Engaging Students around the Complex Socioscientific Issue of Sustainability: Affordances and Tensions of Faculty Working across Disciplines to Develop Transdisciplinary Curricula

Cindy Lenhart†,* and **Jana Bouwma-Gearhart‡**

†Central Oregon Community College and ‡College of Education, Oregon State University, Corvallis, OR 97331-3501

ABSTRACT

There is growing recognition of the importance of engaging postsecondary students in experiences that challenge them to solve complex socioscientific problems, transdisciplinary in nature, requiring students to integrate and synthesize knowledge, skills, and ways of thinking across disciplinary boundaries. Yet these student experiences are atypical. One possible reason is that the cross-disciplinary collaborations of faculty needed to create meaningful transdisciplinary student experiences are likely to be challenging. Lacking insight into these novel collaborations, we conducted a phenomenological study that describes faculty experiences across multiple disciplines and institutions to develop a transdisciplinary curriculum. Faculty were motivated by their professional development needs and a desire to improve their teaching practices and to develop curricula that would enhance student learning, all around a topic of personal interest. Yet faculty experienced tensions related to navigating norms, practices, and language across disciplines, the suitability of transdisciplinary curricula to their courses, and confidence in teaching across disciplines. Project leaders were essential facilitators and codevelopers, helping to alleviate some tensions. We discuss implications for faculty, academic leaders, administrators, and other stakeholders interested in involving faculty working across disciplines to develop transdisciplinary curricula, notably around a timely and important topic in the biological sciences.

THE HARD WORK OF PREPARING STUDENTS TO TACKLE COMPLEX SOCIOSCIENTIFIC ISSUES

Postsecondary students' development within the typical disciplinary boundaries of higher education, reflected in postsecondary programming, is likely insufficient to help students address the complex problems society faces (Ertas *et al.*, 2015; Gibbs, 2017; Lyall and Fletcher, 2013; Moore *et al.*, 2018; United Nations, 2020). Relevant socioscientific problems might include issues of poverty, social inequalities, climate change, and sustainability, challenging to solve because of their complexity—what some refer to as *wicked* problems (Rittel and Webber, 1973). Wicked problems require integrating and synthesizing knowledge, skills, and ways of knowing across disciplines (Klein, 2013).

Responding to various calls for a global citizenry better able to tackle rapidly evolving socioscientific challenges (Brandt *et al.*, 2013; Ertas *et al.*, 2015; Gibbs, 2017; Moore *et al.*, 2018), postsecondary faculty members (hereafter just "faculty") have been encouraged to provide experiences and learning opportunities that frame problems as multidimensional (Barth *et al.*, 2007). The National Science Foundation and the American Association for the Advancement of Science (AAAS) have prioritized

initiatives that can help faculty better prepare undergraduate students to work across disciplines once in the workforce. In the field of biology, specifically, faculty are called upon to engage students in active-learning processes while building understanding around "the interdisciplinary nature of the new biology and how science is closely integrated within society" (Woodin *et al.*, 2010, p. 71). *Vision and Change* provides related recommendations, including that faculty "promote more concept-oriented undergraduate biology courses, and help all students learn how to integrate facts into larger conceptual contexts" (AAAS, 2011).

Yet realizing these teaching and programmatic commitments is likely not an easy lift. Limited research shows that faculty still struggle to engage students in experiences that span disciplines (Gibbs, 2017). Further, the complexities of faculty curricular planning across disciplinary boundaries are still underresearched, primarily due to a lack of such cases to study. Institutions of higher education are organized around centuries-old notions of *disciplines*, or "the tools, methods, procedures, examples, concepts, and theories that account coherently for a set of objects or subjects" (Klein, 1990, p. 104), reflecting both epistemological and social boundaries (Klaassen, 2018). Although disciplines are not static (Lattuca, 2001), organization around them still results in "siloed" institutional units (e.g., colleges and departments) serving as the basis of decisions around hiring, promotion (and tenure) practices, resource allocation, and teaching assignments, student programming, and curricular development (Grossman *et al.*, 2000; Lattuca, 2001). These realities present barriers for faculty and students to work across fields. Curricular planning for individual faculty, generally speaking, is already complex (Lattuca and Stark, 2009; Hora and Ferrare, 2014). Planning activities that cross disciplinary boundaries and involve multiple faculty is likely extra complex due to faculty disciplinary-based teaching experiences and preparation, beliefs around learning and student needs, and the importance of specific knowledge and related outcomes (Lattuca and Stark, 2009; Bouwma-Gearhart, Ivanovitch, *et al.*, 2018; Bouwma-Gearhart, Lenz, *et al.*, 2018).

Postsecondary programs are still largely ill-equipped in preparing students to work on the complex socioscientific problems facing society that require "transdisciplinary approaches," or the integrating and synthesizing of knowledge, skills, and ways of knowing across disciplines (Klein, 2013). The research that may inform these interests is hard to make sense of, partially due to confusion around terminology. Work spanning faculty disciplines is often described as "multidisciplinary," "interdisciplinary," and "transdisciplinary," often interchangeably (Tripp and Shortlidge, 2019). Transdisciplinary approaches move beyond other cross-disciplinary approaches, including multidisciplinary and interdisciplinary approaches. We consider multidisciplinary work to involve disciplinary experts applying disciplinary knowledge to different aspects of a problem, often separately in stages, to exchange new knowledge and methods, but not integrating or iterating (Lattuca, 2001; Stock and Burton, 2011; Fam *et al.*, 2018). Interdisciplinary work involves more integration of knowledge and methods across disciplines (National Academy of Sciences, National Academy of Engineering, and Institute of Medicine, 2005; Stock and Burton, 2011). Transdisciplinary approaches, in comparison, involve "reconstituting and rearranging," potentially a "fusion" of knowledge unseen

even in interdisciplinary work (Stock and Burton, 2011, p. 1099), resulting in new understandings of problems (McGregor, 2017). Those engaged in transdisciplinary collaborations must rely on enhanced communication skills to understand the contributions and expertise afforded by diverse disciplines (Petrie, 1992; Wickson *et al.*, 2006; Funtowicz and Ravetz, 2008) that sometimes emerge during transdisciplinary work.

Our paper explores the cross-disciplinary work of faculty and leaders from the natural and social sciences as they collectively develop novel curricula intended to engage students in transdisciplinary learning and approaches. We reserve our use of "transdisciplinary" to refer to the nature of the curriculum module faculty and leaders worked to develop, specifically around the socioscientific problem of sustainability. We use "cross-disciplinary" to describe the nature of faculty interactions as they work across the diverse disciplines they represent.

Research on the Nature of Faculty Cross-Disciplinary Teaching and Learning-Focused Collaborations That Span Multiple Disciplines

Research that documents faculty developing transdisciplinary curricula is limited, including around instances in which cross-disciplinary collaborations are required of faculty. We are left to consult research concerning faculty engaged in cross-disciplinary collaborations, in general, to hypothesize further what might influence the collaborative development of transdisciplinary curricula. Faculty, overall, perceive cross-disciplinary collaborations as novel and outside their typical teaching duties (Lindvig and Ulriksen, 2019). These collaborations take time, and faculty members, for collaboration success, generally need to be dedicated, willing to learn, able to work with others, and patient (Lattuca, 2001; Weber *et al.*, 2013; McNair *et al.*, 2015; Judge *et al.*, 2020). This reality is especially true as faculty grapple with unfamiliar terminology and content and sometimes struggle to see the relevance of their disciplines as they work. Some research indicates that faculty may perceive a hierarchy of disciplines when engaged in cross-disciplinary collaborations. Specifically, faculty in the social sciences indicate feeling marginalized and dismissed by faculty in the physical sciences and feeling less confident about the "place" of their disciplines. Bouwma-Gearhart *et al.* (2014) found similar issues in science, technology, engineering, and mathematics (STEM) education improvement initiatives that brought faculty from STEM and education sciences into collaborations. STEM faculty were notably skeptical of the value of their education colleagues' contributions and expertise, while education faculty felt their disciplines and expertise were undervalued. While these perceptions faded over time as the groups worked more together, most faculty generally gravitate to working with others from similar disciplines, as within the "soft" disciplines (e.g., social sciences and humanities) or the "hard" disciplines (e.g., natural sciences; Gardner, 2013).

Additionally, faculty members may perceive a lack of departmental and institutional support for their cross-disciplinary collaborations and a lack of recognition of these efforts in promotion and tenure considerations (Lattuca, 2001; Lindvig and Ulriksen, 2019). Administrators and academic leaders may be critical in providing resources and leadership to launch and sustain cross-disciplinary collaborations of faculty (Bouwma-Gearhart *et al.*, 2014; Wright *et al.*, 2015). Faculty who are

successful in their cross-disciplinary collaborations can experience a sense of "ownership" and a reconceptualization of disciplines within the curriculum (Nordén, 2016; Judge *et al.*, 2020) and an ability to perceive socioscientific problems as complex and informed by perspectives outside their disciplines (Clarke and Ashhurst, 2018). Faculty who are successful in their cross-disciplinary collaborations note changes to their teaching practices, including ability and knowledge around new methods (e.g., problem- and project-based teaching and learning, use of instructional technologies). Very limited research around faculty engaged in cross-disciplinary collaborations around issues of sustainability shows that faculty claim to be able to help students engage more with issues of sustainability and see more real-world relevance of these issues in their own lives (Hayles and Holdsworth, 2008; Hurney *et al.*, 2016; Tasdemir and Gazo, 2020).

The emerging research is indeed illuminative. However, given the importance of students' development to help solve complex socioscientific problems, and as more postsecondary education improvement initiatives promote this, we need faculty perceptions of the complexity and realities of such work to inform future initiatives' design and implementation (Oliver and Hyun, 2011; Jahn *et al.*, 2012). This phenomenological study analyzes faculty experiences around faculty codevelopment of a transdisciplinary curriculum module in light of relevant affordances and tensions within their larger context (Foot, 2014). We use cultural-historical activity theory (Engeström, 2009) for its promise to illuminate the complexity of social activity performed by faculty situated within multifaceted contexts, including academic disciplines and higher education organizations (e.g., programs, departments, institutions). Our research questions are: 1) What motivates faculty from diverse disciplines to engage in a project to codevelop a transdisciplinary curriculum module for implementations in their classes? 2) What challenges and affordances do participants experience in transdisciplinary curriculum creation and implementation plans? Our research seeks to provide new knowledge about the realities of a novel faculty-related activity system that is seldom witnessed yet sure to grow in prominence. Based on our findings, we offer suggestions for others attempting or promoting faculty development of transdisciplinary curricula, including attention to relevant contextual elements and their interconnectedness.

CONCEPTUAL FRAMEWORK

We use cultural-historical activity theory (CHAT) to illuminate faculty codevelopment of a transdisciplinary curriculum module. At the root of CHAT are human "activity systems," various factors impacting and impacted by human social interactions (Engeström, 2001). Specifically, we rely on second-generation CHAT (Engeström, 2009; see Table 1). CHAT recognizes six elements (or nodes) interacting in an activity system. These include "subjects," or the individuals or groups engaged in interactions. Subjects rely on "mediating artifacts" or "tools" to guide actions to achieve an "objective," shaped by their needs or norms of the situation (Foot, 2014). Mediating artifacts can be material or conceptual and may involve language, disciplinary methods, cultural artifacts (e.g., symbols), and technologies. By directing the mediating artifacts or tools toward the desired objective (e.g., new curriculum), the actors can produce "outcomes," such as a revised course (Engeström, 2001).

Subjects do not work in isolation but within a "community," which consists of others who influence or collaborate with the subject (e.g., other faculty, administrators) working toward objects and outcomes (Engeström, 2001). "Rules" regulate the actions and relationships of actors in the community toward each other. These norms and conventions of the community can be formal or informal, such as workload or accreditation requirements. A "division of labor" delineates the various actions toward realizing the object to different actors in the system, influenced by some of the rules mentioned earlier, distribution of power, and access to resources in the system (Engeström, 2001; Foot, 2014).

Subjects perceive these aspects of the system as they engage in social actions, including relationships within and between them, as affordances toward realizing the objective. "Tensions" can occur when subjects cannot achieve objects/outcomes, for instance, if a faculty member did not have access to a mediating artifact or tool needed to prepare a course. Tensions can historically accumulate within a system, solidifying barriers toward achieving an object. Nevertheless, system tensions can also be positive for subjects and other community members, acting as opportunities for learning around or redesign of the activity, as actors seek to overcome or address tensions (Engeström, 2015; Alexander and Hjortsø, 2019).

METHODOLOGY

Study Context and Participants

Our research concerns a National Science Foundation (NSF)-funded project that brought together faculty and project leaders from three institutions to develop and implement a transdisciplinary curriculum module around sustainability issues that could be taught in multiple courses across institutions. Seven project leaders across the universities recruited 12 teaching faculty (hereafter just "faculty" versus "leaders," with these groups combined referred to as "participants"). Leaders served as the points of contact and coordination for their institutions and supported all faculty in developing a transdisciplinary curriculum module. Leaders also intended to teach the curriculum module within their courses. Four faculty and four leaders identified their disciplines as science related: chemistry, geology, biology, or environmental studies. Six faculty and three leaders identified their disciplines as business related: economics, finance and accounting, and entrepreneurship. Two faculty members were from anthropology/sociology and information/communication related fields. The 12 faculty participants and seven project leaders are identified with gender-neutral pseudonyms (refer to Supplemental Table 1).

The three universities involved in the initiative include Institution A, where the project's head leader, the principal investigator, worked with two other project leaders and four faculty members. Institution A is a private university in the northeastern United States that serves approximately 4000 predominantly undergraduate students majoring in business education. Lacking separate schools or colleges within the university, Institution A is structured as departments, including departments under the larger category or business (e.g., accountancy, finance, and marketing). Other departments are arguably interdisciplinary, such as natural and applied sciences (e.g., biology, chemistry, and environmental sciences), global studies (e.g., political science, public policy, and international studies), and

TABLE 1. The activity system: Factors influencing faculty development of transdisciplinary curriculum[a]

Elements (nodes)	Description of elements related to study	Findings related to element
Subjects: Faculty and leaders	• Faculty desire for collaborative work around teaching innovation • Faculty interests around sustainability • Confidence (or lack of) around transdisciplinary work	• The main *subjects* of the system of our focus, faculty participants, were motivated to work toward the object, cocreating a transdisciplinary curriculum due to their desire for collaborative work around teaching innovation; interests related to sustainability; and developing a relevant curriculum that benefited students.
Tools Mediating artifacts	• Technological resources and constraints • Project leaders as facilitators and codevelopers • Clarity of work actions • Time and workload constraints	• Faculty encountered tensions related to *mediating artifacts/ tools* in the system, largely the various disciplinary knowledge and expertise, effective teaching methods, and curriculum development; the support (or not) of leaders and administrators; and participants' access and ability to use resources and tools.
Rules	• Typical lack of opportunities for (cross-disciplinary) teaching-related collaborations • Typical means of interactions, made impossible by pandemic • Discipline-based understandings and norms • Program course alignment • Shared conceptions of what to teach • Institutional norms, policies, and processes	• Faculty and leaders (subjects) also experienced tensions related to the system *rules*, which included typical lack of opportunities for cross-disciplinary teaching-related collaborations; interactions and norms per the pandemic; institutional norms, policies, and processes; and discipline-based understanding and norms such as program/course alignment and shared conceptions of what to teach.
Community	• Others involved in the project • Others at their institutions (faculty, administrators, and students) • Other faculty's perceptions of what to teach • Students as unprepared for/unaccepting of transdisciplinary curricula • Administrators with power to support, or not, faculty work	• Subjects interacted with and were influenced by others in their *community* (i.e., faculty, administrators, and students), including other faculty's perceptions of what to teach, students as unprepared for/unaccepting of transdisciplinary curricula, and administrators with the power to support (or not) faculty work.
Division of labor	• Typical roles and influence of others at their institutions • Project leaders as competent, committed collaborators, recognized as organizational leaders, diverse in disciplinary backgrounds • Administrators who help revise and reinforce structures and practices promoting teaching innovations	• Subjects were also influenced by and experienced tensions with the *division of labor*, which includes the typical roles and responsibility of others at their institutions, project leaders as competent, committed collaborators who are recognized as organizational leaders and who represent diverse disciplinary backgrounds. Also included in the division of labor are administrators who help revise and reinforce structures and practices promoting teaching innovations
Object and outcome	• Cocreation of a transdisciplinary curriculum around the sustainability topic • Faculty understandings and experiences around teaching-related transdisciplinary work • Potential for faculty revisioning of other courses	• The activity system we investigated brought together faculty and leaders (*subjects*) to cocreate a transdisciplinary curriculum around a sustainability topic (*object*) that led to faculty understandings and experiences around teaching-related transdisciplinary work and the potential for faculty revision of their courses (*outcome*).

[a]Future implications for teaching and development of a transdisciplinary curriculum relies on the interactions of subjects within the elements/nodes of the activity system.

English and media studies (e.g., creative writing, literature, film studies, cultural studies, and media production). The participants who collaborated in this project generally only worked together within their disciplinary boundaries.

Two leaders and four faculty members worked at Institution B, a large public university in the midwestern United States, serving approximately 13,000 undergraduate students. Institution B has an organizational structure that includes seven degree-granting colleges or schools with more than 60 undergraduate majors. It also has 39 academic departments (e.g., English, finance, history, mathematics, and environmental studies) and various institutes that foster interdisciplinary research and teaching collaborations within similar disciplinary fields (e.g., environmental, energy, and water studies) around topics

such as the environment. The participants who collaborated in this project (i.e., environmental studies and business) had not collaborated across their disciplines previously.

Two leaders and four faculty worked at Institution C, a private, 4-year liberal arts college in the midwestern United States, with approximately 1900 full-time undergraduate students. Institution C has a typical disciplinary departmental structure (e.g., business, communications, education, mathematics, physical sciences, and social sciences). It does not have interdisciplinary institutes, programs, or degrees. In recent years, Institution C has been engaged in a departmental realignment process due to organizational and budgetary factors. Participants who collaborated in this project (i.e., sciences and business) had not previously collaborated across their respective disciplines.

During the study (12 months), project leaders from the three universities planned and facilitated professional development activities with faculty. Leaders met together in planning sessions before each meeting with the faculty. Activities with faculty were all virtual (per COVID-19–related concerns) and both synchronous and asynchronous. The most time-intensive activity for faculty was a synchronous 5-day curricular development workshop held in month 8. Participants codeveloped a 1- to 2-week transdisciplinary curriculum module containing a common exercise, course-specific exercises, and assessments. Three preworkshop sessions were held over the first 7 months, lasting approximately an hour each. Before each session, the faculty completed short readings and assignments designed to help them choose a topic and begin thinking about the curriculum module's design. During the synchronous preworkshop sessions, the faculty shared their perspectives while leaders guided discussions. The faculty chose water quality and health/wellness as the wicked problem of sustainability around which to create the curriculum module. The leaders used a backward design approach (Wiggins and McTighe, 2005) to guide faculty in designing the module.

Participants began the 5-day workshop by identifying student learning outcomes for their selected topic to guide their content development. In addition to determining water quality and health content, participants designed two major activities for students. Students were first to develop a stakeholder map showing nitrogen in the water cycle and subsequently engage in a role-playing exercise. They attend a fictional town hall meeting and present various stakeholder groups' perspectives. The faculty also developed formative and summative assessments for students during the 5-day workshop. We note that project work successfully achieved these planned goals up to this point. Participants interacted via virtual platform technologies, including 1) the Zoom video conferencing platform for small/large group interactions, sharing screens and PowerPoint presentations, and a chat feature; 2) a project management platform that provided collaborative workspaces for communication, storing resources, and working together; 3) Google Docs as a shared document space for collaborative document creation; and d) other Web-supported online platforms designed to act as repositories to facilitate the creation and storage of collaboratively developed documents (e.g., project-sponsored websites).

Data Collection and Analysis
Over the 12 months, we collected data through interviews, observations of meetings, and faculty work documents (see Supplemental Table 2 for descriptions of the activities, data collected, and timeline). C.L. took detailed notes at all leader planning meetings, preworkshop sessions, and the 5-day workshop. J.B.-G. also observed and took observation notes for about one-third of all meeting times. These observations included the 5-day workshop, during which both researchers took detailed notes of general and breakout sessions, noting who was participating and descriptions of key activities and participant interactions. We also collected documents created by the participants at all meetings and the workshop. We used the observations and documents to make sense of the interviews, the primary data informing this paper (analysis detailed in following paragraphs).

We conducted semistructured interviews, a typical phenomenological approach, with the seven leaders in month 2 of the project (see Appendix A in the Supplemental Material for leader interview questions). We asked the leaders to describe affordances and constraints that faculty, departments, and institutions might encounter related to achieving the initiative's goals, namely the successful development of the curriculum module. The results of our interviews with the leaders helped to inform the preworkshop interview (hereafter preinterview) protocol for faculty. We also asked the leaders to describe affordances and barriers they might experience in this initiative and its potential to influence faculty work and organizational structures at their institutions. We conducted postworkshop interviews (hereafter postinterviews) with faculty in month 12, after the development activities were completed but before faculty taught the transdisciplinary curriculum module (see Appendix B in the Supplemental Material for faculty pre/postinterview questions).

We transcribed interviews verbatim before transferring them to Dedoose coding software for qualitative analysis. To develop a coding scheme across all interview transcripts, C.L. created inductive codes from a first read of verbatim transcripts of the leader interviews, drawing perspectives from interviewees' own words toward grounded interpretations of answers to interview questions (Auerbach and Silverstein, 2003). During all parts of the coding process, we employed constant comparative methods (Strauss and Corbin, 1994) and the creation of memos (Montgomery and Bailey, 2007). C.L. extended the codebook, developed via analysis of the leader interviews, to account for emergent findings from preworkshop interviews with faculty (e.g., pedagogical practices). To increase the trustworthiness of the analysis, J.B.-G. coded 20% of the leaders' and preworkshop faculty's interviews. We discussed the initial phase of open coding, identifying common codes. When we encountered discrepancies, we returned to the data to inform a final decision and adjusted future analysis accordingly (see Appendix C in the Supplemental Material for final codes and definitions).

Using the codebook from the inductive phase (which ended up being our final codebook for the instructor and preworkshop faculty interviews), C.L. completed a deductive analysis of all leaders and preworkshop interviews and compiled Excel lists of all interview excerpts for each code. Again, C.L. and J.B.-G. reviewed excerpts and corresponding codes to increase trustworthiness, and when an excerpt was questioned by J.B.-G. (which happened in just a few instances), the excerpt ended up being moved or omitted. About a half year later, J.B.-G. extended the codebook developed via analysis of the leader and preworkshop faculty interviews, including a couple of codes needed to account for emergent findings from postworkshop interviews with faculty (e.g., achieved project goals; the virtual environment). Again, C.L. compiled Excel lists of all interview excerpts for each code and reviewed excerpts and corresponding codes for a reliability check with J.B.-G. When this reliability was questioned by J.B.-G. (which happened in just a few instances), the excerpt ended up being moved or omitted.

The themes presented in this paper (corresponding to headings in the Results section) are compilations of data that emerged under multiple codes in response to our research questions. For example, themes presented around "motivation" include data coded under "opportunities for faculty," "benefits

for students," and "faculty collaborations." Aligned with CHAT, which privileges multivoicedness and interactions within a single holistic system (Engeström, 2001; Foot, 2014), we use a technique known as "semi-quantification," assigning qualitative descriptors (e.g., "a few") to our claims, in lieu of presenting numbers or percentages. This qualitative research reporting practice is advocated by theorists when reporting on studies with small participant groups to put forth regularities or idiosyncrasies in data without inadvertently: 1) implying generalizability, which can potentially be assigned unconsciously by readers (Ritchie and Lewis, 2003; Sandelowski *et al.*, 2009); 2) conveying that interview questions were asked of, or understood, precisely the same way across participants (Neale *et al.*, 2014); or 3) suggesting objective realities (which we do not accept as researchers; Maxwell, 2010). We use these descriptors to present findings: "a few" means claimed by 1–5 participants; "several" means 6–10 participants; "a majority" means 11–15; and "most" means 16–19.

To heighten the analyses' trustworthiness, we spent a prolonged time with the study participants to develop an in-depth understanding of the case (Creswell, 2014, p. 202). C.L., over 12 months, interviewed all participants and attended all participant meetings (including all 5 days of the workshop), during which she wrote observation notes and collected relevant documents. We also used peer debriefing (Guba and Lincoln, 1994) and member checking (Creswell, 2014, pp. 201–202), strategies in which researchers ask selected participants or peers to confirm or provide feedback on the findings. We used these strategies throughout the project to ensure the accuracy and trustworthiness of the analysis and findings. We shared analyses and findings from all interviews and our analysis after the workshop with project leaders to provide an opportunity for them to give feedback around accuracy (Guba and Lincoln, 1982). We felt the leaders were well positioned to provide adequate input given their role in the curriculum's codevelopment and their close work with the faculty in the local learning communities at their institutions.

Limitations
We acknowledge the multiple limitations of our research. First, we cannot claim generalizability, given individuals' lived experiences around a novel activity system. However, we do propose transferability of our findings in light of enough "thick description" data (e.g., contextualized data from interviews and observations in naturalistic settings) and "stability" of research design, meaning a design "emergent so that changes are built-in with conscious intent" (Guba and Lincoln, 1982, p. 377). Our research participants may also bring bias to the results of this study. Project leaders recruited faculty at each of the institutions. Faculty volunteered to participate in this project, and participants may have been predisposed or open to working with other faculty and disciplines. In some cases, participants had experience working with others across disciplines to develop transdisciplinary curricula. Second, we only investigated the period of faculty work around the development of the curriculum module and some planning for its implementation; we did not gather data on faculty's experiences teaching the module, which may have identified additional pertinent factors. As faculty and curricular developers themselves, the authors may have also contributed bias in unidentified ways. Finally, due to

the COVID-19 pandemic, we had to conduct all of our inquiry through virtual means (e.g., Zoom interviews and meetings), which may have influenced the data we could collect and, ultimately, our findings.

RESULTS
Our results are organized around our research questions. We first explore the various motivations of faculty to engage in a project that codevelops a curriculum module they can use in their courses. We then examine the tensions that faculty and leaders experienced during the planning and development process. Finally, we conclude with affordances that supported the creation of the curriculum module (i.e., leaders' roles and influence) and faculty's experiences with and plans for implementation of the module within their courses.

Motivations of Interdisciplinary Faculty to Engage in Codevelopment of Transdisciplinary Curricula
Faculty expressed multiple reasons for participating in the project, including a desire for 1) meaningful collaboration around teaching with peers from other disciplines; 2) enhancement of their knowledge around sustainability; 3) improvement of teaching practices and curriculum, including for promotion and tenure considerations; and 4) creation of a curriculum that would benefit their students via novel and meaningful content.

Motivation for Meaningful Collaboration around Teaching with Peers (in Other Disciplines)
In preinterviews, several faculty claimed to be motivated to participate because of the meaningful collaboration around teaching it would allow. They anticipated the project would allow them the opportunity to get out of their disciplinary "silos," allowing them access to different perspectives. One business faculty, Drew, claimed:

> I think the greatest opportunity is being able to get out of the silo and interact with the people across campus who have different skill sets and different ways of looking at the world…. That's exciting for me.

In the postinterview, this same business faculty, Drew, confirmed their earlier perceptions and further confirmed the novelty of such faculty collaborations. They saw their participation as potentially laying the groundwork for future interdisciplinary collaborations.

> I think the biggest benefit is getting to connect with other scholars from departments and colleges that I would have otherwise never made contact with. I think that's an enormously enriching process in itself.

An accounting faculty, Bailey, also relayed typically feeling "siloed" concerning teaching, even within their department. They saw the project as an opportunity to work with other faculty from business subdisciplines and those outside the business department.

> I feel a little siloed in the business department and even more specifically in accounting, just because we're our own major,

and we really do not share a lot of our curriculum with even those in the business department besides that initial financial accounting course. So being able to work with departments even outside of my own is really interesting to me.

Jodi, a science faculty, compared the project to other professional development opportunities in which they had participated. Overall, they felt the project could be more meaningful and exciting than other opportunities, allowing faculty to learn around the topic of sustainability as they worked on developing the curriculum, which Jodi felt energized participants.

And that's one of the coolest things about this curriculum development project is that the faculty member is engaging in learning. It's like a professional development way of doing things without sitting in some kind of corporate training video type of thing for professional development. It builds this collaboration and the energy that goes on there.

Specifically, faculty indicated a desire to work with "like-minded" others who had an interest or commitment to creating experiences for students that would have them creating knowledge across disciplines. Kelly, an economics faculty, claimed:

And this felt like a whole other avenue to engage with like-minded individuals who are also really interested in pursuing interdisciplinary approaches to really important questions.

Motivation to Enhance Their Knowledge of Sustainability
Several faculty anticipated this project would allow them to understand the complex issues around sustainability, indicating that their knowledge of these issues was limited. One economics faculty, Lee, saw value in learning from science faculty and felt they could share such knowledge with their students.

This project presents a lot of opportunities to just broaden our understanding of the really complex problems we'll be looking at. I look forward to being able to talk about chemistry or biology, or anthropology. I'll just be able to interject into my classes a lot of that interesting context to what we're talking about.

Kelly, an economics faculty, anticipated that their participation would allow them to engage more with sustainability issues, specifically that they perceived to be more concrete than some of the disciplinary problems of their typical focus as an instructor. They expressed a need to work with those outside of their discipline to develop practical understandings around sustainability.

I'm an economic theorist, which means that I often don't get to deal with the hands-on issues, and that's a need that I have. I want to engage more with sustainability issues. And that's something that I don't necessarily get inside of my department.

An information/communication faculty, Peyton, indicated it was important to learn more about sustainability issues as a result of a personal commitment to be a good steward for the natural environment.

I mean, the sustainability goals from the UN really resonate with me a lot. I've always enjoyed nature and I think at the core of it, it's really that we live on a beautiful planet.

Motivation to Improve Teaching Practices and Curriculum, Including for Advancement
Several faculty spoke of a desire to improve their pedagogy generally. Madison, an engineering faculty, spoke of how they anticipated the project activities and development process would allow for this.

It will help improve my teaching, and I expect that I'm going to be learning a lot from the other people. I'm really motivated by teaching. I like to teach, and so I'm interested in ways that can help improve my teaching.

A biology faculty, Shannon, perceived this project would improve their teaching to be less philosophical and academic and more directly applicable to their students. They thought their teaching's cross-disciplinary nature was something they always tried to bring to students, but this project allowed them a specific way to do that, which would benefit their teaching and their students.

I think the most interesting thing about the project has always been the broad interdisciplinarity, and that's something that I always try to bring to my students. Sometimes, as we teach, conversations can be philosophical or academic and not have a lot of direct applicability for students.

One economics faculty, Lee, anticipated that their participation in the project and the resulting teaching of the module would impact the curriculum and teaching methods that they would implement.

I think it'll primarily affect my teaching in that we'll be developing together a set of modules that I will incorporate into my classes. That will directly change what I teach and how I teach it in classes that I teach a lot.

This faculty also anticipated that their involvement would provide them with the opportunity to demonstrate a commitment to pedagogical improvements/innovation, specifically in promotion and tenure bids.

[Engaging in this project] is definitely another motivator [for advancement] to show that I'm always trying to innovate. It is something I'm always doing, but this is a very tangible thing to be able to point to, to say that I'm working to always improve my teaching and tie it to my research.

Motivation to Create a Curriculum that Would Benefit Students
Most faculty and project leaders perceived the transdisciplinary curriculum would benefit students in providing them with new understandings and perspectives. Madison, a business faculty, anticipated that the implementation of the curriculum could help "teach the next generation of business professionals how to engage in sustainability and how to think about sustainability," potentially their only education around these issues. Leslie,

an economics faculty, anticipated the curriculum would provide students with content not covered in a textbook, real-life illustrations, and other content applications.

> I try to have my students not get their heads stuck in the textbook all the time, especially in economics, and to give them real, applicable, timely content so they could think about using the textbook stuff in a broader sense.

One economics faculty, Kelly, anticipated that students would experience concepts in each class that taught this module and be informed by other disciplines, disciplines that they otherwise may have little engagement with.

> The main benefit to students is that they are going to also get this access to interdisciplinary teaching. In every single class, they're in of these [type of] classes; they're going to see a little bit of something. I almost feel like, well, I can't reach every student because they don't all take my intro to environmental class. But with this, I feel like some of my ideas and even just all of our ideas together are going to reach more students as well.

Sidney, a leader, also perceived the curriculum would allow students to see wicked problems from multiple disciplinary perspectives, which would help students understand the complexity of such issues and view the situation holistically as they attempted to address it.

> Another goal is to change, not only change the mindset, but I think really introduce students to a more holistic way of looking at these wicked problem and so our hope is that they'll get exposure to different wicked problems and see it from maybe a business standpoint, a science standpoint, a social science standpoint, all the different perspectives so that it will make them better decision-makers.

Shannon, a science faculty, hoped their students would benefit from a curriculum that wove together science and business to better prepare them for their workforce futures.

> I'm looking forward to building those connections [with business faculty] and adding more of that [business] component to my curriculum and giving my students more of a direct background with some of the business side of material. Because a lot of my environmental studies students are going into small businesses, environmental firms where they will be doing a lot of business management and assessment.

Tensions in the Curriculum Creation and Planning

Participants experienced tensions within the activity system in both the curriculum creation and in planning for/envisioning this teaching. These tensions included: 1) challenges with organizational norms and practices; 2) concerns with navigation around norms, language, and practices given the cross-disciplinary collaboration; 3) realities of the virtual environment in which project activities happened; 4) ambiguity and sense of productivity around group work; 5) suitability of the transdisciplinary curriculum module for courses; 6) perceptions of increased time and revisions to workload; and 7) faculty confidence (or lack of) around teaching transdisciplinary curriculum.

Tensions Related to Organizational Norms and Practices

A majority of participants perceived departmental and institutional norms as tensions surrounding transdisciplinary curriculum development and teaching. One of the leaders, Robin, identified content "territorialism" as one concern for departments.

> There are [departmental] concerns that are real about territorialism, right? Who teaches what gets to be one of the questions that I think are based on the structures we've developed in higher education.

Jackson, a science faculty, echoed this perception that departments protect their rights to curriculum, particularly in light of any suggested curricular reform initiatives.

> Again, it's [developing transdisciplinary curriculum is] part of this whole curriculum reform process. Departments are feeling really protective of what they do, and they're feeling a little bit I don't want to say "isolationist," but I think people are becoming really defensive of, "This is my department, and this is important, and you can't take it from me. I don't really know what you're doing, but this is what we do here." That's obviously unfortunate.

One of the leaders, Jordan, saw such departmental attitudes as an institutional tension due to who participates in improvement initiatives versus not. They relayed that education improvement initiatives were somewhat typical on campuses. Reflecting on past experiences with these, they maintained that an initiative needed to reach and influence more than just a few people for successful and significant changes to attitudes and norms.

> [Changing attitudes and norms] seems to be more of an institutional challenge because any initiative can be run by people who are passionate and interested. In some sense, [initiatives] will keep happening, but whether it becomes an institutional-wide thing means it needs to influence more people and reach those people who are not really interested in doing anything new or different.

Drew, an economics faculty, also detailed constraints at the university level and its culture regarding faculty creation of transdisciplinary curricula. They tied these structures to faculty members weighing their time constraints and knowledge of the work they are typically rewarded for and not.

> I think there are structural challenges. Obviously, the university is not set up to encourage, or in some cases even really to allow, this sort of transdisciplinary approach. I think some of the challenges would be cultural because none of us individually are rewarded or encouraged for reaching out across disciplines. We're all busy, and we're each going to focus on those activities which are going to give us the greatest potential reward at the end of the day.

A business faculty, Madison, perceived a lack of support by university administrators, conceptualized as a disconnect between what administrators said they wanted to happen and what they supported.

In some cases, the disconnect is between the expressed desire and the reality or practice that occurs. Because I think these sorts of activities [development of transdisciplinary curriculum] are the kinds of things that administrators like to talk about, but there's not a whole lot of activity and support for it.

Several leaders were attuned to the complexity of developing and sustaining cross-disciplinary collaborations within departments and institutions, particularly concerning budgetary constraints made worse in the current pandemic. This comment by a leader, Casey, was made before the COVID-19 pandemic became a reality but showed the general tensions faced by those trying to innovate. They felt that the resources for transdisciplinary work were the most limiting, including financial and "recognition" resources, primarily based on a department-based resource-allotment structure.

Based on previous work, it's not hard to propagate interdisciplinarity. I know how to do that. What is hard is to get resources for it and recognition, and we just faced a round of cuts at [University name], and the way the policies and practices of our institution are how those cuts are determined, and the value system of our university is the department, not the interdisciplinary program. So that means if we want to keep success and maintain the current value system, our success needs to look like we're doing stuff for departments, but that is absolutely not the way to move into the future.

Tensions around Discipline-Related Norms, Language, and Practices

A majority of participants spoke of tensions around navigating around other faculty members' norms, language, and teaching practices. We heard from several participants how work norms, and related attitudes of other faculty members within their department, could impede transdisciplinary curriculum development and teaching. A leader, Jamie, claimed that teaching transdisciplinary curricula could be perceived as too outside these norms, too difficult for faculty, allowing them to dismiss attempting it easily.

Change is hard, so I think anytime you're trying to introduce something new into the classroom and a new way of thinking, new approaches, that it might be confusing and easy to kind of fall back onto what you know.

Jamie also reflected on faculty teaching transdisciplinary curriculum and stated that they hear faculty's concern about their discomfort in teaching outside one's discipline.

The common refrain we hear is, "If I'm going to teach this problem from the transdisciplinary perspective, it means I have to teach outside of my discipline or outside of my comfort zone or outside of my knowledge base, and I'm afraid of doing that." They may not say that outright, but we do often hear, "I'm not comfortable teaching outside of my discipline."

Based on their cross-disciplinary research experience, the information/communication instructor, Peyton, anticipated faculty would face different norms and terminology. They would need to form a common language to articulate their perspectives across the disciplines.

We all have different disciplinary norms and terminology and jargon that we all need to wrap our heads around so we can have a common language while people are trying to articulate those perspectives.

One science faculty, Shannon, also discussed concerns with language and terminology associated with different disciplines, stating:

Speaking the same language as people in business or in other programs will be challenging in terms of curriculum development.

Tensions with Realities of the Virtual Environment

The reality of the virtual environment created tensions for a majority of participants due to the novel coronavirus. This reality included the loss of in-person interactions, the virtual platform's restrictions and tools associated with that, and navigating the technology. Participants missed the in-person interactions of traditional face-to-face workshops that allowed them to process conversations and explore concepts more thoroughly. One leader, Sidney, acknowledged the value in typical exchanges between structured activities in face-to-face environments. They felt the loss of those more "organic" exchanges, which also translated to a loss of sharing expertise and knowledge. They did not think these exchanges could be replicated in a virtual environment.

I think what was lost was the exchanges that happen organically over "down times" during a traditional conference. As this time wasn't built in (and I am not sure how you would do this given it is already a lot of time on Zoom), I do think some of this "sharing of expertise" was lost.

Another leader, Jamie, felt similarly. They also perceived that the workshop generally went well and that the tensions other participants felt around collectively creating the module were attributable to the restrictions of the virtual environment and not a result of the workshop's design.

Despite the Zoom format, the workshop went extremely well. Difficulties with the collaborative design and compilation of ideas into a final module were more a function of the online format rather than the workshop design. We really missed those casual conversations, evening discussions over meals/drinks, and other opportunities to brainstorm and synthesize outside the structured daily activities.

A few of the faculty perceived that the virtual environment and the activities were occasionally overwhelming due to the technology's challenges. A faculty member, Peyton, wrote in an evaluation at the end of one of the workshop days that they felt challenged following and finding all of the materials and missed collaborating and brainstorming on a whiteboard or other in-person technology.

The online format has some unique challenges. I sometimes found it difficult to locate instructions or links to shared Google Docs quickly, even though I knew they were usually in a central location on the workshop website. It's also challenging at times to collaborate without access to a physical whiteboard.

However, this same faculty member also acknowledged the value of the online format that allowed them to "quickly screen-share resources like slides from courses, websites, etc., to support discussions" and noted that "Google Docs is a very helpful collaboration tool." As researchers, we also observed the varied use by participants of the online environment's many tools.

Most participants conveyed a general sense of fatigue with the reality of working over several days in the virtual environment. One business faculty, Leslie, felt like they were getting tired of the virtual environment even though they felt like they were productive at the same time. They made this comment in an evaluation: "Just getting a bit burnt out on Zoom, but I understand this is a necessity. I think we are quite productive, given the circumstances."

Tensions with Ambiguity and Sense of Productivity around Group Work

During the workshop, a common activity was to break faculty into small groups to work on different module components separately before convening as a large group to share out their work. Although most faculty felt supported and respected in their efforts, several participants also anticipated tensions during these sessions. They acknowledged that leaders had warned them to expect this discomfort. Bailey, a business faculty, summed it up this way: "Everyone was very supportive and respectful. It did get a little 'messy' in the middle, but we were warned that this would happen."

Still, several faculty struggled with this process; in part, they felt they did not clearly understand what they were trying to accomplish collectively with these group work times toward the final product. Logan, a social science faculty, expressed frustration on an evaluation:

> It did feel less productive having all three groups work separately but simultaneously [meaning on the same module] before having a clear agreement on our overarching direction. That contributed to the disjointed feel of where we ended.

Jackson, a science faculty, felt their group had been very productive in the breakout sessions, but they were frustrated that the progress that was made in the smaller groups did not get built upon when the larger groups met. They felt that lost or unincorporated ideas and concepts left them unclear about what the module would look like and how they would incorporate it into their classes. They made these comments on an end-of-day evaluation:

> I think we had some really great conversations over the course of the week, but my frustrations were in feeling like they never really went anywhere. We would have really productive conversations in breakout rooms that I would feel really positive about, and then somehow, those discussions were lost or weren't incorporated. It is still pretty unclear to me what this module is going to look like or how I might incorporate it in my class.

Kelly, an economics faculty, also pointed to the perceived loss of critical elements in the module that had been previously discussed in the smaller groups. They talked about the two main activities proposed in the module, a stakeholder map/

visualization exercise and the role-playing activity. For the visualization exercise, they felt that one of the breakout groups had not adequately developed the activity, even though it had been discussed numerous times in previous days. Their other concern was with the pedagogical strategies associated with teaching the role-playing exercise, which they felt would need some significant guidance for faculty to implement effectively.

> I have sincere concerns about the vagueness of the common activity in the module. It felt like the second breakout group didn't really do as much as the other two today, even in the second session. I think the visualization exercise wasn't touched at all, despite being the most agreed upon and developed discussion over the past two days and one that really stemmed from the common SLOs identified. A role-playing activity will require real guidance for faculty to implement, and the mechanisms seem underdeveloped.

Tensions with Suitability of the Transdisciplinary Curriculum Module for Courses

Several faculty perceived potential challenges with the suitability or "fit" of the curriculum module within their courses. The faculty discussed suitability in two different ways. One way they discussed it was related to the degree to which the transdisciplinary curriculum module aligned with the rest of the content that would be taught in the course. They also spoke of suitability as the level of complexity of the curriculum in the module, implicating difficulties for students' learning and their teaching.

One science faculty, Shannon, spoke about shifting topics and concepts around within the course to fit the module. They were concerned that their course did not present content via case studies or division into something resembling modules. The module would require adjusting to this new curricular structure and developing a plan to still cover all of the other content that needed to be covered.

> One challenge is just figuring out how to best fit these modules into my class because my current class doesn't use case studies or modules. I'll have to shift how I teach the class and figure out how to do that while still maintaining the basic key concepts that I want to cover.

A science faculty, Jackson, expressed concern that the module's content may not fit well with the other content in their course. They thought students might see the module as disconnected from the other topics they studied.

> My main fear is that it's [curriculum module] going to feel like a random module that was plunked down in the middle of the semester.

Leslie, a business faculty member, conveyed their concerns with the curriculum module's complexity concerning their introductory-level economics course. They were concerned that students might not have the academic preparedness to succeed, especially in light of time constraints over the course term.

> I'm also getting a bit nervous about the complexity of this module for my Principles of Microeconomics course, given the

background of my students and the time available in the course to implement such a broad, new topic.

Tensions with Perceptions of Increased Time and Revisions to Workload

A few faculty mentioned increased time or workload needed for collaborations, especially those altering established curriculum. Drew, a faculty in business, identified the challenge of adjusting curriculum and teaching that may have been in place for many years.

> I've taught these classes in certain ways for a long time, and it is a bit of a challenge to restructure everything. Make the time and the space for other, different material.

Lee, an economics faculty, saw extra time and workload in planning and delivering curricula that deviated from course textbooks.

> From an economic perspective, there's a lot of costs associated with deviating from the textbook because it's so easy to follow what the prescribed curriculum is. This rewriting the script can just take a lot of work, and I think that's why people avoid doing it.

Jodi, a chemistry faculty, indicated that administrators had a role in alleviating some of these concerns and typical institutional limitations around faculty coteaching.

> So one of the challenges is that we've got to make space, and by space, I mean time. And the administration has to be willing to allow faculty members to do things like coteach courses. And coteaching is not, "I'm going to teach the first five weeks of the class, and then you're going to teach." That's not coteaching. So, you truly need to be able to be dedicated to being in the space with each other at the same time, to build off each other's knowledge. That's a structural challenge that has to get addressed.

Tensions with Confidence around Teaching Transdisciplinary Curricula

A few faculty spoke of concerns about their confidence (or lack of) in teaching a transdisciplinary curriculum and working with other faculty to develop it. One social science faculty, Logan, explained their confidence in their syllabus and curriculum design. However, they were less confident about creating a curriculum not squarely in their discipline. They implied discipline-based perspectives about sustainability-related issues that might impede their and others' abilities. They also did not feel confident designing a curriculum used by other faculty in another classroom outside their discipline.

> I think a major challenge is that we really do have a particular way of thinking through these issues. And I think there is going to be an issue of translating across the disciplines. I think that as long as it's within my syllabus and I'm the one person that's in control of it all, I'm fine. But suddenly, when I think about trying to design something that might be used in a business classroom or might be used in a STEM classroom, I feel a lot less confident about how I might go about scripting something or how learning should happen.

Affordances for Curriculum Creation and Alleviation of Barriers for Curriculum Implementation

Most faculty perceived affordances that supported the curriculum creation, mostly the project leaders, who provided significant support for creating the curriculum through leaders' facilitation of the development process, codevelopment of the curriculum, and skillful use of technological tools. Several faculty perceived their participation and the work that resulted would alleviate the faculty-specific barriers and organizational norms noted earlier, including future curriculum implementation. Faculty perceived this project would allow them to 1) alleviate the concerns of other faculty regarding the value of the curriculum, 2) increase their confidence related to teaching and working across disciplines, and 3) increase innovation in their teaching practice.

Project Leaders as Support for Curriculum Creation

Leaders as Facilitators of the Development Process. The majority of faculty perceived the leaders as effective facilitators in the development process. Leaders provided helpful organization of the workshops and meetings and demonstrated effective use of tools in the virtual environment. As facilitators, the leaders often reminded faculty about the project's purpose and why developing a transdisciplinary curriculum is different from creating a curriculum within one discipline. Robin, a leader, made this comment at the beginning of the final day of the 5-day development workshop. They reminded faculty about all of the good ideas discussed during the workshop and how it would be easy to have faculty create their curriculum with their expertise and ideas, but that would not make it transdisciplinary. They saw the transdisciplinary perspectives as the module's strength and acknowledged that as the most challenging part of the work.

> One of the invariable questions is: we've got so much good expertise in here, and I've heard so many people have very good individual ideas, wouldn't it just be easier if we all created our own modules to use for our courses? But of course, the purpose of this is that we're really anticipating the interdisciplinary, the transdisciplinary perspective that comes out of the collaboration. And I think everybody agrees from the feedback we've received that that's such an important part of this and that's the real strength. That's what we're doing differently but that's also one of the most difficult things to deal with.

Peyton, an information/communication faculty, appreciated how the leaders had organized the workshop. They especially appreciated how the leaders organized the groups, so the same faculty did not always end up in the same groups each time.

> I really appreciated the overall organization … and the opportunities to switch up groups multiple times and work with multiple participants. I can see advantages to having consistent groups and a single workspace, but I actually found that it was much more exciting to work with new folks for each major exercise as we did in this workshop, and I also think that this helped avoid some of the potential frustration that can come with groups falling into dynamics that are difficult to change once established.

We also heard from faculty about the skillful use of technology by the leaders and the overall benefits that resulted from

the use of technology. Lynn, a science faculty, described the leaders' masterful use of features in the online platforms (e.g., Zoom) to help faculty stay focused on the activities.

> I am amazed by how well this is working online via Zoom. There is something to be said about the focus it provides or the control it gives the leaders to create that [level of focus].

Leaders as Codevelopers of the Curriculum. Although the leaders wanted to give faculty as much control and ownership over curriculum content and activities as possible (observation notes from the second leader planning meeting), they acted as codevelopers, making comments about what they saw happening throughout the curriculum development process. Here we see a comment that one of the leaders, Jamie, made to the faculty during a large group discussion on day 4 of the workshop. The faculty worked for 2 days developing content and activities and struggled with pulling the different components together. Jamie praises what the faculty have accomplished to that point. They describe what faculty have developed thus far as a set of students activities, such as describing the movement of materials or the potential health and ecosystem impact of chemicals. They asked faculty if that was enough or if they wanted students to explain or analyze questions related to the larger problem of clean water or its impact on social and economic systems.

> I keep sort of nudging us towards the question definition or problem definition. So I love what all the groups have created. I think it's a really interesting range of materials to consider, to build into class activities and so forth. But I'm still seeing [the common exercise] largely as sort of a descriptive set of circumstances or where so far the students will be describing the movement of materials from upstream, downstream or describing the potential health impact, so the potential ecosystem impacts but is that enough or do you want to have the students explain or ponder or analyze some specific question within the context of all that big picture information, chemicals, clothes, social systems, economic systems, and so forth?

Drew, a business faculty, reflected in the postinterviews on the leaders' role in developing a successful module. In particular, this faculty saw the leaders' role in codeveloping the curriculum was to synthesize the input from faculty into a final module, even if not all of the faculty would be pleased with the results.

> Designing by committee is always a challenge, and I think to a certain extent, a project like this is going to be most successful if the leaders are the ones who are leading. Taking input from everybody, but at the end of the day, they themselves have to synthesize that input into the final product without trying to please everybody who offers input.

A science faculty, Lynn, acknowledged the challenges of developing and designing a curriculum module that involved multiple faculty from different disciplines and looked to the leaders to bring all the individual faculty and small groups' efforts together. They saw the leaders' efforts as necessary in creating something that faculty could use.

It's hard to design something like this by committee. Hopefully, the leaders can take all the great input from the individual contributors and subgroups and coalesce that into a direction that the rest of us can continue pursuing.

Leaders' Use of Technological Tools Supported Participants' Work. A few faculty perceived the use of technological tools the leaders planned for the group as a general affordance of participants' work. The information/communication faculty, Peyton, acknowledged the value of the online format and the tools associated with that, which allowed them to "quickly screen-share resources like slides from courses, websites, etc., to support discussions, and Google Docs is a very helpful collaboration tool."

One of the science faculty, Shannon, acknowledged the benefits of the online format as a tool to keep the meeting focused and on target, even though they acknowledged the exhaustion of collaborating in this way.

> Some of the benefits of that format, though, is [*sic*] you have to keep on target. You have to be succinct. You have to keep to time because everybody's exhausted with it. So I do see both in that summer workshop and in my day-to-day life the fact that meetings are kept on time is a really nice side effect of all of this.

Alleviating Reservations of Other Faculty around Transdisciplinary Curriculum

Several faculty felt like their participation in the project might help alleviate the concerns of other faculty members' practices and perspectives by providing a framework for collaborating and an example of transdisciplinary curriculum creation and teaching. Leslie, an economics faculty, claimed this, especially if other faculty were exposed to the new curriculum.

> We will have already laid out the framework, highlighting how you can collaborate, and then you go from there. So I think it eases the transition [of developing transdisciplinary] and makes it more attractive and more able for faculty to hit the ground running instead of having to think, "Oh, I would love to work with someone in that department," but then have to figure out how you could actually do that.

Jackson, a science faculty, also saw the curriculum resulting from the project potentially helping to alleviate other faculty members' concerns around courses' worth. They felt that infusing a transdisciplinary curriculum into their courses may show the importance and possibility of teaching science to students majoring in business. They thought this might change the perspectives of some of the senior faculty in business, which they acknowledged were slowly changing but still too influential.

> I think that [the project] is a really big opportunity to be able to change perspectives. I think that from a challenge point of view, we are pretty siloed. There are people who think, "This is a business school. Why are you [science faculty] even here? We shouldn't have a science department. This is a business school. Students who take accounting, they should take finance, they should take some computer classes, and frankly, I don't even know why you are here."

Participation Increased Confidence in Teaching and Working across Disciplines

In the postinterviews, a few faculty expressed an increase in their confidence in teaching and working across disciplines. Bailey, a business faculty, confirmed the value of the novel experience of collaborating with other faculty that the project afforded. This faculty spoke about how the experience alleviated their concerns about how they would teach the transdisciplinary curriculum in their course, the increase in their understanding of teaching because of these interactions, and precisely how they might incorporate a transdisciplinary module in a course.

> I think seeing how other professors have been able to do this [develop curriculum and implement it into their courses]. I felt like I got to learn a lot from some of the other members and just how they're going to approach it [teach the curriculum] and how maybe they've done something in the past to expand out of just their discipline.

Additionally, this same business faculty, Bailey, stated that they had increased their awareness about sustainability issues because of their participation and indicated that this focus helped them imagine work across disciplines. They said: "It definitely increased my personal awareness about sustainability and just the idea of doing things that are across disciplines." A business faculty, Drew, also saw the benefit of connecting with other faculty that would not have happened without this project. They, too, saw this as an enriching process.

> For me, I think the biggest benefit is getting to connect with other scholars from departments and colleges that I would have otherwise never make contact with. I think that's an enormously enriching process in itself.

Participation Increased Innovation around Teaching Practices

In the postinterviews, a few faculty perceived that cross-disciplinary collaborations inspired increased innovation around their teaching practices. This science faculty, Jackson, said participation in the project allowed them to innovate around their teaching and in a way they would not have otherwise. For this faculty, the trade-off of relinquishing some other course content, and control around course content, was worth having the new curriculum that they could now use in their classes.

> But I think that [developing transdisciplinary curriculum] is really good because it is sort of sacrificing control of a part of your course. I think it brings in so much more potential for you to innovate in ways that you wouldn't have thought. Because of course, everybody thinks that they teach an excellent class, and I liked in many ways, not in others, but in many ways, sacrificing some element of control and just saying, of course, I am going to make room for this in my course content, and how can I do that now that I have to do it because it forces you to innovate.

A business faculty, Leslie, saw the new curriculum module as a catalyst for redesigning a new approach to their introductory economics courses, which they thought would help students not feel overwhelmed by a large amount of information. They

felt that designing their courses around themes related to wicked problems would help students see the connection between economics and sustainability. They acknowledged that the new approach would be a challenge and a way to redesign and teach their courses.

> It really helped challenge me to think of a new approach to teaching my course. So what I'm launching this in is Principles of Microeconomics, so it's the very first econ course that a lot of my students are taking. And it's sort of this overwhelming deluge of information that we try to explain to them in one semester. The way that I approached it is that I didn't want this module to be something kind of standalone thrown in the class, this all of a sudden, we were going to focus on this. And so, I ended up introducing wicked problems on the very first day, and then throughout, as we're learning new topics, I'm having them address questions related to the sustainable development goals as we go.

DISCUSSION AND IMPLICATIONS

We have shared the results of an exploratory study that detailed the complex work of faculty from the natural and social sciences and business disciplines as they worked together to develop a curriculum module around a topic related to sustainability issues, arguably an area concerning the most pressing socioscientific problems of our time. Using a theoretical framework of cultural historical activity (CHAT), we documented relevant components important to faculty participants as they developed the module (see Table 1).

Diagnosis of the components of an activity system can be powerful in guiding future related work, including by illuminating system tensions. System participants themselves can learn about and help resolve tensions to more effectively accomplish their objectives, while others considering engagement in a similar activity system can plan around factors known to impede and afford their objectives (Engeström, 2009). Our findings demonstrate the complexity of cross-disciplinary work and the codevelopment of transdisciplinary curricula specifically. This complexity included long-standing disciplinary and organizational norms (the system rules, community, and division of labor) that often present as barriers to faculty work, reinforcing and aggravating system tensions around cross-disciplinary collaborations. The system also included affordances (mediating artifacts and tools) that could help remedy these barriers and assist faculty in achieving their goals. In this section, we discuss this novel activity system and suggest recommendations for promoting faculty's successful cross-disciplinary, transdisciplinary curriculum planning work.

Faculty as Motivated Subjects Due to a Typical Lack of Relevant Professional Opportunities

We found that faculty were motivated to engage in the project to meet their professional development needs, namely, to enhance their capacity to understand and gain confidence to engage students in exploring transdisciplinary issues. Faculty were especially motivated around the topic of sustainability, a problem that held both professional and personal interest. Faculty also desired the opportunity to collaborate with other faculty across disciplines, to learn from these colleagues. Perhaps faculty motivations for engaging in the project are not too

surprising, given that our interviewees had all volunteered to take part. Other researchers have confirmed that faculty participation in professional development activities around teaching is motivated by a typical lack of opportunities to develop their pedagogical knowledge and skills (e.g., Barth *et al.*, 2007; Bouwma-Gearhart, 2012a). Yet our findings highlight largely unknown faculty desires for transdisciplinary, teaching-focused work and thus might indicate the desires of other faculty that may be met with the offering of similar initiatives. These include collaborations with other faculty and disciplines (Bouwma-Gearhart and Adumat, 2011; Lindvig and Ulriksen, 2019).

The activity system we studied is one that faculty might perceive to be particularly daunting, that is, faculty members' collaborative work with those from other disciplines to create transdisciplinary curricula around wicked socioscientific problems. Others may assume these endeavors to be particularly hard to support. Indeed, before in-depth participation in the project, participants expressed concerns about their confidence/competence in engaging in such work. Nonetheless, professional realities motivated them to engage. Proponents of transdisciplinary education can offer and advertise support for this work, highlighting what respected faculty peers within and across disciplines have accomplished with this support, including support in mitigating perceived barriers. For instance, assessing faculty members' transdisciplinary work in promotion and tenure considerations may motivate faculty.

Other faculty may be motivated to do teaching-related transdisciplinary work to learn more about specific socioscientific issues and to better their understanding and that of their students. Our findings suggest that the particular subject of focus may also motivate for more personal reasons; for instance, climate change and threats to social justice may draw faculty in for different reasons than, say, professional development focused on more general teaching practices (e.g., active learning). Once "at the table" around this interest, faculty can be exposed to other research-confirmed best teaching practices (like the backward design used in creating the transdisciplinary curriculum for the project we studied).

At the same time, those faculty and leaders not yet working across disciplinary boundaries may broadly anticipate their professional realities as impediments. While we only investigated the perceptions of faculty already committed to codeveloping a transdisciplinary curriculum, our participants also identified constraints that may impede faculty participation in such work and success in doing so. We must further consider these influences and constraints, which we now turn to in order to strategize mitigations in further support of faculty success.

Faculty Were Influenced by the Rules, Mediating Artifacts, and Community of Their Professional Activity System

Before in-depth participation in the project, participants expressed concerns with "stepping outside" typical teaching and work norms. Participants came with disciplinary backgrounds that conferred certain understandings, norms, and processes that influenced their thinking and contributions to developing a transdisciplinary curriculum. In CHAT conceptualization, these rules and mediating artifacts included faculty perspectives around the importance and appropriateness of content and how students might best learn content. In some cases, these perspectives were voiced as tensions, including how suit-

able or appropriate the curriculum module would be in their courses and where the transdisciplinary curricula would "fit," with respect to both its focus and the sequencing of content.

For some faculty, incorporating the module in their courses was daunting enough; for others, (mis)alignment with other courses and perceptions of other faculty in their programs were concerning. Faculty were apprehensive about how their new transdisciplinary curriculum and teaching might bring their work outside the rules of their academic programs. Several participants even anticipated that other faculty and administrators within their community would perceive their involvement in such an initiative as operating too far outside the normal disciplinary and departmental boundaries. Business faculty, in particular, discussed the typical rules in using textbooks as curricular centerpieces and anticipated that inserting the transdisciplinary curriculum into their courses would be problematic when coordinating with other business faculty. We note some alignment of these findings with other researchers investigating cross-disciplinary faculty collaborations. As described by Lindvig and Ulriksen (2019), our participants may have been indicating a concern for the "othering" of their cross-disciplinary activities, accompanied by a concern around professional ramifications from this othering.

Faculty also relayed that such work collaborations would not be considered a high priority by many departmental administrators. As discussed by other researchers, our faculty anticipated the extra time and effort to develop and incorporate transdisciplinary curricula (Lattuca, 2001). They noted a heightened risk to participating in such endeavors without additional resources or policy changes. Others have documented the power of administrators in supporting (or not) these kinds of collaborations. An absence of policies or financial backing, often promoted or sustained by administrators, can act as deterrents for faculty involvement in teaching-related initiatives and innovations (McClam and Flores-Scott, 2012), including cross-disciplinary collaborations (e.g., Bouwma-Gearhart, 2012b; Wright *et al.*, 2015).

Further tensions involved faculty's anticipated perceptions of the transdisciplinary curriculum by their students, another important group in their professional community. Faculty anticipated that students might perceive, with the module's addition, a violation of typical norms experienced in most of their discipline-based courses, perceiving sustainability topics, or any transdisciplinary curricula, as irrelevant. Several faculty also contemplated whether students would grasp the complexity of the concepts presented in the curriculum module, especially those students who may struggle with the multiple, and in many cases unfamiliar, perspectives and challenges present when addressing complex problems related to sustainability.

We also noted faculty struggles with the technologies the project had to rely on (due to COVID-19 travel and physical distancing constraints) that allowed their participation and collaboration (e.g., Zoom, Google Docs, and Slack). While faculty did report finding these helpful for cocreation and capturing ideas and content, exchanging the pertinent information, and general project management, interactions with and via these tools created some tensions. Faculty struggled at times with locating information among the plethora of resources. Somewhat still unfamiliar electronic interactions replaced familiar, face-to-face ones. Overall, faculty and leaders largely lamented

the loss of chats in hallways between breaks, conversations over dinner, and nonverbal cues that could have likely lessoned some tensions with other barriers faculty experienced, such as the novelty of the project experience overall, as well as communications concerns.

Implications for Faculty and Leaders Engaged in the Activity System

The concerns expressed implicate both administrators' and faculty leaders' work and support. For instance, designers and leaders of future initiatives might include the most effective elements of virtual and in-person workshops and professional development activities, including leaders who can work and teach well around technologies used. In fact, leaders in this project system to a certain extent anticipated some of these faculty concerns and addressed them head-on through discussions with faculty. Leaders also provided ideas about implementing the transdisciplinary module (and past transdisciplinary curricular experiences in their courses), which may have served as illustrations for others to emulate. Overall, we recommend leaders should be sensitive to such concerns and faculty realities, allowing faculty to anticipate, voice, and help problem solve around such issues. Leaders may specifically need to remind other faculty of the typical student pushback against teaching-related innovations (Wright *et al.*, 2015) and the long-term trade-off of transdisciplinary experiences in developing students' critical-thinking and problem-solving skills. Interestingly, some participants were hopeful that their participation in the project and its results might help change departments and programs to better privilege their work. Leaders among faculty may be especially well positioned to increase the chances of transdisciplinary curricula being incorporated into program courses.

Overall, competent, committed, and recognized project leaders were seen as the most significant affordance of faculty work. Faculty leaders with appropriate levels of trust and credibility with other faculty may be the best support, including leaders representing diverse disciplines who may be positioned to help address and resolve tensions around different disciplines' language, norms, and practices, like those observed in this project. The leaders in this project, who came from various disciplinary backgrounds across the sciences and business fields, may have also set a tone that alleviated some tensions that could have otherwise been present. We heard nothing about a "disciplinary hierarchy" of sorts that can happen in some interdisciplinary faculty collaborations (e.g., Gardner, 2013; Bouwma-Gearhart *et al.*, 2014). Faculty can also be discouraged from fully participating if they perceive their disciplines (and expertise) are not represented or recognized as meaningful in collaborations. Our participants did not indicate such concerns, which may also be due to participants being one of a few (among other faculty and leaders) from either business, the natural or social sciences.

A seasoned and respected leader may also be more effective in working with different departmental structures to mediate potential tensions (e.g., negotiate workload considerations and compensations) and to provide the infrastructure (e.g., facilitate meetings, scheduling times, places, and activities) that acts as a bridge between departments that may operate very differently. Project leaders recognized for their disciplinary and pedagogical expertise may successfully recruit and support skeptical faculty. Leaders with experience with previous cross-disciplinary collaborations and who show a willingness to enact codeveloped curricula may have additional credibility and skills necessary to help faculty feel comfortable giving up a measure of control over their curricular development. Strategic involvement of leaders as codevelopers of transdisciplinary curricula may have helped ensure success.

For their part, administrators (like department chairs, deans, provosts, and presidents) can help alleviate faculty concerns for operating outside normal disciplinary and organizational rules by influencing policies, practices, and cultures that value teaching-related transdisciplinary efforts. Administrators working with faculty governance structures might help better recognize and reward faculty's transdisciplinary efforts in promotion structures, including teaching evaluations. Administrators can also help secure resources, course releases, or stipends to allow faculty to devote effort to transdisciplinary work. Beyond freeing up faculty time, these can also send a powerful message to faculty and departments prioritizing such work. Administrators can be extra strategic in planning these supports to mitigate "content territorialism" that participants noted impedes implementing transdisciplinary curricula. Administrators inhabit a crucial role in framing teaching innovations as, ultimately, related to student success and retention issues. Through messaging and policies, administrators can motivate faculty to envision and offer transdisciplinary experiences complementary to essential disciplinary knowledge and ways of knowing.

Obviously, the actions and commitments of faculty are central to realizing the meaningful cross-disciplinary collaborations needed to create the foundations for transdisciplinary student experiences. We call on faculty, and those within the natural sciences specifically, to consider perceptions, structures, and processes that might be barriers to such work. These barriers may include advocating for the hard work of transdisciplinary curricula creation to be recognized as such, for instance, when workloads are being planned and in promotion and tenure reviews. Faculty can also challenge some preconceived notions about their abilities and their disciplinary colleagues to attend to sustainability issues. Indeed, many science faculty, especially those in the life sciences, recognize and embrace their role in developing students' capacity to understand and attend to such issues. Yet they must also acknowledge the contributions that other disciplines and their experts can make to solving these problems and the importance of helping students as they attempt to do so, considering, applying, and integrating knowledge and practices typically associated with more disparate disciplines.

CONCLUSION

Like other research, ours points to some difficulty realizing meaningful teaching-related collaborations with faculty outside of their disciplines, around transdisciplinary curriculum development, specifically faculty navigating cross-disciplinary language, norms, and practices; suitability of the transdisciplinary curriculum module in courses; time and extra effort needed to make cross-disciplinary collaborations successful; and confidence (or lack of) around teaching transdisciplinary curricula (Lattuca, 2001; Lindvig and Ulriksen, 2019). However, some of these tensions were remedied by skilled and experienced leaders and faculty's motivations to develop a transdisciplinary

curriculum with faculty from other disciplines. Colleagueship appears to be important in curricular/course planning, even when faculty teach alone, as faculty can find that working with others on curricular/course planning inspires new ideas (Lattuca and Stark, 2009). Faculty also may find cross-disciplinary STEM collaborations meaningful in making sense of new pedagogical practices (Bouwma-Gearhart *et al.*, 2014), and even faculty members with less experience with disciplinary material may find cross-disciplinary collaborations provide opportunities to seek guidance and resources from other faculty (Bouwma-Gearhart, Lenz, *et al.*, 2018).

In light of our findings, we charge natural science faculty to consider the benefits of collaborative cross-disciplinary initiatives. While faculty operating within science disciplines in general, and the life sciences in particular, may regard their disciplines as already collaborative in nature, we see a need to be much more intentional in these collaborations. Science faculty can use their previous experience and knowledge with cross-disciplinary collaborations to facilitate and advocate for the inclusion of diverse disciplines and perspectives. In their studies of postsecondary biology instructors, Bouwma-Gearhart, Ivanovitch, *et al.* (2018) found that disciplinary colleagues (e.g., those in the same program or department) may have a privileged role in supporting and motivating faculty members' uptake and enactment of the evidence-based practices these initiatives often promote. Further, biology faculty members' typical lack of training regarding teaching and learning may make their enactment difficult. Interestingly, a lack of pedagogical training can motivate faculty to engage with teaching initiatives and other educators, including those from other disciplines (Bouwma-Gearhart, 2012a). Once faculty become engaged in learning communities, these initiatives afford them support to overcome barriers in the way of changes to their pedagogical practices and, specifically, to make incremental revisions to curricula (Bouwma-Gearhart, Ivanovitch, *et al.*, 2018).

In the end, science faculty must choose to participate in these types of collaborations, as we owe it to our students to prepare them to be scientifically and technologically literate and to have the ability to address wicked problems that cannot be solved by engaging just one or even two disciplines. Faculty must anticipate and be willing to sit with the discomfort these situations may entail and realize their potential benefits. Additionally, they need to be commended by leaders and administrators for such efforts and how they demonstrate faculty members' commitment to their students and their preparation of students for success in future endeavors. Thankfully, faculty and leaders/administrators can also realize additional benefits from this challenging work. Cross-disciplinary collaborations can encourage a faculty mindset, open to growth around their teaching-related practices, and learning of and appreciation for diverse disciplinary knowledge bases and perspectives.

FUTURE DIRECTIONS

Postsecondary faculty and leaders are being encouraged to expand their traditional offerings to students to incorporate curricula that require students to merge discipline-based bodies of knowledge and skills, allowing them to address society's most complex problems (Aldrich, 2014; McGregor, 2017). As more and more faculty work to create and implement transdisciplinary experiences for students, discipline-based norms and

faculty perspectives toward teaching-related transdisciplinary work may evolve. Our future work will explore this and document a unique project bringing faculty together to work across natural and social science disciplines to implement, test, and revise transdisciplinary curricula for undergraduate students across diverse institution types. Participants in this project are now charged with implementing the module, gathering student impact data via common assessments, and coming back together to discuss and make pertinent revisions to the curricula. Our future research will explore the ready-to-teach transdisciplinary curriculum module in faculty implementation of transdisciplinary experiences for students. Specifically, will this initiative stand in contrast to many other teaching-related improvement initiatives when faculty struggle to turn the "best" practices promoted into pedagogical practice (Austin, 2011; Henderson *et al.*, 2011)?

Research investigating faculty from multiple disciplines developing transdisciplinary curricula is still rare (Oliver and Hyun, 2011; Fam *et al.*, 2018). We encourage others to share their experiences and collectively work to further faculty development and resulting curricula and instruction that benefit students' development as problem solvers around some of our society's most pressing socioscientific concerns. Research that assesses these collaborations' success and implementation and demonstrates measurable student learning outcomes can provide the needed insight to inform future work. Exploring these still-rare faculty efforts may provide insight, including successful cases to learn from and, potentially, emulate. We see it as especially important in these investigations to consider the complexity of systems in which faculty function.

REFERENCES

Aldrich, J. H. (2014). *Interdisciplinarity: Its role in a discipline-based academy*. New York, NY: Oxford University Press.

Alexander, I. K., & Hjortsø, C. N. (2019). Sources of complexity in participatory curriculum development: An activity system and stakeholder analysis approach to the analyses of tensions and contradictions. *Higher Education*, *77*(2), 301–322. https://doi.org/10.1007/s10734-018-0274-x

American Association for the Advancement of Science. (2011). *Vision and change in undergraduate biology education: A call to action*. Retrieved May 27, 2021, from https://live-visionandchange.pantheonsite.io/wp-content/uploads/2011/03/Revised-Vision-and-Change-Final-Report.pdf

Auerbach, C. F., & Silverstein, L. B. (2003). *Qualitative data: An introduction to coding and analysis*. New York: New York University Press.

Austin, A. E. (2011). *Promoting evidence-based change in undergraduate science education*. A paper commissioned by the National Academies National Research Council Board on Science Education. Washington DC: National Academies of Science.

Barth, M., Godemann, J., Rieckmann, M., & Stoltenberg, U. (2007). Developing key competencies for sustainable development in higher education. *International Journal of Sustainability in Higher Education*, *8*(4), 416–430. https://doi.org/10.1108/14676370710823582

Bouwma-Gearhart, J. (2012a). Research university STEM faculty members' motivation to engage in teaching professional development: Building the choir through an appeal to extrinsic motivation and ego. *Journal of Science Education & Technology*, *21*, 558–570.

Bouwma-Gearhart, J. (2012b). Science faculty improving teaching practice: Identifying needs and finding meaningful professional development. *International Journal of Teaching and Learning in Higher Education*, *24*, 180–188.

Bouwma-Gearhart, J., & Adumat, S. (2011). Fostering successful interdisciplinary postsecondary faculty collaborations. *International Journal of University Teaching and Faculty Development*, 53(4), 207.

Bouwma-Gearhart, J., Ivanovitch, J., Aster, E., & Bouwma, A. (2018). Exploring postsecondary biology educators' planning for teaching to advance meaningful education improvement initiatives. *CBE—Life Sciences Education*, 17(3), ar37. https://doi.org/10.1187/cbe.17-06-0101

Bouwma-Gearhart, J., Lenz, A., & Ivanovitch, J. (2018). The interplay of postsecondary science educators' problems of practice and competencies: Informing better intervention designs. *Journal of Biological Education*, 52, 1–13. Retrieved June 27, 2018, from www.tandfonline.com/doi/full/10.1080/00219266.2018.1472130

Bouwma-Gearhart, J., Perry, K., & Presley, J. (2014). Improving postsecondary stem education: Strategies for successful interdisciplinary collaborations and brokering engagement with education research and theory. *Journal of College Science Teaching*, 44(1), 40–47. Retrieved August 6, 2018, from http://proxy.library.oregonstate.edu/login?url=http://search.ebscohost.com/login.aspx?direct=true&db=ehh&AN=97663554&site=ehost-live

Brandt, P., Ernst, A., Gralla, F., Luederitz, C., Lang, D. J., Newig, J., ... & von Wehrden, H. (2013). A review of transdisciplinary research in sustainability science. *Ecological Economics*, 92, 1–15. https://doi.org/10.1016/j.ecolecon.2013.04.008

Clarke, A., & Ashhurst, C. (2018). Making collective learning coherent: An adaptive approach to the practice of transdisciplinary pedagogy. In Fam, D., Neuhauser, L., & Gibbs, P., (Eds.), *Transdisciplinary theory, practice and education: The art of collaborative research and collective learning* (pp. 151–165). New York, NY: Springer.

Creswell, J. W. (2014). *Research design qualitative, quantitative, and mixed methods approaches* (4th ed.). Los Angeles, CA: Sage.

Engeström, Y. (2001). Expansive learning at work: Toward an activity theoretical reconceptualization. *Journal of Education and Work*, 14(1), 133–156. https://doi.org/10.1080/13639080123238

Engeström, Y. (2009). Expansive learning: Toward an activity-theoretical reconceptualization. In Illeris, K. (Ed.), *Contemporary theories of learning* (pp. 53–73). New York, NY: Routledge.

Engeström, Y. (2015). *Learning by expanding: An activity-theoretical approach to developmental research* (2nd ed.). Cambridge, England: Cambridge University Press.

Ertas, A., Rohman, J., Chillakanti, P., & Baturalp, T. B. (2015). Transdisciplinary collaboration as a vehicle for collective intelligence: A case study of engineering design education. *International Journal of Engineering Education*, 31(6), 1526–1536.

Fam, D., Leimbach, T., Kelly, S., Hitchens, L., & Callen, M. (2018). Chapter 7—Meta-considerations for planning, introducing and standardising inter and transdisciplinary learning in higher degree institutions. In Fam, D., Neuhauser, L., & Gibbs, P. (Eds.), *Transdisciplinary theory, practice and education: The art of collaborative research and collective learning*. New York, NY: Springer.

Foot, K. A. (2014). Cultural-historical activity theory: Exploring a theory to inform practice and research. *Journal of Human Behavior in the Social Environment*, 24(3), 329–347. https://doi.org/10.1080/10911359.2013.831011

Funtowicz, S., & Ravetz, J. (2008). Values and uncertainties. In Hadorn, G. H., Hoffmann-Riem, H., Biber-Klemm, S., Grossenbacher-Mansuy, W., Joye, D., Pohl, C., Wiesmann, U.,& Zemp, E. (Eds.), *Handbook of transdisciplinary research* (pp. 361–368), New York, NY: Springer.

Gardner, S. K. (2013). Paradigmatic differences, power, and status: A qualitative investigation of faculty in one interdisciplinary research collaboration on sustainability science. *Sustainability Science*, 8(2), 241–252. https://doi.org/10.1007/s11625-012-0182-4

Gibbs, P. (2017). *Transdisciplinary higher education: A theoretical basis revealed in practice*. Springer. Retrieved November 4, 2019, from http://ebookcentral.proquest.com/lib/osu/detail.action?docID=4865042

Grossman, P., Wineburg, S., & Beers, S. (2000). Introduction: When theory meets practice in the world of school. In Wineburg, S., & Grossman, P. (Eds.), *Interdisciplinary curriculum: Challenges to implementation*. New York, NY: Teachers College Press.

Guba, E. G., & Lincoln, Y. S. (1982). 19. Epistemological and methodological bases of naturalistic inquiry. *Educational Communication and Technology Journal*, 30(4), 233–252.

Guba, E. G., & Lincoln, Y. S. (1994). Competing paradigms in qualitative research. In Denzin, N. K., & Lincoln, Y. S. (Eds.), *Handbook of qualitative research* (2nd ed.) (pp. 163–194). Thousand Oaks, CA: Sage.

Hayles, C. S., & Holdsworth, S. E. (2008). Curriculum change for sustainability. *Journal for Education in the Built Environment*, 3(1), 25–48. https://doi.org/10.11120/jebe.2008.03010025

Henderson, C., Beach, A., & Finkelstein, N. (2011). Facilitating change in undergraduate STEM instructional practices: An analytic review of the literature. *Journal of Research in Science Teaching*, 48, 952–984.

Hora, M., & Ferrare, J. (2014). Remeasuring postsecondary teaching: How singular categories of instruction obscure the multiple dimensions of classroom practice. *Journal of College Science Teaching*, 43, 36–41.

Hurney, C. A., Nash, C., Hartman, C.-J. B., & Brantmeier, E. J. (2016). Incorporating sustainability content and pedagogy through faculty development. *International Journal of Sustainability in Higher Education*, 17(5), 582–600. https://doi.org/10.1108/IJSHE-12-2014-0180

Jahn, T., Bergmann, M., & Keil, F. (2012). Transdisciplinarity: Between mainstreaming and marginalization. *Ecological Economics*, 79, 1–10. https://doi.org/10.1016/j.ecolecon.2012.04.017

Judge, P. K., Buxton, J. A., Sheahan, T. C., Phetteplace, E. R., Kriebel, D. L., & Hamin Infield, E. M. (2020). Teaching across disciplines: A case study of a project-based short course to teach holistic coastal adaptation design. *Journal of Environmental Studies and Sciences*, 10(3), 341–351. https://doi.org/10.1007/s13412-020-00610-z

Klaassen, R. G. (2018). Interdisciplinary education: A case study. *European Journal of Engineering Education*, 43(6), 842–859. https://doi.org/10.1080/03043797.2018.1442417

Klein, J. T. (1990). *Interdisciplinarity: History, theory, and practice*. Detroit, MI: Wayne State University Press.

Klein, J. T. (2013). The transdisciplinary moment(um). *Integral Review*, 9(2), 189–199. Retrieved December 3, 2019, from https://doaj.org

Lattuca, L. R. (2001). *Creating interdisciplinarity: Interdisciplinary research and teaching among college and university faculty*. Nashville, TN: Vanderbilt University Press.

Lattuca, L. R., & Stark, J. S. (2009). *Shaping the college curriculum: Academic plans in context*. Hoboken, NJ: Wiley. Retrieved January 4, 2021, from http://ebookcentral.proquest.com/lib/osu/detail.action?docID=469096

Lindvig, K., & Ulriksen, L. (2019). Different, difficult, and local: A review of interdisciplinary teaching activities. *Review of Higher Education*, 43(2), 697–725. https://doi.org/10.1353/rhe.2019.0115

Lyall, C., & Fletcher, I. (2013). Experiments in interdisciplinary capacity-building: The successes and challenges of large-scale interdisciplinary investments. *Science and Public Policy*, 40(1), 1–7. https://doi.org/10.1093/scipol/scs113

Maxwell, J. A. (2010). Using numbers in qualitative research. *Qualitative Inquiry*, 16(6), 475–482. https://doi.org/10.1177/1077800410364740

McClam, S., & Flores-Scott, E. M. (2012). Transdisciplinary teaching and research: What is possible in higher education? *Teaching in Higher Education*, 17(3), 231–243. https://doi.org/10.1080/13562517.2011.611866

McGregor, S. L. T. (2017). 4/22 – Challenges of transdisciplinary collaboration: A conceptual literature review. *Integral Leadership Review*, Retrieved August 1, 2020, from http://integralleadershipreview.com/15402-challenges-of-transdisciplinary-collaboration-a-conceptual-literature-review/.

McNair, L. D., Davitt, M., & Batten, G. P. (2015). Outside the 'comfort zone': Impacts of interdisciplinary research collaboration on research, pedagogy, and disciplinary knowledge production. *Engineering Studies*. http://www.tandfonline.com/doi/pdf/10.1080/19378629.2015.1014817?needAccess=true

Montgomery, P., & Bailey, P. H. (2007). Field notes and theoretical memos in grounded theory. *Western Journal of Nursing Research*, 29(1), 65–79.

Moore, M., Martinson, M. L., Nurius, P. S., & Kemp, S. P. (2018). Transdisciplinarity in research: Perspectives of early career faculty. *Research on Social Work Practice*, 28(3), 254–264. https://doi.org/10.1177/1049731517708033

National Academy of Sciences, National Academy of Engineering, and Institute of Medicine. (2005). *Facilitating interdisciplinary research*. Washington, DC: National Academies Press. https://doi.org/10.17226/11153

Neale, J., Miller, P., & West, R. (2014). Reporting quantitative information in qualitative research: Guidance for authors and reviewers: Editorial Note. *Addiction*, *109*(2), 175–176. https://doi.org/10.1111/add.12408

Nordén, B. (2016). Transdisciplinary teaching for sustainable development in a whole school project. *Environmental Education Research*, 1–15. https://doi.org/10.1080/13504622.2016.1266302

Oliver, S. L., & Hyun, E. (2011). Comprehensive curriculum reform in higher education: Collaborative engagement of faculty and administrators. *Journal of Case Studies in Education*, 1–20.

Petrie, H. G. (1992). Interdisciplinary education: Are we faced with insurmountable opportunities? *Review of Research in Education*, *18*(1), 299–333.

Ritchie, J., & Lewis, J. (2003). *Qualitative research practice: A guide for social science students and researchers*. Thousand Oaks, CA: Sage.

Rittel, H. W. J., & Webber, M. (1973). Dilemmas in a general theory of planning. *Policy Sciences*, *4*(2), 155–169.

Sandelowski, M., Voils, C. I., & Knafl, G. (2009). On quantitizing. *Journal of Mixed Methods Research*, *3*(3), 208–222. https://doi.org/10.1177/1558689809334210

Stock, P., & Burton, R. J. F. (2011). Defining terms for integrated (multi-inter-trans-disciplinary) sustainability research. *Sustainability*, *3*(8), 1090–1113. https://doi.org/10.3390/su3081090

Strauss, A., & Corbin, J. (1994). Grounded theory methodology: An overview. In Denzin, N. K., & Lincoln, Y. S. (Eds.), *Handbook of qualitative research* (pp. 273–285). Thousand Oaks, CA: Sage.

Tasdemir, C., & Gazo, R. (2020). Integrating sustainability into higher education curriculum through a transdisciplinary perspective. *Journal of Cleaner Production*, *265*, 121759. https://doi.org/10.1016/j.jclepro.2020.121759

Tripp, B., & Shortlidge, E. E. (2019). A framework to guide undergraduate education in interdisciplinary science. *CBE—Life Sciences Education*, *18*(2), es3. https://doi.org/10.1187/cbe.18-11-0226

United Nations. (2020). Sustainable development outlook 2020: Achieving SDGs in the wake of COVID-19: Scenarios for policymakers. Retrieved March 19, 2021, from https://www.un.org/development/desa/dpad/publication/sustainable-development-outlook-2020-achieving-sdgs-in-the-wake-of-covid-19-scenarios-for-policymakers/

Weber, E., Fox, S., Levings, S. B., & Bouwma-Gearhart, J. (2013). Teachers' conceptualizations of integrated STEM. *Academic Exchange Quarterly*, *17*(3), 9.

Wickson, F., Carew, A. L., & Russell, A. W. (2006). Transdisciplinary research: Characteristics, quandaries and quality. *Futures,*, *38*(9), 1046–1059. https://doi.org/10.1016/j.futures.2006.02.011

Wiggins, G. P., & McTighe, J. (2005). *Understanding by design*. Alexandria, VI: Association for Supervision and Curriculum Development.

Woodin, T., Carter, V. C., & Fletcher, L. (2010). Vision and change in biology undergraduate education, a call for action—Initial responses. *CBE—Life Sciences Education*, *9*(2), 71–73. https://doi.org/10.1187/cbe.10-03-0044

Wright, M. F., Cain, K. D., & Monsour, F. A. (2015). Beyond sustainability: A context for transformative curriculum development. *8*(2), 19.