/10.1021/acs.jchemed.0c01033.

Topic selection process, preproject survey, and post-project survey (Figures S1–S3) (PDF, DOCX)

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Notes

The authors declare no competing financial interest.

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