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Project-based development as a model for transdisciplinary research and education

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Abstract[1]

Project-based educational environment that focuses on real-world problems and cross-sector collaboration instills students' learning pathways with the proficiency to move from the domain-specific to the domain-general knowledge. We conceptualize a project-based curriculum model as central to undergraduate education. Focusing on iterative design and development during each year of the undergraduate degree allows for further enrichment of the undergraduate curriculum. We present a case study of a project-based model in action within Virginia Tech, a large public polytechnic university in the United States. Working with seventy-five industry partners serving as project mentors and twenty-seven transdisciplinary faculty, we discuss methodology key to ensuring student learning and project outcomes within this model, including embedding industry partners within project teams, developing transdisciplinary project teams, and encouraging just-in-time implementation of disciplinary knowledge.

Keywords: *Project-based learning, Transdisciplinary research, Transdisciplinary undergraduate education, Cross-sector collaboration and communication.*

1. Introduction

Project-based coursework enriches student experiences by enabling them to understand the complexities of real-world problems and actionable approaches to address them. In standard course design, learning outcomes are directly mapped to course-related assignments and activities. In project-based learning where unstructured problems drive the course activities, achieving learning outcomes requires an adaptive approach to the course and curricula structure. In this paper we

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present a core element of our project-based model, curricula that is adaptive in response to input from cross-sector collaborations between industry professionals, faculty, and students. Aligned with (Clarke & Ashhurst, 2018), the project-based model encompasses principle-based shifts from traditional to interdisciplinary research and education. However, as (Barron et al., 1998) mention, implementing project-based learning requires attention to changes in the existing instruction. Authors in (Arnold et al., 2021) provide a framework and evidence that a project-based approach is beneficial in tackling complex problems and finding solution opportunities. Extending from this scholarship, and in collaboration with industry partners, revised project-based coursework emphasizes analytical thinking and decision-making based on real-world input, develops practical competency via iterative design, and evaluates outcomes based on feedback from industry partners.

Students enrolled in the curriculum also enroll in coursework outside their area of expertise to enhance the transdisciplinary nature of the program. For example, students whose degree requirements do not ordinarily include courses in coding learn these concepts, while students who would not ordinarily take coursework in visual storytelling and presentation take those courses. Requiring these courses fosters transdisciplinarity by giving students the ability to engage in development beyond disciplinary boundaries. This project-based model has resulted in projects that, for example, provide adaptive training for aerospace manufacturing mechanics using virtual reality, develop accessible designs for airplane seating arrangement, and mitigate injuries for factory workers using collaborative robots. These interdisciplinary projects show students that learning happens across multiple layers of cognition and communication.

In this article, we present project-based curricula as a model for transdisciplinary education. We develop this model through (1) Communication with industry partners to determine problem spaces and mentor students; (2) Building interdisciplinary teams of students and faculty; and (3) Structuring learning that embodies vertical and horizontal cognitive growth. We anchor this case study with three years of program assessment data, including perspectives from industry partners and project outcomes. This case study demonstrates how project-based education can equip students for transdisciplinary collaboration as they progress toward their career goals.

2. Cross-Sector Collaboration and Communication

Industry-academic partnerships provide research and education opportunities that enrich student experiences. This cross-sector collaboration affords mentorship opportunities and aid the transfer of knowledge from classroom instruction to professional development. Enhanced with this mentorship, students evaluate their solutions based on stakeholder benefits, costs, and risks. The competitive global environment is motivating academic and industrial institutions to improve their collaborations (Sandberg et al., 2011) and innovate (Awasthy et al., 2020; Rybnicek & Königsgruber, 2019). However, as scholarship in university-industry collaboration has noted, balancing these collaborations requires careful attention. Authors in (Bay et al., 2018) note that maintaining connections with industry partners over time can be challenging.

To develop student competencies that translate to the professional work environment, it is critical to capture the complexities of those environments in academic curricula. To provide this perspective, we are collaborating with industry partners from the Boeing Company, General Electric, Caterpillar, the Association for Financial Professionals, the Capital Youth Empowerment Program, and Ithaka S+R. In the design of undergraduate curricula, we acknowledge and emphasize that real-world problems are multifaceted and require consideration of multiple perspectives and stakeholders (Carayannis & Alexander, 1999; Rikakis et al., 2019). The complexity of industry-motivated problems increases when these problems move beyond a purely technical domain into the sociotechnical space, as the shift generates interdependencies within the system of focus (Vidal & Marle, 2008). This motivates us to emphasize human-centered approaches in our educational environment. Our collaboration with industry partners provides an integrated research and educational setting in which students see these interdependencies and develop suitable approaches to address them.

3. Project-Based Learning Environment

We designed our project-based learning environment in collaboration with industry partners. In this collaborative space, the co-creation of content and methodology affords adaptability, suitability, and responsiveness of structure. Maintaining a competitive advantage in the marketplace motivates university-industry collaboration on research and innovation (Sandberg et al., 2011; Sannö et al., 2019). Recognizing the importance of societal impact, various research methodologies have been introduced to facilitate knowledge production between researchers and practitioners when engaging with stakeholders and communities. These approaches include action research (Bradbury, 2015; Coughlan & Coghlan, 2002; Petersen et al., 2014), collaborative practice research (Mathiassen, 2002), and interactive research (Ellström, 2007), among others (Sannö et al., 2019). To integrate research and education, a joint approach called action research and action learning, has also been studied (Coghlan & Coughlan, 2006). The role of design practices, prototyping, and tools in collaborative university-industry partnerships have been investigated as well (Jussila et al., 2020).

To encourage the high-level and low-level considerations of the problem at hand, we implemented methodology that encourages students to leverage systems thinking and practice. Systems thinking is defined as "thinking about a question, circumstance, or problem explicitly as a system—a set of interrelated entities" (Cameron et al., 2016). Additionally, we encourage students to take planned steps toward addressing the problems that they identify in the system. We imbue this methodology with the scholarly work rooted in Action research (an orientation to inquiry that aims to bridge ideas and practices in the service of humans (Reason & Bradbury, 2007)).

Students take these actionable steps by implementing an iterative design approach. In this context design is broadly defined and emphasizes approaches rooted in Design Thinking. Emphasizing co-creation pedagogy, Jussila et al. (Jussila et al., 2020) underscored the value of design thinking and iterative design in interdisciplinary teams for providing solutions to ambiguous business challenges. Furthermore, the role of prototyping in new product development across various disciplines has been studied as well (Elverum et al., 2016). This work highlights the importance of design tools and practices in understanding the diverse needs of stakeholders (end users) (Simeone et al., 2017a) along with knowledge translation (Simeone et al., 2017b). Moreover, a designerly approach (one that adopts a solution-focused strategy) has been introduced as a methodology to reduce barriers between academia and industry when addressing problems (Wallin et al., 2014).

Working directly with stakeholders aligns with the goal of participatory design (Muller & Kuhn, 1993). By shifting the focus from the product to the end user, design developers can obtain insight into users' current and future utilization of technology (Grønbaek et al., 2017). Our collaborative learning environment builds on the knowledge developed in these studies and allows the permeation of knowledge from all the stakeholders in the project-based learning setting of the program.

4. Calhoun Honors Discovery Program

The Calhoun Honors Discovery Program (CHDP) is a four-year transdisciplinary program located within the university's Honors College. CHDP is in its third year since inception. Through course substitutions for general education pathways coursework, students enroll in the program's studio-centered curriculum, taking a three-credit studio course in the fall semester of the first year (Transdisciplinary Fusion Studio 1), second semester of the second year (Transdisciplinary Fusion Studio 2), every semester of the third year (Transdisciplinary Junior Design Studio 1 & 2), and every semester of the fourth year (Transdisciplinary Senior Design Studio 1 & 2). Students who lack experience in transdisciplinary skillsets, e.g., programming in Python, market analysis, humanities, or design enroll in one-credit 5-week courses to gain those skills, again through course substitutions. Importantly, all students regardless of major are required to complete six credit hours of technical communication coursework during their time in the program. The coursework in communication is integrated in the first- and second-year studios to allow permeation and application of the acquired knowledge in teamwork settings of project development. Students who complete the program's studio-centered curriculum receive a Collaborative Discovery diploma from the program in addition to their major diploma.

5. Collaborative Sociotehnical Innovation Model

In our approach to co-creation with industry partners, we aim to combine scientific methodologies with practical benefits for societal impact. To this end, in addition to the methodology discussed in Section 3 we developed the Collaborative Sociotechnical Innovation Model (CSIM), which lays the foundation of the instruction and mentorship plans in the studio (Arnold et al., 2020). This model is an expansion of the IDEO's design thinking model and emphasizes sustainable practices that consider larger impacts of innovative solutions (Fig. 1). Students evaluate sociotechnical innovation based on four criteria: desirability (is there a human defined need?), feasibility (what is an enabling technology approach?), viability (can it be built and is it financially sensible?), and sustainability (does it possess social, economic and environmental endurance?).

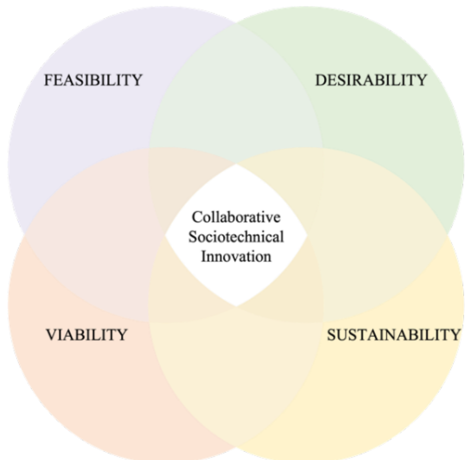

Figure 1: Collaborative Sociotechnical Innovation Model

We form the teams in the studio environment using various criteria that includes students' interest, balance of majors and expertise within the team members, and the complexity of the problem space. Together these criteria define the size of the team and the distribution of majors to afford an opportunity for peer-learning among the students in the team. Team collaboration and individual member's reflection on the process of project development is central to our learning environments. Inspired by the works of Donald Schön (Schön, 2017), in this collaborative environment, undergraduate students take a reflective approach to addressing a problem. The research and practice that embodies CSIM in the CHDP studios affords students direct access to industry professionals and academic mentors throughout all four years of their undergraduate studies. The evolution of these relationships will be studied in upcoming student cohorts.

In implementing CSIM, we emphasize the temporal aspect of the system in focus. Students take an iterative approach, evaluating the problem space and solution concept with the CSIM perspective throughout the project development process. In each iteration, students incorporate the four lenses of the CSIM model and evaluate the problem space and causal relationships between sets. A typical implementation cycle of CSIM encourages students to begin analysis of the problem space using systems thinking methodologies and tools such as systems diagrams. Then, students define the problem-space by identifying the scope and scale of the system in focus.

Finally, students develop a solution concept informed by this process and present their results in a formal milestone presentation to industry and academic partners. Collaboration is not limited to these milestone presentations. Students meet remotely with these experts on a regular basis throughout the process. Additionally, to engage the end-users in the design process, the educational environment emphasizes direct communication with end users to the students as they work through the iterative design process. Industry partners facilitate connections with their respective internal workers/users to elicit feedback on proposed solutions and/or receive additional information regarding the environment where the solution will be implemented. Incorporating this information into the design review process assists the students as they refine their prototype solutions and enhances the likelihood of successful integration into industry systems. Student teams present preliminary, underdeveloped, conceptual, and prototype of a solution to academic and industry expert groups. Each studio follows a subset of NASA's project development milestones (*NASA Systems Engineering Handbook - Revision 2*, 2020): Mission Concept Review (MCR), Preliminary Design Review (PDR), and Critical Design Review (CDR).

6. Integrated Research and Education Outcomes

In this section we present the results of three years of program assessment data, including perspectives from industry partners and project outcomes. We highlight three student team project outcomes and present data from student surveys in the first- and second-year studios along with the data from industry partner focus groups. Industry partner focus groups are conducted at three points during each academic year. During these events, industry partners, faculty, and other university stakeholders discuss sociotechnical problems and organize them into broader outcome areas. Outcome areas, representing areas of interest for industry, provide organization for students and themes to focus on in the upcoming year. As well, industry partners suggest additional point-of-need learning areas that students should engage with to learn more about outcome areas.

In Figures 2-4 we present the student project outcomes in the Transdisciplinary Fusion Studio II (second-year, spring semester). Student teams present the outcomes of their semester-long projects to academic and industry partners during the showcase. The showcase allows for an enhanced feedback exchange between stakeholders. While the full breadth of projects cannot be captured in this case study, we selected a set of projects that demonstrate approaches that students selected to address the problems. Figure 2 presents the outcome of a project that focused on providing enhanced training for drilling operations using virtual reality. Figure 3 presents the design of a foldable airplane seat that allows passengers with disabilities to remain in their own wheelchair when entering the aircraft aisle and situated in their spot for flight. Figure 4 presents the prototype of a remote-controlled robot arm that reduces Musculoskeletal Disorders caused by repeated exposure to the forces and vibration of drilling in aerospace manufacturing.

Figure 1: Student project, adaptive training for aerospace manufacturing mechanics using virtual reality

Figure 2: Student team project, accessible designs for airplane seating arrangement

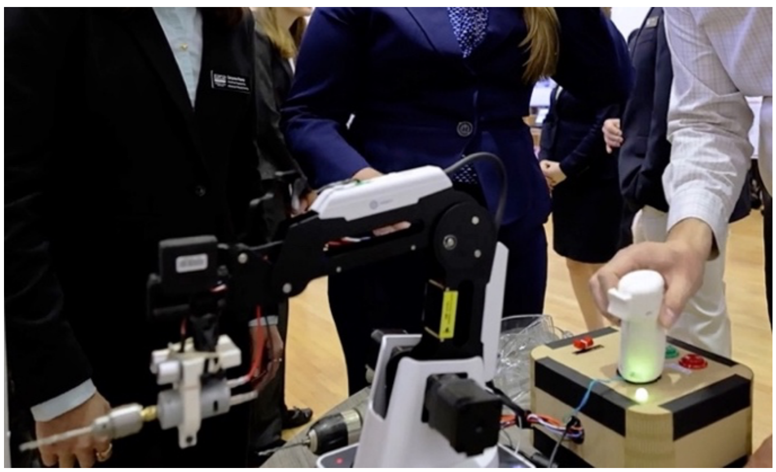

Figure 3: Student team project, mitigating injuries for factory workers using collaborative robots

Studio course design includes multiple assessment points to capture students' feedback of the learning environment that motivates timely adaptation of the course structure to enhance the educational experience. After each milestone in the studio, we provide a survey to students that asks questions about their satisfaction with the project-based environment across multiple aspects: their perception of learning new concepts, their interactions with mentors, access to information and facilities among others. Below we present the survey results from Transdisciplinary Fusion Studio 1 (fall semester, first year students) & Studio 2 (spring semester, second year students).

Our project-based environment allows for vertical and horizontal integration of knowledge. That is, students incorporate the knowledge gained in their major coursework (domain-specific) into the broader application space of the studio (domain-general). In both courses we emphasize key aspects of project development and provide opportunities to students to learn concepts related to those aspects. To that end, Transdisciplinary Fusion Studio 1 (first-year) emphasizes problem analysis, project and team management, and stakeholder need identification. We acknowledge that these concepts are challenging for incoming college students and provide just-in-time mentorship to students to navigate the studio experience successfully. Figure 5 presents the individual student satisfaction with the project-based learning environment in the first-year studio from two different years, Fall 2020 and Fall 2021. In Fall 2020 we offered the studio in an online format because of an in-person restriction caused by the pandemic. While this model provided a convenient structure for class meetings, as shown in the results of student's higher level of satisfaction, it severely limited access to labs and other facilities for students to apply the knowledge. Although the students in Fall 2020 indicated overall satisfaction and maintained that level of satisfaction throughout the semester, they did not experience growth. In contrast, in the Fall 2021 studio we implemented a hybrid model with video lectures and in-person class time spent on project development. The increase of students' satisfaction between the first and third milestones indicates growth from the in-person development activities and encourages us to develop this adaptive model further. Figure 6 presents the student perception of learning new concepts during the first and last phase of the first-year studio. Our studio curriculum is based on gradual reduction of new concepts, focusing more on learning ideas early in the semester and then application later in the semester. Results from both years demonstrate that students understand this aspect of the studio environment.

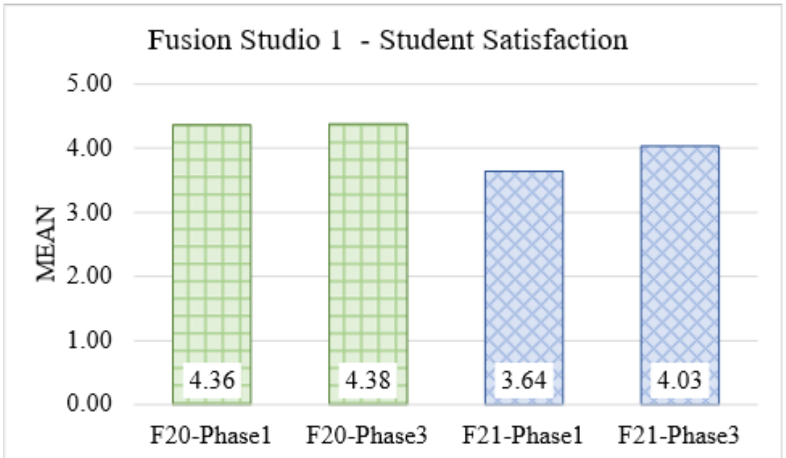

Figure 4: First-year studio, mean of responses to the satisfaction of the learning environment

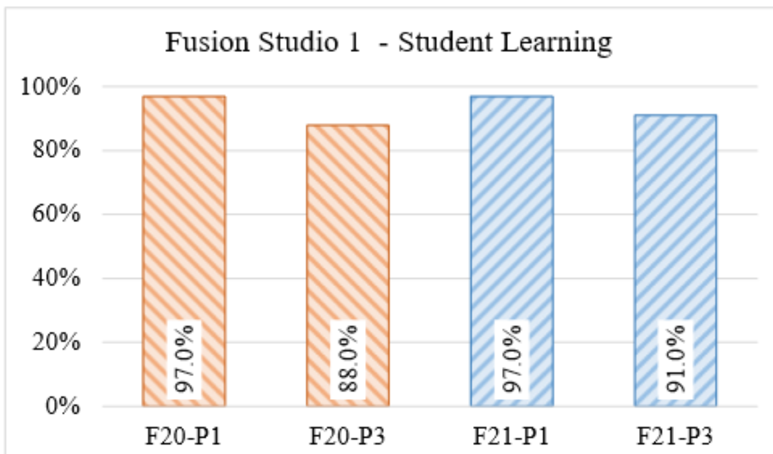

Figure 5: First year studio, students' responses to whether they have learned new concepts during each phase of the studio

Transdisciplinary Fusion Studio 2 emphasizes quantitative thinking, prototyping, and business plan development. Students in this studio environment begin the development of prototypes as early as possible. The pandemic restrictions were lifted prior to the Fall of 2021, bringing back in-person classes. The noticeable increase in students' satisfaction of the learning environment (Figure 7) between Spring 2021 and Spring 2022 is likely attributed to this factor. Additionally, in Spring 2022 between the two phases of this studio we emphasized action learning which provides a more seamless peer-learning opportunity. Students' positive responses to this model is captured in Figure 8.

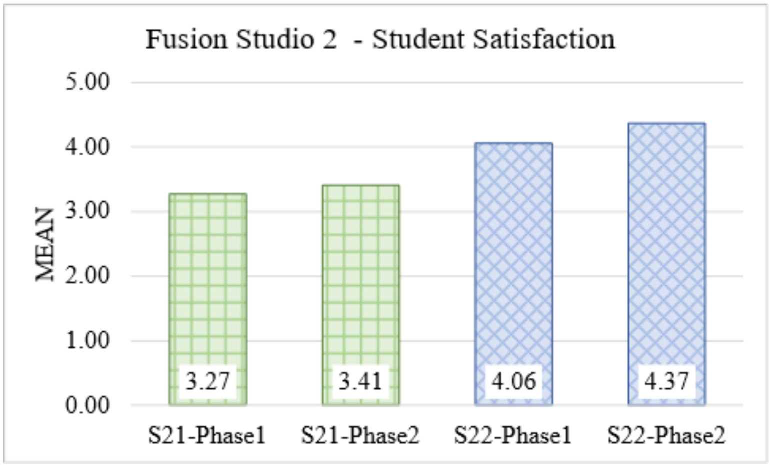

Figure 6: Second year studio, mean of responses to the satisfaction of the learning environment

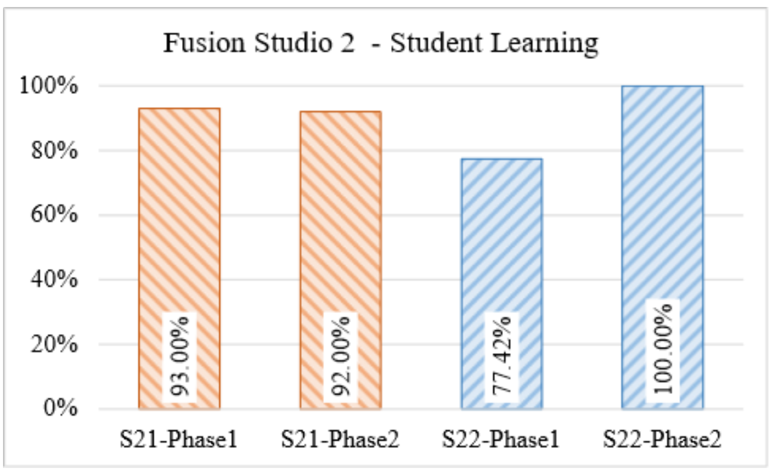

Figure 7: Second year studio, students' responses to whether they have learned new concepts during each phase of the studio

7. Limitations and Future Work

Our program accepts approximately 35 students from 15 majors each year from various colleges at Virginia Tech. Currently the distribution of students from each major is balanced and the represented majors provide sufficient expertise to tackle complex real-world problems with transdisciplinary teams; however, we aim to provide the project-based learning model of the CHDP to a larger population of students and a wider range of majors. One of the challenges in doing so is course substitutions that meet the requirements of the variety of disciplinary four-year plans. To overcome this challenge, we plan to provide a combined first- and second-year studio as an elective course in Fall 2022. This studio experience will incorporate the methodology of CHDP studios and including access to industry mentorship. Furthermore, this combined studio environment will be available to all students in our institution.

8. Conclusions

In this paper, we discussed our project-based framework for transdisciplinary research and education, rooted in systems thinking and action research. We presented our model developed in close collaboration and communication with industry partners. The Collaborative Sociotechnical Innovation Model at the core of our project-based model demonstrates the benefits of transdisciplinary and cross-sector collaboration. Our findings demonstrate that our methodology provides an adaptive and responsive learning environment for students to better understand and analyze real-world problems. Students' positive responses to the learning environment and its adaptation to student learning needs encourage us to extend our project-based environment to a larger population of students in a wider range of majors.

9. AKNOWLEDGMENT

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