Engaging Graduate Students as Co-creators of Educational Modules on an Interdisciplinary Topic

Abstract

Co-creation in higher education is the process where students collaborate with instructors in designing the curriculum and associated educational material. This can take place in different scenarios, such as integrating co-creation into an ongoing course, modifying a previously taken course, or while creating a new course. In this Work-In-Progress, we investigate training and formative assessment models for preparing graduate students in engineering to participate as co-creators of educational material on an interdisciplinary topic. The topic of cyber-physical systems engineering and product lifecycle management with application to structural health monitoring is considered in this co-creation project. This entails not only topics from different disciplines of civil, computer, electrical and environmental engineering, business, and information sciences, but also humanistic issues of sustainability, environment, ethical and legal concerns in data-driven decision-making that support the control of cyber-physical systems.

Aside from the objective of creating modules accessible to students with different levels of disciplinary knowledge, the goal of this research is to investigate if the co-creation process and the resulting modules also promote interest and engagement in interdisciplinary research. A literature survey of effective training approaches for co-creation and associated educational theories is summarized. For students, essential training components include providing (i) opportunities to align their interests, knowledge, skills, and values with the topic presented; (ii) experiential learning on the topic to help develop and enhance critical thinking and question posing skills, and (iii) safe spaces to reflect, voice their opinions, concerns, and suggestions. In this research we investigate the adaption of project-based learning (PjBL) strategies and practices to support (i) and (ii) and focus groups for participatory action research (PAR) as safe spaces for reflection, feedback, and action in item (iii). The co-creation process is assessed through qualitative analysis of data collected through the PjBL activities and PAR focus groups and other qualitative data (i.e., focus group transcripts, interview transcripts, project materials, fieldnotes, etc.). The eventual outcome of the co-creation process will be an on-line course module that is designed to be integrated in existing engineering graduate and undergraduate courses at four different institutions, which includes two state universities and two that are historically black colleges and universities.

1.0 Motivation

This research investigates novel approaches to engage students in better understanding the challenges brought about by new technologies such as cyber-physical systems (CPS) and practices such as product lifecycle management (PLM) that aim to integrate environmental sustainability, ethical use of data and other societal factors throughout the lifecycle of a system or product. The goal is to produce insightful educational modules on these topics that can be integrated into existing undergraduate courses so that students acquire a broad understanding of potential research and career pathways in these emerging fields. These applications may also motivate students to better assimilate, gain and retain foundational knowledge in fundamental principles taught in core engineering courses. The design of CPS and PLM involves multiple disciplines across the fields of engineering, computer science, business, health sciences, and ethics that in a conventional educational curriculum would require students complete a series of pre-requisite courses to enroll in a higher-level graduate course on CPS. However, these topics by their very interdisciplinary nature can serve as motivating examples for students with varied backgrounds and interests to engage in early in their educational pathways. This motivates our desire to develop a new educational model that is not only student-centered but also serves the immediate and future needs of the employers in diverse sectors that are building cyber-physical systems with attention to their lifecycle management [1] [2] [3] [4].

The educational model explored in this research includes project-based learning (PjBL) [5] for the students involved in this project and the co-creation of educational modules by teams of graduate and undergraduate students, faculty, researchers, and external partners that include experts from industry. The PjBL approach is particularly suited for first-year graduate students who are embarking on a research program and acquiring research skills in distilling a problem, observing a related phenomenon, asking pertinent questions, and building experiments and models to describe the phenomenon. The co-creation process further promotes the communication skills of students as they work to both acquire needed information from faculty and external partners and write descriptive modules that are accessible to a broad audience.

Section 2.0 reviews some of the key literature that provides the rationale for the selected educational model. Section 3.0 outlines the recruiting, participant demographics, and the technical overview of the project design. In Section 4.0, the methods applied for formative assessment of the project are presented. Section 5.0 outlines the direction for future research in the next phase of this project.

2.0 Rationale: Pedagogical Theory and Co-Creation

Despite implementation of new educational practices such as "flipped" classrooms [6, 7] and innovative teamwork projects [8] [9], some engineering students continue to be taught in the traditional lecture-lab format that prioritizes teacher authority and student compliance. In this traditional approach, students are viewed as consumers of content rather than partners in learning [10]. This approach has been criticized by Paulo Freire as a "banking concept" of education, where ". . . knowledge is a gift bestowed by those who consider themselves knowledgeable upon those whom they consider to know nothing" [11]. In contrast, Freire proposes student-teacher partnerships and "problem-posing" education wherein the "teacher-student contradiction (is) resolved" through dialogue and mutual engagement [11].

In her book, *Teaching to Transgress,* bell hooks discusses the impact of Freirean ideas on her own educational theories, especially Freire's idea that education should involve the practice of freedom rather than the reinforcement of power hierarchies. In her words, "the classroom should be a space where we're all in power in different ways" [12] . To accomplish this transformation, ". . . we have to challenge and change the way everyone thinks about the pedagogical process. This is especially true for students. Before we try to engage them in a dialectical discussion of ideas that is mutual, we need to teach about process." [12].

Multiple scholars have argued for educational models that more directly involve students in the creation of knowledge, scholarly works, and curricula (cf. [13]; [14]; [10]). In addition to the limits of the traditional lecture-lab format as promoting a banking model and reinforcing power hierarchies, this format also emphasizes a focus on memorization of content that reduces student engagement, understanding, and retention in STEM fields [15]. Active learning techniques, including class discussion and problem-solving, have been shown to boost student understanding of STEM concepts beyond traditional lecture [16]. However, some of these so-called "active learning" interventions still were fairly low-involvement techniques, such as using a personal response system or completing a worksheet [16]. As mentioned above, there has been a push for greater student involvement in their own learning through flipped classrooms [6], [7] and a team-based focus [8], [9]. Our focus is on co-creation, a learning technique that has taken different forms depending on its application. Sometimes, co-creation is an alternative term for "student voice," in which students provide feedback on what they learned, and this feedback shapes curricular decisions [17], [18]. In contrast, our work focuses on a partnership model of co-creation.

According to [10], co-creation via partnership is defined as all parties being actively engaged in collaboration and standing to gain from the collaboration. In some partnership models, students and faculty work together to address pedagogical concerns [19]. However, in our project, co-creation teams of undergraduates, graduate students, faculty and industry mentors will work together to create a learning module for undergraduate students in an introductory engineering class. Levels of technical expertise differ significantly in these groups, but this can benefit student learning by allowing for growth within students' zones of proximal development [20], a concept from sociocultural theory that suggests that, in this case, group members with advanced knowledge can help scaffold the learning of the students through collaboration [21]. Further, explicit in our design is the idea that students are not "depositories" but bring experiential knowledge of their own to this process that is critical for the success of the co-created learning module. For example, because they have recently taken introductory engineering classes, some students have personal experience with learning that allows them to critique how materials are presented and explained in these courses. Gen-Z students also have firsthand knowledge regarding how students in their generation are most likely to react to various teaching approaches. By asking questions and bringing "beginner's minds" to the co-creation team, students may stimulate dialogue and the formulation of new ideas that would have been unlikely if only seasoned "experts" were creating the learning module. In the words of Shunryu Suzuki, "In the beginner's mind there are many possibilities, but in the expert's there are few" [22]. The concept of beginner's mind is associated with openness and curiosity, as well as an ability to see with fresh eyes—all of which may also encourage divergent, "out-of-the-box" thinking [23].

Co-creation, as a form of collaborative learning, can have multiple benefits for the partners who are involved. Hmelo-Silver and Chinn [21] note that benefits of collaborative learning include increased knowledge gain due to elaborative processing of material, which promotes deep learning. Students who take part in co-creation report greater academic engagement and feelings of belonging [13], [19]. Faculty also report increased engagement, as well as improved teaching and classroom experiences [10]. For practitioners from industry, the opportunity to become engaged in an academic pursuit with students can result in reflection on new ways to communicate their practices to an audience unfamiliar with the broader goals and objectives of the people and company they typically work with.

Yet, because students, faculty, and industry experts may be used to more traditional expert-novice power relationships, working as partners in a co-creation team brings many initial challenges that may be experienced differently for each person. Authors in [13] [24] report that faculty are concerned about meeting professional requirements, relinquishing pedagogical responsibilities, and navigating institutional structures and norms and in [24] it is suggested that students may resist co-creation in traditional classroom settings because they are worried that there will not be enough support for their learning. Several practices known to enhance collaborative learning [21] can be applied to overcome these initial challenges, such as applying cognitive strategies like elaboration and monitoring understanding, and implementing social strategies such as ensuring balanced participation.

3.0 Methods

This section outlines the participants, recruiting and research methods implemented in this study. Two state universities, University of Massachusetts Lowell (UML) and University of Massachusetts Dartmouth (UMD) and two HBCUs, the University of the District of Columbia (UDC) and North Carolina A&T State University (NCAT) are collaborating on this research. All four are PhD granting institutions.

3.1 Recruiting and Participant Demographics

Once approval for this project was obtained from the lead institutional review board (IRB) at UML, students, faculty, and external experts were recruited to participate through online information sessions and personal outreach from the research team. Following the IRB and funding sponsor guidelines, participants are not being paid for their participation. Students are also not receiving course credit, so members of the research team who are professors are not responsible for grading these students, to avoid conflict of interest. Participants in the co-creation project were also given the option of participating in the ongoing research and assessment of the co-creation process or declining to participate in this component of the project.

Students, faculty, and external partners who agreed to participate in research/assessment data collection activities included four graduate students, four undergraduate students (including three from UML and one from UDC), four professors (three faculty members at UML and one from UDC), two industry professionals and a post-doctoral research practitioner at another academic institution. The four graduate students are all UML students and include three women (one South Asian/Arab, one Southeast Asian, one South Asian/British) and one South Asian man. Three of the graduate students are studying Electrical/Computer Engineering and one is studying Biomedical engineering. Among the undergraduates, the UDC student is studying Mechanical Engineering, and two of the UML students are studying electrical engineering and one is studying civil engineering. Two of the undergraduates are women (one is a White American of European descent, one is African American) and two are men. One of the men is Jamaican of Asian descent (Korean and Filipino) and the other is African American.

The four faculty members include two electrical and computer engineering professors at UML (one South Asian woman and one African American man), one business professor at UML who is a White woman, and one Mechanical Engineering professor at UDC who is an African American man. The two experts engaged in this effort are a White woman who is a consulting engineer from the General Electric Aviation Company and has trained employees in PLM practices, and a South Asian/White woman who is a post-doctoral research fellow with a PhD in environmental and occupational health sciences, implementing a community wide air-pollution monitoring system and assessing the resulting data on community impacts. These two experts will be referred as external partners in the research.

3.2 Research Methods

The research described in this paper addresses the first phase of a larger project that involves two phases. This project seeks to design and test innovative graduate education models. The goal of the first phase is for students to embark on a cyber-physical systems (CPS) or product lifecycle management (PLM) topic and in partnership with experts and faculty mentors develop two online educational modules that describe an application-oriented view of CPS and PLM. In the second phase of this research, these modules will be integrated in existing undergraduate or first-year graduate courses at four different institutions (2 SUs and 2 HBCUs). This will be followed by an assessment of how students learn from the co-created material and an associated experiment that demonstrates key concepts of the CPS.

Eight students were recruited and divided into two teams, one charged to co-create the CPS-related module and the other to develop the PLM-related module. The project requirements for both teams were for graduate students to exhibit initiative, leadership, teamwork and communication skills while following the PjBL stages and complete the final product of completing two publications on the CPS and PLM topics.

The CPS team consisted of three graduate students and one undergraduate student who is a senior, graduating this semester. The PLM team consisted of two graduate students, a senior undergraduate and a junior undergraduate student. The focus of this study is on training graduate students to take on participatory roles in leading education and research initiatives, and in this context their interaction in guiding undergraduate students has been important. All of these students were participants in the research groups of four engineering faculty mentors engaged in this project.

For both teams, the project began with a faculty mentor presenting a simple physical system and its dynamics and asking the teams to explore the reasons for its behavior and further understand how the system dynamics may be measured. The physical system was a tape-measure that was fixed at one end at the edge of a table and the experiment consisted of incrementally drawing out the tape-measure from the edge of the table and observing the conditions when it buckled. Fig. 1 shows the experiment in three stages: the equilibrium, onset to loss of equilibrium and the buckled state. Although simple in design, the tape-measure dynamics are representative of more complex systems such as the unraveling and deployment of structures made out of light-weight flexible material in space applications that may also be subject to vibration and buckling under external forces [25]. The objective in selecting this experiment was for students to not become overwhelmed by system complexity, rather allowing them to focus more on addressing the key questions posed and develop the questioning and writing skills for the project.

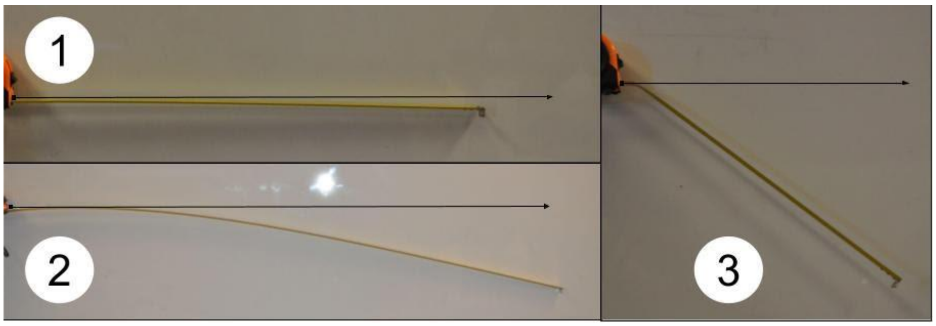

Fig. 1: Tape-measure experiment to model CPS. System state at equilibrium (1), transition to buckling (2) and buckled state (3).

From the CPS perspective, the goal is to determine what measurements could be recorded and transmitted to a computational engine that can estimate the likelihood of the system buckling and in such a case determine an appropriate control action, although the control actions were not addressed at this stage. The PLM team, on the other hand, was charged to conduct interviews with two experts and better understand how lifecycle management is to be integrated in the early design of modern physical systems that are integrated with sensors and network connectivity to decision making computational engines. Since PLM is often specific to a company's product or system, the team's goal was also to understand how PLM is applied in the experts' domain. Specifically, these domains are aviation and environmental monitoring.

3.3 Student Training

Following the demonstration by the faculty mentor, students were provided a background on project-based learning (PjBL) and their roles in this process. The adoption of PjBL is motivated by the work of several researchers on interdisciplinary learning and education that has demonstrated the utility of a PjBL approach in helping develop professional skills such as leadership, communication, and teamwork [26]. Moreover, it provides a sequence of well-studied steps that students can apply and is result oriented in that the end goal is a defined product. The first six stages of PjBL as proposed by the gold standard PjBL [27] are shown in the graphic of Fig. 2 and each stage is associated with the specific actions of the two project teams.

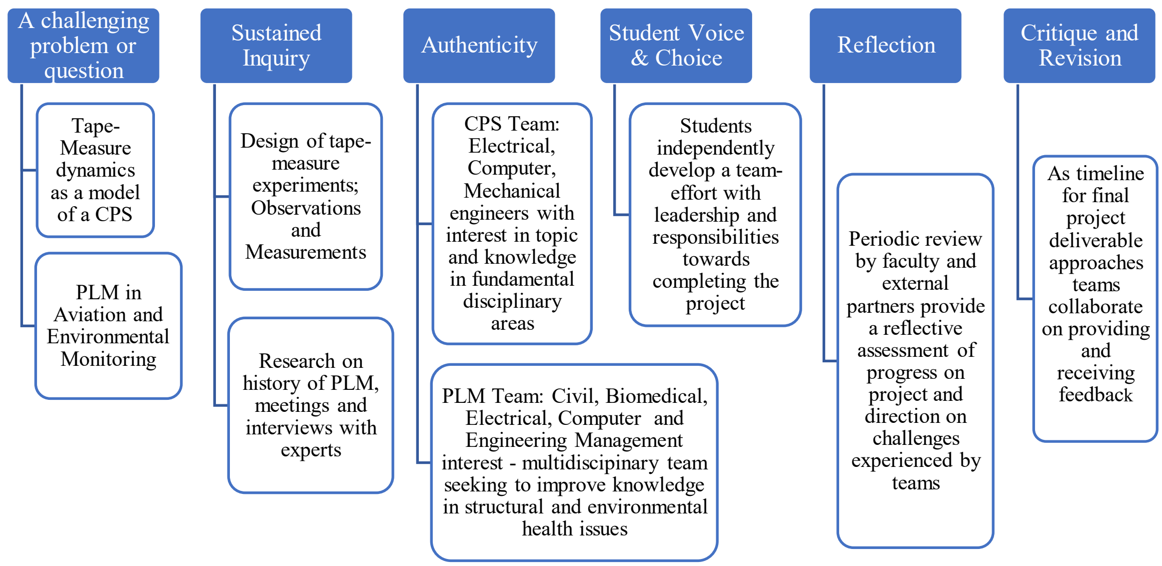

Fig.2: Six stages of the project-based learning gold standard [27] recommendation implemented in this research.

To support the sustained inquiry stage, the students were also given guidance on developing an organized process of questioning. The work from the Right Question Institute noted as the Question Formulation Technique (QFT) [28] was presented to students for their discovery process. This technique includes the following steps that students are advised to follow during collaborations with their team members and other participants once a question focus has been introduced. The four steps to follow are: (a) *Producing Questions* by following the rules of asking as many questions as needed, not stopping to discuss, judge or answer, recording exactly as stated and changing statements into questions and numbering the questions; (b) *Improving the Questions* by categorizing them as open or closed-ended and changing questions from one type to another; (c) *Strategizing:* By prioritizing questions, identifying an action plan for next steps and sharing; (d) *Reflecting* on the process as a team. This process led to initial exchanges between project teams and faculty mentors who responded to the questions posed by the students. During weekly team meetings with faculty mentors, the teams continued to pursue inquiry on their individual projects and they were encouraged to practice the questioning techniques presented.

The final step in the seven stage PjBL gold standard process is the public product. In this research, the teams developed papers on the CPS and PLM topics and submitted drafts of the respective publications to the ASEE 2022 regional conference that took place at Wentworth Institute of Technology. This step also involved the presentation of their work at this conference. Project based learning was selected in response to students' needs that was shared during the first focus-group (described in Section 4.1) wherein they requested some structure for embarking on their projects.

One of the first tasks completed by the teams was formulating abstracts for the aforementioned conference and sharing these drafts with faculty mentors and external partners they were working with. Upon acceptance of their abstracts, the task of developing the full paper was undertaken by each team. Following the PjBL steps, the paper design incorporated early on the aspect of authenticity by individual students choosing to take on writing sections of the paper that they were interested in. The steps of incorporating their own voices and choices, reflecting on the emergent team dynamics, and working with faculty and external partners to resolve issues as they came up were reinforced as needed. In Phase 2 of this research, these publications will be mapped to two online educational modules in a format designed to be accessible and interesting to students who may have not seen these topics before.

4.0 Assessment: PAR Student Focus Groups, Interviews with Faculty and Industry Mentors, and Ethnographic Fieldnotes of Group Meetings

This research draws from multiple disciplines that include tools and techniques from social science and evaluation instruments designed by researchers in psychology and education to provide a periodic formative assessment in tracking the goals and objectives. In this section, the findings from focus group, interviews, and ethnographic observations are summarized. Fig. 3 shows the time-trajectory of these activities and a brief summary of outcomes that has supported the project team to be responsive in adapting to the needs identified.

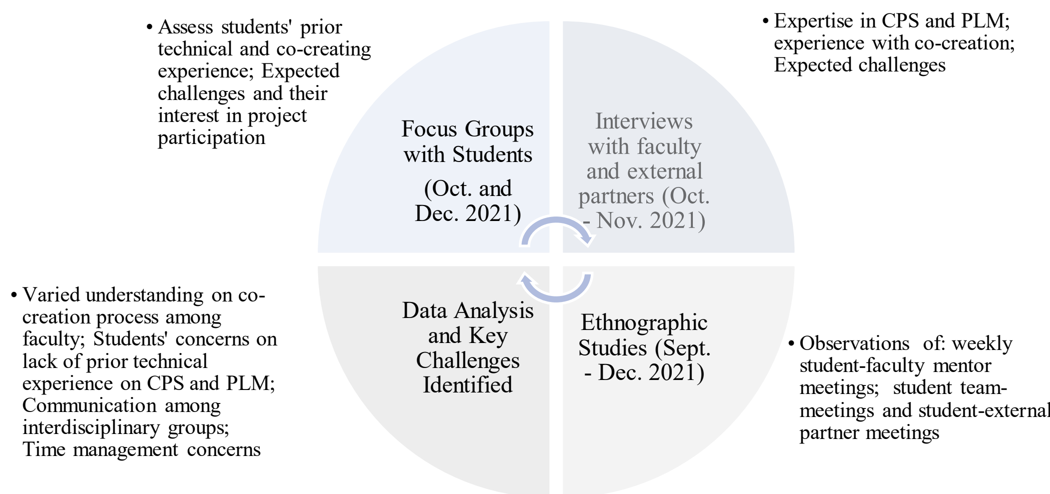

Fig. 3: Formative assessment activities carried out in the first phase of this research with main objectives and outcomes from the data analysis

4.1 PAR Focus Groups

To document and study the process of co-creating the CPS and PLM learning modules, prior to starting the co-creation work, in October 2021 a focus group was held online with student participants. In October and early November 2021, personal interviews were conducted with four faculty and two industry mentors. Once the co-creation process began, fieldnotes were recorded for group meetings and informal discussions, and a second focus group was held with student participants in December 2021. Each focus group took approximately one hour.

The focus groups were conducted within the framework of participatory action research (PAR), which emphasizes listening and learning from the voices of all participants and creating a safe space for open discussion and problem-solving [29] [30]. A member of the research team who is a social scientist facilitated these groups.

4.1.1 Focus Group Design

The first focus group with students was held on a Saturday afternoon via Zoom. The focus group began with introductions and an icebreaker activity to build rapport. To facilitate this online group, an interactive "padlet" board (padlet.com) was created with questions regarding expectations for the project and prior experience with co-creation and cyber-physical systems. Students were asked to post 'sticky notes" on the board to share their ideas with the group. The session began with introductions and an icebreaker, followed by sharing and discussing responses to questions about prior experiences with co-creation, expected challenges and opportunities for this particular co-creation project, and what types of support would be most beneficial for successful participation.

The second focus group began with an icebreaker "word cloud" activity via mentimeter.com asking students to choose words they felt described how they were currently feeling. The rest of the focus group centered on providing students the opportunity to voice their thoughts regarding how the co-creation project was progressing so far and suggestions for change. The specific questions asked were: "What is going well with this project?" "What has been most challenging?" "What, if any changes would you like to see in the project?" Students were given time to think about each question and write their responses on index cards, and then the facilitator asked them to share and wrote the responses on a whiteboard. After all the responses were posted, the whole group discussed reactions to the responses, including how the ideas suggested might help improve the project as it moves forward.

4.2 Interviews with Faculty Members and External Partners

The interviews with faculty members and industry partners included questions about prior experiences with co-creation and expectations for this co-creation project, including anticipated challenges and suggested outcomes. Questions were also included about individual expertise in CPS and/or PLM. Each interview took approximately 20-30 minutes to complete and was conducted by a student research assistant either in person or via Zoom. The recordings were transcribed either automatically via Zoom or using Otter Ai transcription software. The transcripts were coded by one of the researchers and the student research assistant using Dedoose. Each interview was reviewed and coded thematically by both researchers to eliminate any discrepancies. The themes were also reviewed and discussed by the research team.

4.3 Ethnographic Observations and Fieldnotes

In addition to the focus groups and interviews, a member of the research team attended project group meetings and workshops held on Friday afternoons during the weekly meetings of students and faculty mentors, and recorded observations of group interaction and comments.

Students were also asked to record their Zoom meetings with industry and research partners and their co-creation team Zoom meetings, so these recordings could be reviewed and analyzed on an on-going basis by the research team.

4.4 Data Analysis: Prior Experiences with Co-Creation

Prior Experience with Co-Creation: Students, Faculty and Industry Professionals

During the first focus group, only one student said they had any prior experience with co-creation, which involved creating a curriculum for high school students. With regard to the faculty and industry professionals, responses about experience with co-creation varied. One professor and one industry professional interpreted co-creation as co-teaching, and discussed ways they had collaborated with other instructors to create learning materials. Another professor commented that as a graduate student, he had created material for high school students, but now that he was a professor, he "was on the other side of that." But he was confident he had a good understanding of the co-creation process. Another professor had led a long-term, funded collaborative project between graduate students and high school teachers to create lesson modules for high school students. While co-creation can involve multiple ways to interact with students as partners [10], the eventual outcomes for our teams will be co-creation of curricular materials.

One professor stated he had not had any prior experience with co-creation, but was interested in exploring this alternative: "I think that usually, it's been a huge intellectual transfer. Well, I come up with the lectures and stuff and they listen to it. And I think that that's why this is different. We're trying to figure out alternative ways of doing during that instruction." This professor's comment illustrates the contrast between traditional hierarchical methods of education and partnership models ([10] [11] [12]).

Finally, one professor went into depth about how she had co-created materials with her graduate students and "a lot of that was about empowering them to really help make the class as relatable and relevant for their particular area." This professor's comment aligns with results from [19], who found that one benefit of co-creation was increasing students' development as active agents in their own development, including increasing confidence and feelings of empowerment.

Field notes from group meetings confirm that both faculty and students were initially uncertain regarding the particular shape the co-creation process would take during this project, and how it would facilitate the creation of the CPS and PLM learning modules.

To make the co-creation process less abstract, the research team decided to focus on project-based learning (PjBL), as described in Section 3.0. A presentation about PjBL was given to the student teams in November 2021 that described the goals and objectives of this approach, and how it could help facilitate collaboration and provide structure for the co-creation project they were undertaking. The seven steps of PjBL discussed in Section 3.3 and the question formulation technique was shared as a model for their future meetings.

4.5 Data Analysis: Anticipated Challenges with the Co-Creation Project

Challenges for the Co-Creation Project voiced by Faculty and Practitioners

The interviews conducted with faculty and industry professionals prior to the start of the co-creation project revealed the following challenges:

1) *Lack of student technical expertise in CPS and PLM*—especially given the complexity of these areas. As one professor stated: "I think the idea of the student, co-creating—you know, we'll have to see what kind of type of expertise they have to bring to the table to make that helpful. That's really the difficulty." As another faculty member stated, "I might not have the patience to listen to what the student has to say, especially if it's something that I taught in class and they come in and present it to me." Another faculty member pointed out the chronological differences in age between some faculty members and students: "They're 20 years old and we're like 60."

2) *Communication between students of diverse backgrounds*. Faculty and industry professionals were concerned with how to make sure misunderstandings don't arise, especially given the diversity of the project teams, and also potential issues with online communication and collaboration. As noted by [10], partnerships need to address issues of inclusivity, power, and identity. Doing so promotes productive collaboration [21].

3) *Time availability and management.* Faculty were concerned that students don't have time for the project given their schedules and commitments. One faculty member felt that students might become overwhelmed and quit; another was concerned with how to keep them motivated despite lack of payment or course credit.

4) *Maintaining high interest level among external partners:* One faculty member stated that maintaining a high interest level among the industry professionals and making the co-creation project worth their time might also be an issue.

Challenges for the Co-creation Process Voiced by Students

Challenges voiced by students were somewhat similar with the first three faculty concerns noted above, and included learning new knowledge and skills, such as delving into the mechanical dynamics of the CPS, computer integration and coding; understanding the material in CPS at a deeper level; managing the writing part of the project; having time for the project; being clear about what they needed to do; not having much research experience; and working with new people on an interdisciplinary topic. As one student commented: "I don't have much knowledge of coding, or on cyber-physical systems, so it might be a problem for me. Being in my senior year, I also believe time will be a challenge. I do look forward to learning more throughout the project."

Another student expressed confusion about what was expected of them: "I wish I was more clear what activities or task I should do." And others brought up potential challenges with collaboration: “For me, the challenges would be around working with new people in an interdisciplinary work. Looking forward to get to know all of you better.”

Despite these potential issues, students were looking forward to this project as an opportunity to learn new skills and develop connections with peers, faculty, and industry experts, while also being aware of what support would be helpful. As one student commented: “The support I need from others would be to be open minded to learn from each other. I'm very new to research but I'm eager to grasp information from everyone and grow throughout the process.”

4.6 Data Analysis: Student Reactions after One Month’s Work on the Project

The second focus group was held in December 2021, about one month after the co-creation project began. Regarding what was going well with the project, several students commented on the teamwork process, mentioning good communication and collaboration between team members, and that team members were understanding of each other. Other students stated that they were learning new skills such as formulas, theories, and writing academic papers for an upcoming academic conference. Dialogue between students and faculty and between the two co-creation teams was also mentioned as being positive. The Friday afternoon group meetings were appreciated as being encouraging and “keeps us going.” Finally, gaining resources from industry experts and “letting students lead” were also recognized as positive developments.

By far the most common challenge voiced by students was connected with time—including timing of meetings, “time management with classes,” and “how to use time wisely.” Students felt these time issues exacerbated their stress. Another challenge mentioned by several students was academic writing, in particular writing the abstracts for the conference papers each team is working on about their co-creation projects. Other challenges included acting on one’s own initiative, being proactive, understanding complex derivations, “making an effort to expand our interests,” and “understanding the objective of what we’re doing and being able to get a strong understanding in a short amount of time.”

When asked what suggestions they had for improvement, students mentioned both personal changes they were responsible for and changes in the overall organization of the project. Regarding personal changes, students included attending meetings consistently, gaining more knowledge to explain the project, staying engaged, and “doing work when there isn’t a deadline.” As for changes in the overall organization, they mentioned they would like more time for in-person meetings rather than “waiting for replies on Slack,” setting goals/objectives for meetings, more faculty check-ins, more reflection times, and clearer connections between the team activities and the learning module they will create. Students also mentioned that they wish they had understood better what they were doing at the beginning of the project—this became much clearer to them after writing the abstracts for the papers.

5. Discussion and Future Work

Thus far, our work highlights some of the benefits and challenges of co-creating learning modules in teams that are composed of students, faculty, and external experts. The team members looked forward to the process of collaborating to produce the modules, showing engagement in the project, which is key for successful collaboration [10] [11]. By working in teams towards the conference papers, students also were able to more deeply learn [21] these new topics of CPS and PLM. Common challenges expressed by team members included concerns about collaborating in teams with different levels of knowledge and time management, concerns that were not reflected in the co-creation and collaboration literatures. It is important to note that previous research has focused on situations in which co-creation occurs as part of a class (e.g., [13] [24]) or through more traditional research mentorship models (e.g., [10]), which provide additional structure that we needed to apply in this project. The PjBL strategies [5] [27] employed in our work helped to scaffold students' learning within the teams, and could be one way to facilitate the co-creation process.

Future work will include detailed analysis of the co-creation process through recordings of the Zoom student team meetings and meetings with external experts, continuation of the focus groups and observation of in-person group meetings with students, and completion of interviews with faculty and external experts once the learning modules are finished. In particular, we will be interested in exploring how the co-creation relationships develop between students, faculty, and external experts to see whether they align with the dialogic relationships suggested by Freire [11] and hooks [12] or develop in other ways. We will also explore student perspectives on creating an inclusive learning environment for students of all genders, races, and ethnicities; increasing student proficiency and comfort level with interdisciplinary work; and assessing whether our project-based learning approach was successful in developing new knowledge about CPS and PLM.

After completion of the first phase described in this paper, execution of the second phase of the project will begin. Specifically, the completion of Phase 1 will involve the development of two online educational modules that describe an application-oriented view of CPS and PLM. Once these modules are complete, the students from the project teams will be asked to write about what they've learned for a non-specialist audience. Prior to embarking on Phase 1, they were asked to complete the same exercise. Their writing will be analyzed for use of technical terms, clear examples, and overall clarity. In Phase 2, the online educational modules will be integrated in existing undergraduate or first-year graduate courses at the partner institutions. This will be followed by an assessment of how students learn from the co-created material vs. traditionally created material.

Acknowledgements

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