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Engaging Aerospace Students with Experiential Learning in Hybrid Project-based Courses

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Introduction

As the Stanford Aeronautical and Astronautical department's project-based Spacecraft Design Capstone course returned to in-person instruction, elements of online teaching and learning that were introduced in response to the COVID-19 pandemic were retained. The Capstone course is designed to be a final curricular experience within the Aeronautical and Astronautical degree programs. The course is offered as a 'mezzanine' course, open to both undergraduate and graduate Masters students from a range of Major programs within the Stanford School of Engineering, with Aeronautical and Astronautical Engineering being the most common Major.

The nano-satellite (nano- meaning under 10 kg) kits and technology tools were provided to students to help them engage in experiential learning, described by Kolb as hands-on activities requiring the student to take an active role in their learning [1], which increases learning effectiveness [2, 3]. Students do practical activities using legitimate technologies and tools from the aerospace industry to advance their learning, and build a community of practice as defined by Wenger to collaboratively solve a problem [4]; the course's space 'mission' challenge projects. The Capstone course was designed to incorporate experiential learning experiences to promote student engagement, defined as students participating in practical activities to develop their engineering skill competencies, as experiential learning can improve student learning experiences [5] and increase student academic outcomes [6].

Within the Stanford Spacecraft Design Capstone course the technology tools and remote learning kits that have previously been identified as beneficial to student learning in prior case study [7] are now being combined with in-person learning to form a hybrid course. Earlier versions of the Spacecraft Design course (prior to 2019-2020 and COVID-19) were exclusively delivered through in-person instruction, with lectures, small discussion sections with Course Assistants, and a single experiential project led by the course instructor. Students worked on a final project individually, contributing to building a single satellite. While this allowed students the opportunity to develop practical engineering skills, students did not contribute to defining project goals or leading the project, and work occurred exclusively during limited class times.

During the COVID-19 pandemic in 2020-2021, all instruction at Stanford was shifted to remote learning, and the Spacecraft Design course was re-designed to provide practical projects remotely. Students were shipped build-it-yourself nano-satellite kits, such as shown in Figure 1, and were provided with a range of online technology tools used to foster the collaborative project work.

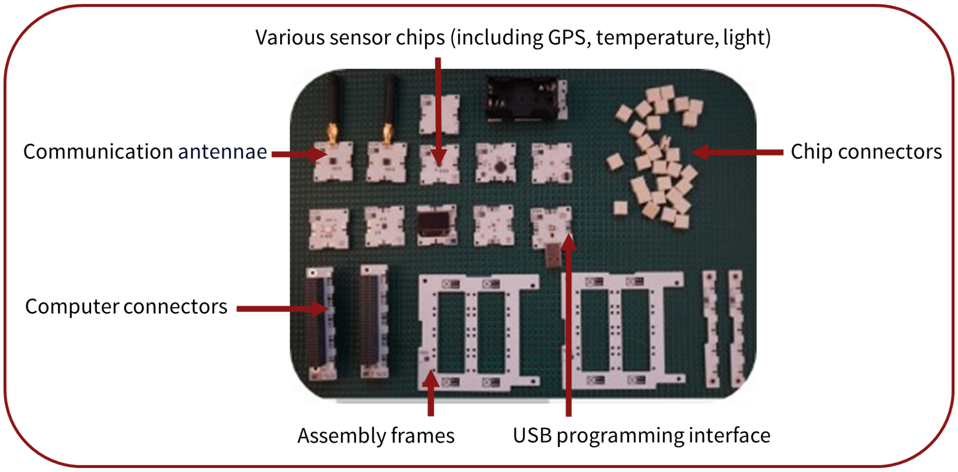

Figure 1: Nano-satellite kit components used within the Stanford Spacecraft Design course, showing various square connectable sensors chips, communication antennae, and connectors.

Each nano-satellite kit contained all the electronic components, 3D-printed component housing, safety equipment, and tools needed for the student to design their own nano-satellite, including a locking box to ensure safety within student homes. This shift to kits and using online technology tools to collaborate online was an opportunity for the department's educational staff and course instructors to work together to entirely *redefine* the practical project; instead of a single instructor-led project, students formed teams and 'pitched' their own project Spacecraft 'missions'. Students then worked individually and in their teams with the nano-satellite kits to design and test solutions involving nano-satellites, and they presented their progress at weekly 'design reviews' and at final team presentations. The kits and technology tools provided students with the opportunity to engage in experiential learning, advancing their knowledge through the experience of using legitimate aerospace industry satellite hardware and software technologies. Working in teams and collaborating with these kits and tools also gave students the opportunity to build a community of practice [4], to collaboratively solve the course's space 'mission' challenges.

As Stanford returned to in-person learning in AY (Academic Year) 2021-2022, the Spacecraft Design course had the opportunity to iterate into a hybrid course, integrating in-person lectures and discussion sections while also retaining the remote technology tools and kits found to be beneficial for students during the AY 2020-2021 remote iteration of the course, as shown in Figure 2. The AY 2021-2022 hybrid iteration of the course began with remote instruction for two weeks, followed by two weeks of in-person instruction, and then moved into a mix of in-person and remote instruction for the remainder of the course. Technology tools and nano-satellite kits were provided to students for use individually, and continued to be used within student teams as instruction shifted to in-person lectures and practical classes.

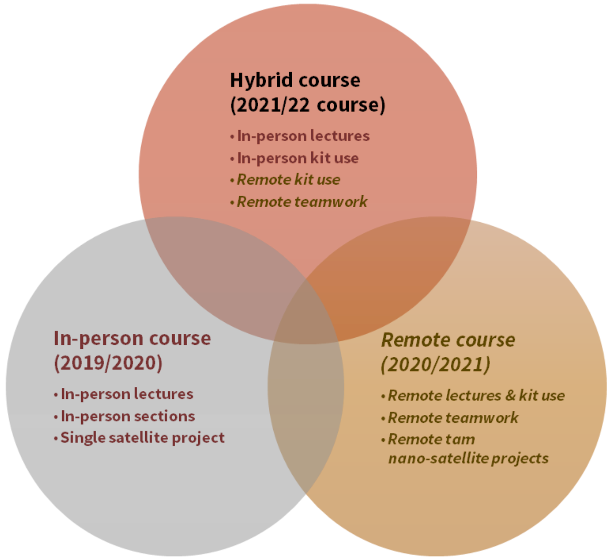

Figure 2: Spacecraft Design remote, in-person, and hybrid course design iterations

This case study describes quality improvements in the evolution of how these kits and tools were used within the Spacecraft Design hybrid course to facilitate students' engagement with experiential learning using hands-on activities [2], and examined their value in supporting students in building a community of practice to work collaboratively to solve technical challenges. Student experiences and perspectives on learning outcomes, between the prior online and the current hybrid course iterations, were evaluated using quantitative and qualitative data sourced from this case study and from previously published studies. To do this, we investigated three key pedagogical questions:

1) *How do the kits and tools engage students in experiential learning in the hybrid course?*
2) *How do the kits and tools support students to build a community of practice in the hybrid course?*
3) *How effective are these compared to the prior online iteration of the courses?*

This case study will be of interest to STEM programs and institutions who are combining remote and in-person learning into hybrid courses, which include experiential learning to engage students. While the findings are not generalizable, the perspectives of students and instructors on the kit and tools improvements within the Spacecraft Design course can be of interest to other educators in learning about the practices that promote positive student learning experiences.

Conceptual framework

To help us answer these pedagogical questions we analyzed the approaches taken in the hybrid course using Puentedura's SAMR (Substitution-Augmentation-Modification-Redefinition) model shown in Figure 3. This model has been used to assess the introduction of new educational technologies [8], and provides a structured way to interpret how the tools and approaches of each iteration had an impact on student learning, to help find improvements to the use of kits and tools.

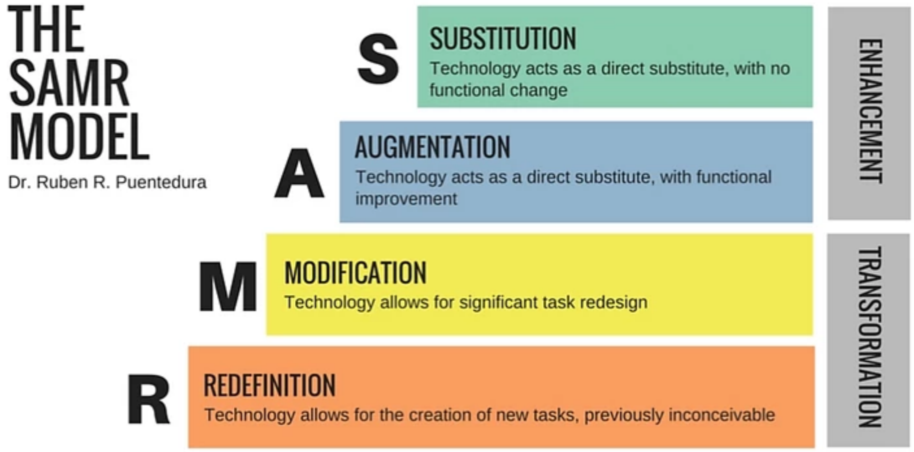

Figure 3: Puentedura's Substitution, Augmentation, Modification, Redefinition model [9]

Prior case study of online Capstone remote course iteration

As part of the prior case study in [7], the previous pre-COVID AY 2020-2021 entirely-online iteration of the Capstone course, SAMR model was used to describe the trajectory of the evolution of the course. This previous entirely-online course iteration showed that students and instructors reported using technology tools, namely Zoom for video-conferencing and Piazza for online discussions, as *substitutions* or *augmentations* of prior in-person learning activities. Instructors viewed the nano-satellite kits as beneficial for student learning, and that implementing these kits required significant *redefinition* of the course assignments [7]. While students valued the kits as an opportunity to engage with experiential learning and to be able to define their own projects, the challenges of assembling, testing and using electronic components entirely remotely proved considerable, with troubleshooting being a serious stressor and barrier to learning for students. Instructional staff addressed these needs during the course by introducing more Zoom sessions with Course Assistants to solve troubleshooting issues. Along with these expert-based communities of practice [10] formed by the students and expert Course Assistants, the prior case study [7] also discovered that students self-formed communities of practice. For example, as students discovered a hardware or software issue with the nano-satellite kit, they would share their problems and self-designed solutions via Piazza, which became a hub for students to share and collectively solve issues with the kits. It should be noted many of these issues were unknown despite extensive testing by the instructional staff prior to the Spacecraft Design course beginning, and the issues were often found to be inherent to the technology and required a 'workaround' solution. Instructors noted this itself was a legitimate facsimile of issues and problem solving activities engineers working in industry face, but also noted that the process was unsustainably time-consuming for instructional staff and impeded student learning.

Hybrid course design and logistics

During the prior years of in-person instruction in the Spacecraft Design course, the learning objectives were fixed, and they focused on the design principles of spacecraft rather than the application and use of them in a 'mission' emulated from the aerospace industry. As the Capstone course shifted to online instruction during COVID, it was an opportunity for the learning objectives to be *redefined*, refocusing them on the use and application of satellite technologies as described in Table 1 below.

Table 1: Spacecraft Design Hybrid Course Learning Objectives

	Learning Objective
1	Synthesize aeronautical and astronautical knowledge and apply it to the design of a spacecraft system
2	Work within a small team to develop and implement a satellite system design
3	Prototype spacecraft systems including mechanical, electrical, and embedded software components

As the course shifted to a hybrid design, the course learning objectives were retained. The objectives 2 and 3, to work in small teams and to prototype spacecraft systems, were achieved through both in-person and remote learning formats that were phased in during the course. The hybrid course was designed to begin with two weeks of remote instruction followed by two weeks of in-person instruction, then transitioned to a hybrid format of both remote and in-person instruction as shown in Figure 4. This course design decision was made to reduce disruption due to the evolving COVID-19 campus restrictions, and the travel and housing challenges that students experienced in returning to campus during the first two weeks of term.

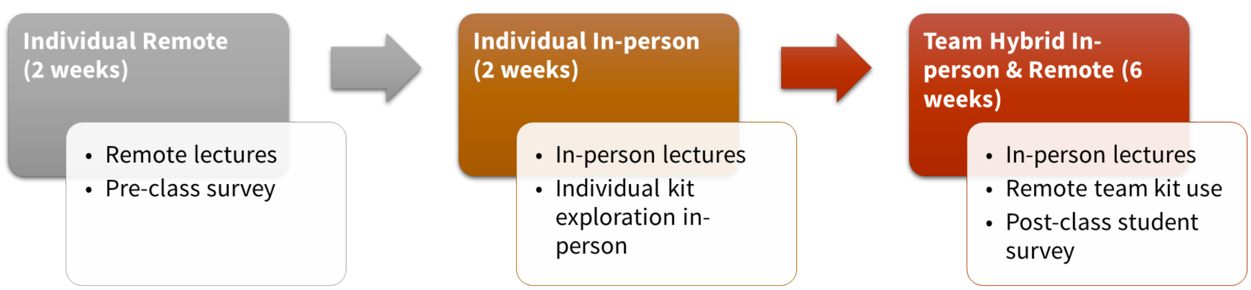

Figure 4: Spacecraft Design AY 2021-2022 hybrid course map

Lectures were held remotely using Zoom conferencing software for the first two weeks of the course, and the nano-satellite kits were distributed to students via outdoor socially distanced collection, or through shipping if students were quarantining or unable to return to the campus. Students were encouraged to explore and play with the kits, and were not given specific assignments or assessed on their progress to encourage students to develop familiarity and confidence with experiential learning. Once in-person instruction began in week three, students worked individually on simple debugging assignments to ensure everyone was able to assemble the basic kit components and verify all the hardware and software was functional. Alongside working individually with their kits, students were also encouraged to engage in groups to explore their project interests, and prepare to form into teams and 'pitch' their team 'mission' to the class, then finally join the team 'mission' they wanted to work on.

As the hybrid instruction began in week five, Course Assistants used Zoom meetings to help students connect hardware correctly and debug software issues, alongside in-person lectures with time for hands-on learning to guide students through correctly setting up the kit hardware and software. Student teams defined the project space 'missions', for example collecting sensor data in an extraterrestrial environment on Mars, and began using the kits both in-person and remotely outside of the classroom. Remote kit use was largely by each student building the component designs and programming code in parallel with their team, so each member of the team could work on the same setup remotely. In the final weeks of the course, teams continued to work remotely and Course Assistants continued to support students with troubleshooting via Zoom, alongside in-person lectures until the final team 'mission presentations' and the course concluded.

Students were encouraged to form communities of practice by working together in teams, to promote participating in the three dimensions of a community of practice as defined by Wenger as [11]; *joint enterprise* of students working on a collaborative team 'mission', *mutual engagement* of students and instructors interacting together while learning, and a *shared repertoire* of tools, language and knowledge. Learning activities, both in-person and online, were designed to foster development of communities of practice. These included dedicated class times for teams to work collaboratively, discussion sessions for teams to connect with instructors and share project progress, team presentations where students were encouraged to give constructive feedback to fellow teams, and use of the Slack messaging platform to collate and share technical information relating to the assembly and troubleshooting of the electronic components. The class assignments included short 'design review' shares where students described the progress made on their projects during these teamwork times and discussions sessions. The dedicated teamwork times in class provided allocated opportunities for students to work together as a team and to engage in *joint enterprise*, and the discussion sessions provided opportunities for students and instructors to engage in *mutual engagement*.

Methods

To complete the aim of identifying best practices of how to engage students in experiential learning and to form a community of practice in hybrid project-based courses, pre-and post-course surveys were completed with the students taking the Capstone course and semi-structured interviews were conducted with the course instructors. The surveys and interviews were designed to discover themes of positive and negative experiences in engaging with experiential learning and in building a community of practice within the hybrid course. The number of students surveyed was limited to the sixteen students representing the entire cohort of Aeronautics and Astronautics undergraduates who opted to take the Capstone course in their Senior year.

The pre-course and post-course student surveys were designed and implemented to explore student experiences with the nano-satellite kits and technology tools, the efficacy of the kits and tools in engaging students in experiential learning, and to explore how students used the kits and tools to build communities of practice. This case study was completed as part of course evaluation and feedback processes, in order to identify improvements to how the course kits and tools were implemented and supported. All processes were completed under the supervision and with the approval of the course instructors. The survey questions, shown in Appendix 1 in Table 2, included open-ended questions to explore students' feedback on the benefits of kits and their value in supporting their learning, and any barriers they experienced in using them. Questions with Likert scale rating for students to rate an item on a 1-to-5 scale [12], were used for determining level of student engagement and measuring students' self-efficacy in developing design, experimentation, analysis and debugging skills with the nano-satellite kit. The survey also included a statement that the survey was not connected to the grades or assessments within the course, to encourage students to participate fully in the survey and to express honest feedback.

The instructor interviews were designed and implemented to identify how the instructors integrated technology tools and kits into their course during the in-person and remote phases of the course, and to explore effective use of them in the hybrid course setting. Interviews were conducted remotely via Zoom, using a semi-structured interview protocol with standardized open-ended questions [13]. The set of structured questions are listed in Table 3 in Appendix 1. The instructor interviews were recorded with the subjects' permission, so the videos could then be transcribed to text for analysis. References within transcriptions to the interview participants' individual identities were removed before analysis to ensure confidentiality. One interviewee was the instructor of record, a Stanford Aeronautical and Astronautical alumnus with prior experience of the Capstone course, who also designed the course syllabus and learning objectives and implemented the weekly lectures. The other two interviewees were Course Assistants, graduate-level students in the Aeronautical and Astronautical department responsible for leading discussion sessions and troubleshooting via Zoom.

Quantitative data from the student surveys, including Likert scale rating questions on student engagement level and self-efficacy in engineering skills, were analyzed to compare the responses between the pre- and post-course surveys. To explore the effectiveness of the approach of using kits and technology tools to engage students in the Spacecraft Design Capstone course and to support skill development, the resulting findings about the themes of the student surveys and instructor interviews in the hybrid course format were compared to the prior online-only iteration of the course. To accomplish this, the themes found from the analysis were first evaluated with Puentedura's SAMR framework, and then compared to prior results from the past online course iteration [7], with the aim of identifying best practices for hybrid project-based courses.

To explore the qualitative text data collected from instructor interviews and student surveys, a qualitative analysis method of emergent coding [14] was used to identify the common responses. A primary coding cycle was used to identify common keywords, and to create a codebook [15] which was used to analyze the interviews in a secondary coding cycle. This gathered common codes and themes [16], used to explore themes of positive and negative experiences engaging with experiential learning and building a community of practice within the hybrid course.

Results

The survey was offered to the Capstone class cohort of sixteen students, which included the entire cohort of five Aeronautics and Astronautics undergraduate program taking the final

Capstone course in their Senior year, plus eleven Masters students taking the course as an optional class in their graduate Aeronautics and Astronautics program. Ten students completed the pre-course survey, with one additional student completed the post-course survey totaling eleven.

Surveying students' reported self-efficacy at engineering skills pre- and post-course helped explore the impact of experiential learning using the kits, with students rating their confidence at a set of engineering skills they used to:

- Conduct experiments, build prototypes, or manipulate equipment to develop or evaluate a design
- Analyze the operation or functional performance of individual components
- Analyze the operation or functional performance of a complete system
- Design a new sub-system or component to meet specified requirements
- Develop and integrate electronic components to build a complete system or product
- Troubleshoot hardware or software technical problem

This set of engineering skills was used to measure students ability to use them to apply their engineering knowledge to complete learning tasks within the course. Assessing the Capstone students' development of these skills, by measuring them pre- and post-course, was important to explore if engaging in experiential learning with the kits and technology tools resulted in an increase in these skills. Past research has found students' self-efficacy in using them increases student confidence in their engineering skills, better prepares them to become practicing engineering professionals, and results in higher outcome expectations by students of their future engineering careers [17, 18, 19]. Ten students completed the pre-course survey in Figure 5. One additional student completed the post-course survey in Figure 6, totaling 11.

The pre-course survey results in Figure 5 below show that all students were '*Very confident*' or '*Somewhat Confident*' at conducting experiments and building prototypes etc, but students' confidence was lower for analyzing and designing systems and subsystems. Developing electronic components to build a complete system was students' least confident skill with 5 of 10 (50%) reporting '*Somewhat Unconfident*' or '*Very Unconfident*'. Students' second least confident skill was Troubleshooting, with 3 of 10 (~30%) of students '*Neither Confident or Unconfident*' or '*Somewhat Unconfident*', and 1 of 10 (~10%) '*Very Unconfident*'. This means that prior to the course, students were confident about remembering and applying knowledge developed during their prior classes to conduct experiments, but were less confident about using their knowledge and skills to develop and debug electronic systems.

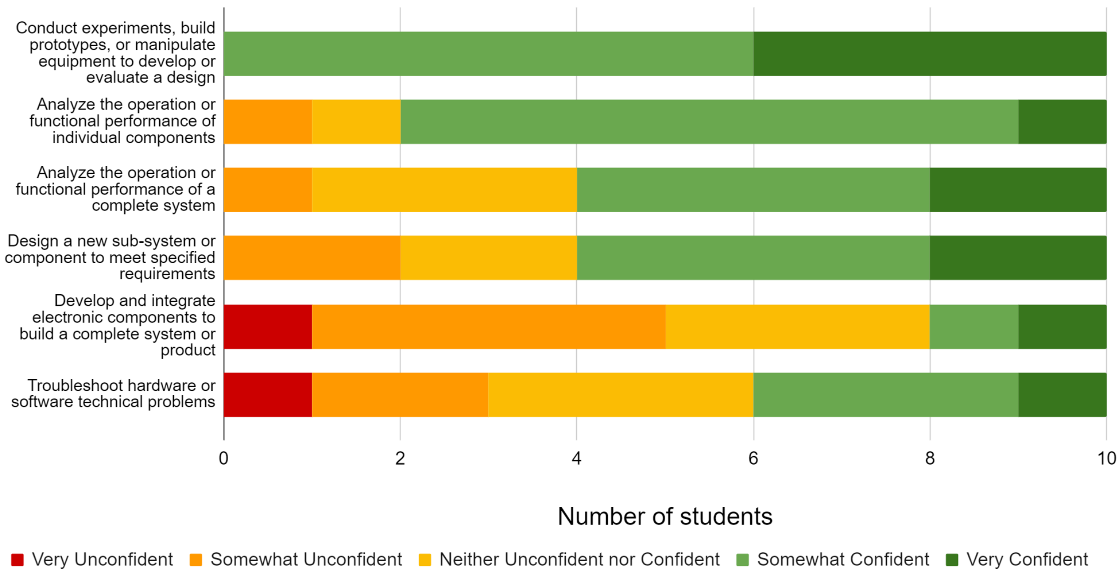

Figure 5: Results of the pre-course survey of students' self-efficacy in engineering skills

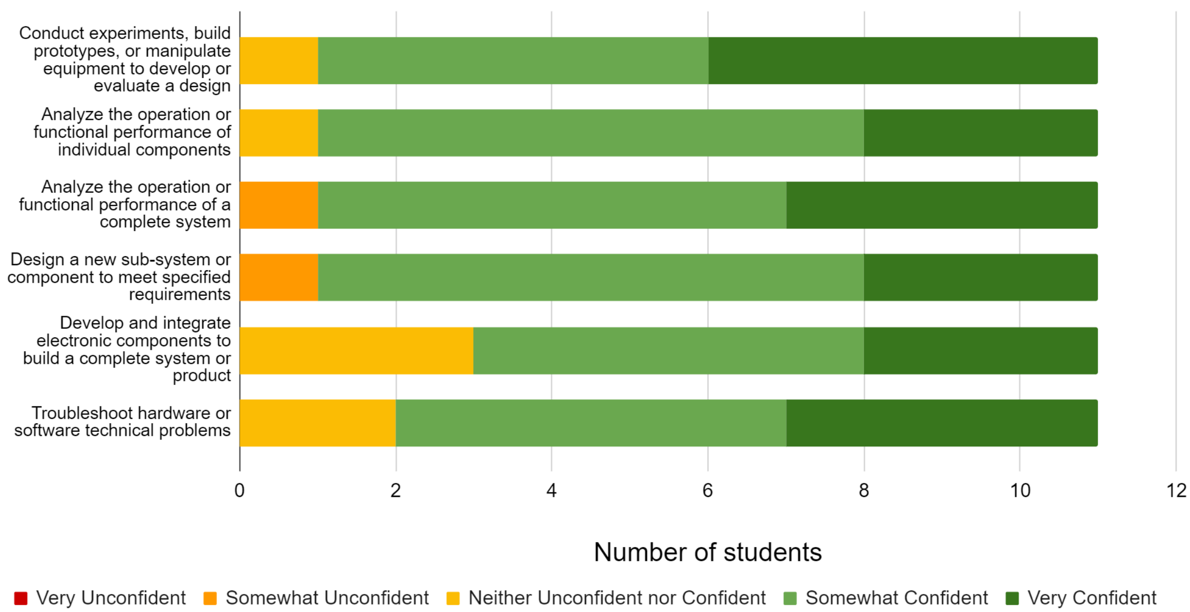

Figure 6: Results of the post-course survey of students' self-efficacy in engineering skills

The post-course survey results in Figure 5 above show that in all but one of the skill categories, students rated their self-efficacy at engineering skills higher, compared to the pre-course survey. This means that the majority of students had increased their confidence in their engineering skills, with 90% of the students becoming either '*Very confident*' or '*Somewhat Confident*' across all the surveyed engineering skills. This suggests that students' use of the kits increased their confidence in their engineering skills. The most gains in self-rated efficacy at engineering skills are seen in developing and integrating electronic components into a complete system, with the pre-course survey showing only 2 of 10 (20%) students being either '*Somewhat Confident*' or '*Very Confident*', which increased substantially in the post-course survey to 8 of 11 (~70%). This reflects the role of the kit in helping students to build skills in designing, analyzing and testing electrical components and integrating them to build a nano-satellite system that would achieve their project 'mission' goals. Gains in students' confidence were also seen in the skill of troubleshooting, with the pre-course survey showing 4 of 10 (40%) of students being either '*Somewhat Confident*' or '*Very Confident*', which increased to 9 of 11 (~80%) in the post-course survey. The small decrease in the number of students' level of confidence at conducting experiments and building prototypes etc, was identified as being due to the one additional student responding to the post-course survey than the pre-course survey, to total 11 respondents.

To gauge students' level of experience with the nano-satellite kits, students self-rated their level pre- and post-course. Pre-course, students fitted into two broad categories; '*beginner*' and '*competent*' as shown in Figure 8. Anecdotal notes by instructors linked students with higher competency level to having taken prior Electrical Engineering major courses which featured practical use of electronic components and systems.

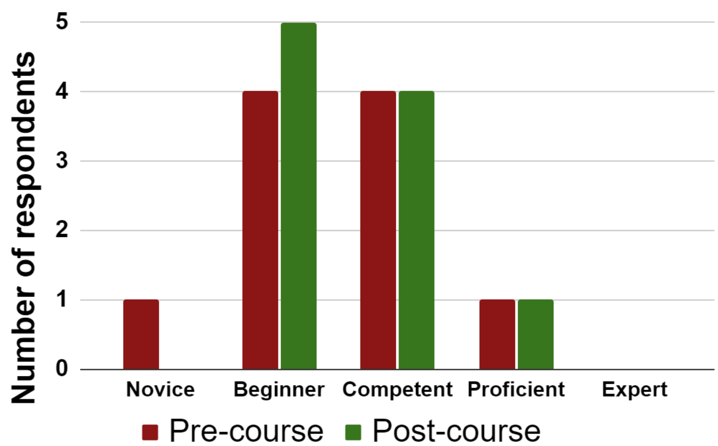

Figure 7: Students' self-rated pre- and post-course level of experience with the electronics-based nano-satellite kit

Interestingly, the post-course survey showed that students did not rate themselves as becoming more experienced with the kits, after using them during the course. Students' lack of change in self-rated experience level could suggest that they did not feel they gained enough proficiency with kits during the course. However, as students also reported a positive increase in their self-assessed efficacy at a range of engineering skills as explored above, the lack of increase in experience level with kits instead suggests that students found the course was not long enough to become accustomed to using the kits. This was supported by students' open-ended feedback on identifying barriers to their learning as needing "*more time*" to use the kit, and the instructors' feedback that the kit's complexity made it challenging for students to use them. As part of the survey, students were also invited to share their self-perception of having an identity as an "Engineer". As developing an identity as an "Engineer" is a key part of retaining students in their chosen STEM field [20], use of the kits should not diminish students' perception of themselves as Engineers, even if the kits prove technically challenging to master. Pre-course, students strongly identified as being an "Engineer", with 7 of 10 (70% identifying themselves on a Likert scale as '*5 - A lot*', and a further 2 of 10 (20%) identifying as '*4 - Strongly*'. Post-course, the distribution of responses remained constant. This indicates that students already identified as being an "Engineer" irrespective of their initial or final level of proficiency with the kits, which fits with the capstone course being a final step in the undergraduates' and graduates' programs.

Discussion

The self-efficacy survey findings suggest that students increased their engineering skills while using the kits to complete their space 'missions', which was also reflected by the student teams' final presentations successfully demonstrating their completed nano-satellite systems operation and capabilities. To further understand the findings, word clouds (Figure 8) were created from students' responses to the open-ended survey questions in order to get a general impression of how students felt the kits and tools engaged them in their learning experiences.

Figure 8: Pre-course (left) and post-course (right) word cloud of student responses to the question "How do you think the nano-satellite kit will support/supported your learning?"

The pre-course word cloud on the left in Figure 8 shows students' survey responses to asking how they felt the kit would support their learning, with the increasing size of the word corresponding to increasing word frequency in student responses. Student responses centered around thinking and applying their knowledge, and practical work with the kit hardware. Students clearly connected using the kit's "*components*" to "*learn*", with a focus on the value of the kits' components in "*thinking*" about and "*understanding theoretical material*", through "*seeing*" and "*building*" with "*practical*", "*hands-on cubesats*". Students also shared a focus on "*play*", suggesting students positively viewed the opportunity to use the kits to engage in experiential learning. The post-course word cloud on the right in Figure 8 shows that students shared fewer responses and less variation compared to the pre-course cloud. The equal size of the majority of keywords in the post-course cloud means that students had more homogenous post-course responses, which were focused on their increased "*understanding of electronics hardware*". Students focused on using one particular component, a "*feather*" circuit board which is a key part of the electronics kit, and focused less on the role of the kit in their learning in comparison to the pre-course keywords. Students again focused on the use of the kits for experiential learning with keywords such as "*hands on work*".

The survey's open-ended questions related to how kits supported students' learning were also aimed at understanding the role of kits and tools in supporting students' collaborative work, by forming communities of practice. Students' feedback was analyzed to identify students' creation of Wenger's three dimensions of community of practice; *joint enterprise*, *mutual engagement*, and a *shared repertoire*. Both the impressions of pre- and post-course feedback seen in Figure 8 had no keywords related to teamwork or collaboration, with the majority of keywords instead relating to experiential learning using the kits' components. However, instructors' shares noted that students were using the kits in teams, both during in-person class time and during remote discussion sessions. For example, when students needed help troubleshooting a hardware issue, they first worked collaboratively to solve the problem, then would seek the help of instructors. This suggests that students used kits within a student-based community of practice, engaging in *joint enterprise* and *mutual engagement* both in-person and remotely in the hybrid course.

When students needed help with practical activities while using the kits, the hybrid design of the course gave them the opportunity to connect with instructors online or in person. The pre-course survey indicated around half of students planned to use Zoom and Slack to do so, alongside all responses noting the expected use of email, the Canvas learning management system, and GoogleDrive which housed technical guides to the kits. The post-course survey showed the majority of students in fact chose to use Slack, an instant messaging platform, as the main tool they used to ask for help while using the kits. The word cloud in Figure 9 below shows students' post-course responses to what tools they actually used to support their learning, with the increasing size of the word corresponding to the increasing word frequency. Anecdotal evidence from instructors highlighted students' choice of Slack as being due to its immediacy, which allowed students to receive help quickly at the time they encountered issues while using the kit, rather than waiting for an email reply or waiting to ask during in-person class time. This suggests students were connecting to the instructors' expert *shared repertoire* of communal knowledge resources to help them to use the kits effectively. Anecdotal shares by instructors also noted the value ofscaffolding tasks involving the kits, providing step-by-step guides to help students with assembling and programming the complex electronics of the kit. Scaffolding has been found to help students shift towards developing their own understanding and skills during the early stages of learning [21], and instructors' feedback also noted how scaffolding helped engage students at their individual level of experience due joining the course from a range of programs of study.

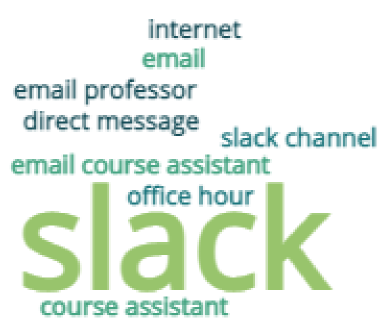

Figure 9: Post-survey word cloud of responses on how tools supported experiential learning

Using the SAMR framework to interpret the changes occurring from the Spacecraft Design hybrid iteration, the technology tools were used as *substitutions* or *augmentations*. Zoom was used as a *substitute* for in-person time with instructors, particularly for troubleshooting, and Slack was used as an *augmentation*, replacing in-person questions or email with the functional improvement on the immediacy of the messaging platform to get help rather than waiting for structured class times. The prior SAMR analysis of the previous online iteration of the class published in [7], also found tools were used as *substitutions* or *augmentations*. Since students continue to use both online and in-person ways to engage with the course and the instructors in the hybrid format, future iterations of the course can support student engagement by continuing to offer tools that provide multiple ways for students to connect. During the hybrid course iteration, teams used the kits as *modifications*, redesigning the tasks needed and reconfiguring the kits' components to complete their project space 'missions'. The kits enabled the learning activities to be tailored to each teams' different level of experience as undergraduate or graduate students, and their teams' specific project goals, without requiring significant time or resources from the instructors. The prior online iteration of the class had found the introduction of kits *redefine* the tasks, which were then continued to be developed in the hybrid course iteration but with a lesser degree of change. Including kits in future course iterations can continue to help students have projects tailored to their level of expertise and interests, which helps students be engaged in experiential learning. Overall, comparing the most recent hybrid iteration of the course in AY 2021-2022 and the prior AY 2020-2021 online iteration, students continued to engage with experiential learning through using the kits and tools to solve the space 'mission' challenges they chose to design solutions for.

Limitations

The size of the Capstone course enrollment at 16 students limited the number of surveys that could be completed. This was due to the small size of the Aeronautics and Astronautics undergraduate program, a newer program only inaugurated in 2017, which feeds into the Capstone course. A greater number of survey responses would provide more opportunity to analyze the significance of the results. However the results were still useful in helping the teaching team understand the overall focus by students in their learning experiences, and how the kits and tools helped engage student learning in a hybrid course.

Further case studies would give the opportunity to continue to explore students' experiences in using kits and tools, as the case study describes students' generalized impressions which can inform where to follow up for further work. While the findings of this case study are pertinent to the Stanford Spacecraft Design course and not widely generalizable, COVID-19 catalyzed the need for novel ways to engage students through the evolution of the use of kits and tools. Further exploring the value of these kits, and how they are used by students in varying circumstances and capacities, can help inform how students can best be supported in their experiential learning. This case study's findings could be built upon with a formal research effort investigating equitable use students' use of kits and tools, for example understanding students' decisions in choosing to use the kits in class or at their homes, or how kits and tools could support students with additional needs that prevent them from attending in-person classes.

Implications and Directions for Future Research

In this case study, we sought to explore the value that nano-satellite kits and learning technologies and tools offered in the latest hybrid iteration of the Stanford Spacecraft Design Capstone course, and how they helped students engage in experiential learning and to connect to communities of practice. In this study we set out to answer the questions:

1) *How do the kits and tools engage students in experiential learning in the hybrid course?*
2) *How do the kits and tools support students to build a community of practice in the hybrid course?*
3) *How effective are these compared to the prior online iteration of the courses?*

Through exploring student experiences and perceived self-efficacy in a range of engineering skills, after using the kits during the course the majority of students had increased their confidence in their engineering skills, with most gains seen in developing and integrating electronic components into a complete system, and troubleshooting. Students' survey responses to asking how they felt the kit would support their learning centered around applying their knowledge and practical work with the kit hardware. Instructors' shares noted that student teams used kits both during in-person class time and remotely, suggesting that students were connecting to student-based communities of practice, engaging in *joint enterprise* and *mutual engagement*. Student teams used the kits to *modify* tasks, redesigning the tasks needed and reconfiguring the kits' components to complete their project space 'missions'. Kits were used by teams both in-person and remotely, which enabled the students to complete learning activities in groups outside of structured class times, supporting the formation of student communities of practice to build spacecraft systems. Including kits in future course iterations can continue to help students have projects tailored to their level of expertise and interests, which helps students be engaged in experiential learning. Scaffolding tasks involving the kits included step-by-step guides to help students with assembling and programming the complex electronics. Providing access to this *shared repertoire* of knowledge and resources needed to solve technical issues created by both instructors and students. When students needed help with the kits, the hybrid design of the course gave them the opportunity to connect with instructors online or in person. Zoom was used as a *substitute* for in-person time with instructors, particularly for troubleshooting, and students used Slack as the preferred method of connecting to the instructors' expert community of practice Slack was used as an *augmentation*, replacing in-person questions or email, with functional improvement on the immediacy of the messaging platform to get help rather than waiting for structured class times or asynchronous communications like email. and Slack was used as an *augmentation*, with the functional improvement on the immediacy of the messaging platform to get help rather than waiting for structured class times or asynchronous communications like email.

Compared to the prior entirely online iteration of the Capstone course, the new hybrid format proved beneficial, being more effective in providing students with a combination of ways to engage in experiential learning. Building in structured times for students to use kits in-person and remotely, helped build communities of practice for students teams and instructors to work together to solve problems. Future iterations of the course should continue offering technology tools, and continue to develop the hybrid course format to provide students with opportunities to form communities of practice and engage in experiential learning. Both the kits and tools seemed effective in engaging students in experiential learning in a hybrid course format, and future iterations of the course can support student engagement by continuing to offer tools that provide multiple ways for students to connect together in teams and to instructors. Future case studies could give the opportunity to continue to further explore students' experiences in using kits and tools, and how they are used by students in varying circumstances and capacities to support them in experiential learning.

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Appendix 1 - Pre-course & post-course student survey questionnaire

Table 2: Pre-/Post-course student survey questions

<table>
<tr><th>Number</th><th>Question</th><th>Answer type</th><th>Options</th></tr>
<tr><td>1</td><td>Class?</td><td>Radio button</td><td>Aeronautical and Astronautical 136A or Aeronautical and Astronautical 236A</td></tr>
<tr><td>2</td><td>Year?</td><td>Radio button</td><td>Freshman, Sophomore, Junior, Senior, Graduate - Masters, Graduate - PhD</td></tr>
<tr><td>3</td><td>Major?</td><td colspan="2">Open-ended text field</td></tr>
<tr><td>4</td><td>Select any of the following affinity groups which you feel you identify with: (Check all that apply</td><td>Multiple selection</td><td>Black / African American, Chicano / Latin, Indigenous / Native American / Native Alaskan, Pacific Island, LGBTQA+, Male, Female, Gender non-binary / Gender fluid, Person with a disability, Non-traditional background, Other</td></tr>
<tr><td>5</td><td>How much do you identify as an "Engineer"?</td><td>Likert scale</td><td>1 (Not at all) to 5 (A lot)</td></tr>
<tr><td>6</td><td>Which is your preferred learning style? (Check all that apply)</td><td>Multiple selection</td><td>Auditory, Practical, Visual</td></tr>
<tr><td>7</td><td>How confident are you in your ability to do each of the following at this time?</td><td>Likert scale for each statement</td><td>1 (Very Unconfident) to 5 (Very confident) for:
● Conduct experiments, build prototypes, or manipulate equipment to develop or evaluate a design
● Analyze the operation or functional performance of individual components’
● Analyze the operation or functional performance of a complete system’
● Design a new sub-system or component to meet specified requirements
● Develop and integrate electronic components to build a complete system or product’</td></tr>
</table>

			• Troubleshoot hardware or software technical problems
8	How confident do you feel in your understanding at each of the following at this time?	Likert scale for each statement	1 (Very Unconfident) to 5 (Very confident) for: • Synthesize material from prior courses and apply it to the design of a spacecraft system • Work within a small team to develop and implement a system design' • Prototype spacecraft systems including mechanical, electrical, and embedded software components
9	How excited do you feel with the course so far?	Likert scale	1 (Not excited at all) to 5 (Very excited!)
10	When learning IN-PERSON / IN CLASS, which technology tools do/did you use? (Check all that apply)	Multiple selection	Zoom, Canvas, Google Drive, Piazza, Slack, Email, Phone, Other.
11	When learning REMOTELY, which technology tools do/did you use? (Check all that apply)	Multiple selection	Zoom, Canvas, Google Drive, Piazza, Slack, Email, Phone, Other.
12	What worries, concerns or barriers do you have about those learning technologies?	Open-ended text field	
13	How would you describe your current level of experience with the kit components in the kit?	Radio button	Novice, Beginner, Competent, Proficient, Expert
14	How excited are you about using the kit?	Likert scale	1 (Not excited at all) to 5 (Very excited!)
15	How do you think the nano-satellite kit will	Open-ended text field	

	support/supported your learning?		
16	What worries, concerns or barriers do/did you have about using the nano-satellite kit?	Open-ended text field	
17	When working REMOTELY, how will/did you troubleshoot issues?	Open-ended text field	
18	Would you recommend including a kit for future courses?	Radio button	Yes, No
19	Is there anything else you would like to share?	Open-ended text field	

Table 3: Instructor Interview Questions and SAMR Association

SAMR Association	**Instructor Interview Questions**
Substitution	Question 1: What was included in the kit you sent to students? Question 11: Which learning technologies did you use in the course? Question 12: How did you find the learning technologies to be useful? Question 17: If anyone who did you work or collaborate with related to planning and using learning?
Augmentation	Question 7: Did you have worries or concerns using kits in the course? Question 3: What challenges did you have with the kits? Question 14: Did you have worries or concerns about using learning technologies in your course? Question 13: What challenges did you have with the learning technologies?
Modification	Question 4: Did you adapt your learning objectives for the hybrid course design? And if so, how? Question 5: Did you adapt your assignments for the use of kits? And if so, how?
Redefinition	Question 9: Will you continue to use kits in the class?

	Question 18: Which learning technologies will you continue to use in future courses? Question 16: If you taught this course previously, not in a remote learning environment, how did it differ?
Other / Mixed	Question 8: How did students work together in the class? Question 15: How did you seek feedback from students on their experiences with the learning? Question 10: Did anything surprise you related to using kits in the course? Question 19: Did anything surprise you related to the learning technologies in the course? Question 20: Is there anything else you would like to mention related to learning technologies or kits?